JRSR 5 (2018) 5-12

Journal of Rehabilitation Sciences and Research

Journal Home Page: jrsr.sums.ac.ir

Original Article

Comparison of Muscle Recruitment Patterns During Sit-to-Stand and Stand-to-Sit in "Movement System Impairment" Subgroups of Low Back Pain and Healthy Women

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ARTICLE INFO

Article History:
Received: 03/05/2018
Revised: 26/ 05/2018
Accepted: 10/06/2018

Keywords:
Low back pain
Classification
Surface electromyography
Recruitment pattern

ABSTRACT

Background: While various studies have examined motor control differences between subjects with and without low back pain (LBP), only a few have investigated the muscle recruitment pattern in classified LBP patients during functional activity. The aim of this study was to investigate the firing pattern of the main muscles involved in sit-to-stand (STD) and stand-to-sit (STS) tasks in two prevalent LBP subgroups based on movement system impairment (MSI) classification.
Methods: A total of 37 women between 18 and 50 years of age voluntarily participated in this cross-sectional study. They were divided into three groups (15 healthy, 15 lumbar extension rotation syndrome (LERS), and seven lumbar flexion rotation syndrome (LFRS)). Surface electromyography was recorded bilaterally from the trunk stabilizer muscles—i.e. the internal oblique (IO), lumbar erector spine (ES), and hip mobilizer muscles—and the medial (MH) and lateral (LH) hamstring muscles during STD and STS tasks. The variations in EMG onset muscle timing and asymmetry in side-to-side muscle timing were measured.
Results: The firing sequence during the STD task showed no significant difference among groups. However, in the healthy and LFR groups the trunk stabilizer muscles were activated before the hip mobilizer muscles, and in the LERS group an insignificant delay was shown in the onset of the ES activity. There was no significant difference of bilateral muscle timing during STD. In the STS task no consistent order of pattern was found even in the healthy group. The bilateral muscle timing of IO (mean difference, -427.00; P=0.021) and ES (mean difference, 1964.57; P=0.000) had significant difference in the LFRS group during STS.
Conclusion: The cumulative effects of recruitment pattern impairment may contribute to continuing the cycle of lumbar movement impairments and subsequent persistence of LBP.

Introduction

Low back pain (LBP) is a prevalent musculoskeletal problem [1]. In a large number of individuals (10–59%) symptoms continue to be chronic [2] and lead to functional disabilities [3]. A total of 85% of this population with chronic pain is categorized as having "nonspecific" low back pain (NSCLBP) since no pathoanatomic cause or radiologic abnormality is detected [4]. Heterogeneity in adult NSCLBP is well documented. Therefore, multiple

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classification systems [5-7] have been developed to divide LBP subjects into homogeneous subgroups of similar characteristics based on biophysical, psychosocial, or both variables. The classification models categorize the patients into homogenous subgroups with the aim of increasing the effectiveness of treatments.

The movement system impairment (MSI) scheme, which uses the kinesiopathological approach, is an evidence-based classification system that uses standardized clinical examination to categorize patients with low back pain (LBP) [8]; it involves interpreting data of standardized tests related to movements and alignments perceived to most consistently contribute to the LBP symptoms, and are accordingly categorized into five subgroups, namely lumbar flexion, lumbar extension, lumbar rotation, lumbar-rotation-flexion, and lumbar-rotation-extension [9]. The MSI approach proposes that loss of precision in joint movements resulting from repeated movements and prolonged static postures during daily activities may induce motor control alterations in patients with mechanical low back pain [10, 11]. The repetition of direction-specific strategies contributes to changes in passive elements—for example muscle tissue and active elements—in regard to timing and force production of muscle [12]. A number of important muscle adaptations contribute to the patient's movement and alignment impairments including motor control alterations in recruitment patterns and timing [13]. Hence, although early studies of trunk muscle function focused on the strength and endurance of trunk muscles in patients with LBP, more recently the focus has been shifted to issues of motor control [14]. It is theoretically possible that altered balance of muscle activation timing leads to altered movement patterns [15]. Moreover, some researchers have reported that muscle imbalance caused by side-to-side differences are particularly important because they may lead to the generation of unexpected asymmetrical movements [16]. Previous research shows that there were differences in muscle recruitment patterns between healthy people and patients with non-specific mechanical low back pain [14]. However, the results are highly contentious [14]. One potential reason for the contradictory findings could be that prior research did not take into consideration the aspect that LBP is a heterogonous condition and needs to be classified in homogenous subgroups.

The underlying theory of MSI approach maintains that correction in performance of the functional activities causing pain is more important than developing a therapeutic exercise program [11]. If movements are performed repeatedly during the day, these movements could contribute to the persistent and recurrent course of LBP [11]. Van Dillen also suggested that training chronic LBP patients to correctly perform daily activities helped improve the function and pain "because people adhere to the training for prolonged periods of time, and the training results in improved short-term and long-term outcomes" [17].

Workers perform sit-to-stand (STD) and stand-to-sit (STS) activities as two common daily functional tasks [18] on an average of 60 times per day [19]. Assembling this seemingly simple task requires a complex coordination of the central nervous system and neuromuscular system [20]. Patients with LBP often report difficulties during STD and STS activities [21]. Previous studies have shown that STS correlates with functional activities such as walking speed, independent ambulation, and stair climbing [19], and it has been reported as a predictor for future disability and falls [21]. Hence, it can be set that if transitioning of impaired STD and STS are identified early and interventions are administered, the loss of functional abilities and fall incidents can be prevented [22]. Several studies have analyzed STD and, to a lesser extent, STS tasks in different population samples (e.g. acute or chronic symptoms and young or old patients) and from different aspects (e.g. kinematic, motor control) often in unclassified LBP subjects [23-28]. Claeys et al. [29] in a kinematic study found that patients with mild non-specific LBP display significant delay in anterior pelvic rotation initiation during sit-to-stand-to-sit task. It could be hypothesized that a delay in the onset of anterior pelvic rotation results in more trunk flexion during this movement. Furthermore, repeated flexion along with mild compressive loads is a crucial risk factor in the development of low back injuries and pain. The author suggested that delayed onset of deeper abdominal muscle activity could be one of the possible mechanisms to explain the delay of lumbopelvic control and anterior pelvic rotation initiation. However, since that study used patients with unclassified LBP, it prevents us from precisely understanding how the flexion loading causes the back pain during the sit-to-stand-to-sit task. Recently, Hemming and colleagues [30], in two LBP subgroups of motor control impairment in flexion or extension direction based on O'Sullivan classification investigated the surface electromyography amplitude of side-to-side trunk muscles while performing multiple functional tasks including STD and STS. However, in that study the muscle recruitment pattern had not been examined in classified LBP subgroups. Given the high repetition of STS and STD functional tasks in daily activity, the identification and subsequent early correction of specific muscle recruitment pattern dysfunction, as an important contributing factor affecting the movement pattern in LBP subgroups could prevent the persistent and recurrent course of LBP. Therefore, the purpose of this study is to compare the sequence or order of muscle firing along with the asymmetry in muscle timing between two NSCLBP subgroups classified on the MSI approach and healthy controls during STD and STS functional tasks. In the present study, the subgroups of lumbar flexion rotation syndrome (LFRS) and lumbar extension rotation syndrome (LERS) were selected because: (1) these subgroups have been reported in previous research [31] to be the most prevalent of the five subgroups in MSI classification system; and (2) during STD and STS, the movement patterns are mainly confined to the sagittal plane [32]; hence subgroups with flexion or extension direction impairment presumably show more disorders than healthy people. We hypothesized that a different muscle recruitment pattern should be determined in LBP subgroups.

Methods

This study used cross-sectional design to compare muscle recruitment patterns during STD and STS tasks in two MSI-based subgroups of patients comprising NSCLBP and healthy control. In total, 37 subjects between 18 and 50 years of age voluntarily participated in this study. Sample size was calculated based on a previous research of similar variables [33], with power of study at 80%. A total of 15 healthy control subjects with no history of LBP were enrolled as control group and 22 subjects with nonspecific mechanical LBP were divided into two subgroups by standardized clinical MSI approach examination (15 subjects in the LERS LBP subgroup and seven subjects in the FRS LBP subgroup). The average subject age, height, and weight are reported in Table 1. The inclusion criteria for LBP subgroups were the ability to stand and sit without assistance [9], with back pain that has continued for at least six months of the previous year, limitation in performance of daily activities for more than three days, or requiring medical treatment [34]. People were excluded from the study if they reported any of the following: (1) diagnosis of marked spinal deformity (kyphosis and scoliosis), spondylolisthesis, spinal stenosis, spinal instability, ankylosing spondylitis, systemic inflammatory condition, or other serious spinal complications (e.g. tumor or infection) [34]; (2) previous spinal fracture and surgery [34]; (3) current or previous lumbar disk herniation signs and symptoms diagnosed by a physician or presented by the patient (including pain or paresthesia distal to the knee, loss of bowel or bladder function, decreased coordination, or loss of motor or sensory function) and degenerative disc disease [1]; (4) lower extremity impairment such as previous lower extremity surgery or leg length discrepancy of more than 20 mm, which could affect the kinematics of the spine and hip [32]; (5) osteoporosis [9]; (6) current pregnancy [1]; and (7) LBP exceeded 3/10 on an 11-point visual analogue scale (0–10, 10 being worst possible pain) on the day of testing [34]. Because of the known gender differences in lumbar spinal muscle geometry, only women participated in this study [34].

Clinical Examination

The clinical examination was completed by trained physical therapists having 15 years of experience in MSI classification assessment. The subjects were examined using a two-step primary and secondary test procedure to diagnose lumbar syndrome based on the findings of physical examination [8]. The examination involved a series of primary tests in which the examiner observed the subject's preferred strategy (i.e. the presence and direction of lumbar movement or alignment) for performing limb and trunk movements and assuming different positions. The subject's symptoms were monitored and the primary tests that were symptom-provoking were immediately followed by secondary tests. In these tests the lumbar region movement, as observed in the primary tests, was either restricted by standardized modifications or the said region was positioned in a neutral alignment. When the secondary test reduces the symptoms, the test is confirmed to be positive. For classification into the LFRS, the primary tests are provocation tests designed to assess movements or stresses in flexion and rotation motion. Secondary tests are confirmatory tests designed to correct or inhibit the flexion and rotation motion. To be classified as a LFRS, the subject must report an increase in symptoms with at least two flexion tests and one rotation test or one combined rotation with flexion test. For classification into the LERS, the primary tests as provocation tests are designed to assess movements or stresses in extension and rotation motion, and secondary tests are confirmatory tests are designed to correct or inhibit the extension and rotation motion. The person must report an increase in symptoms with at least one extension test and one rotation test or one combined extension and rotation test to be classified as a LERS. The reliability of trained examiners to sub-categorize people with LBP based on the MSI model has been found to be acceptable [35].

Procedure

Before the procedure, each patient completed a self-report measure of activity limitation using the Persian translated version of the Oswestry Disability Index (ODI) Questionnaire [36]. The modified Oswestry Questionnaire is a disease-specific measure that indexes a patient's perceived activity limitation from LBP based on 10 items [37]. It uses a 0–100% scale, with higher values indicating greater activity limitation. The modified

Table 1: Subject characteristics of the low back pain (LBP) subgroups and healthy control group, and questionnaire and pain measure data for the LBP subgroups; mean (standard deviation).

Characteristics	**Control group (N=15)**	**flexion rotation subgroup (N=7)**	**extension rotation subgroup (N=15)**	**P value**
Age (years)	32.88 (4.50)	34.38 (6.96)	32.18 (4.99)	0.54[a]
Height (cm)	160.31 (6.51)	163.25 (5.75)	160.65 (5.51)	0.76[a]
Weight (kg)	64.25 (11.21)	67.38 (7.81)	69.00 (11.69)	0.37[a]
Duration of LBP (years)	-	4.1 (2.86)	2.9 (2.30)	0.49[b]
Visual Analogue Scale for current LBP (0–10)	-	1.71 (1.10)	2.2 (1.11)	0.81[b]
Visual Analogue Scale for last week LBP (0–10)	-	2.43 (.97)	2.9 (1.10)	0.47[b]

[a]P values in the ANOVA; [b]P values in the t-test

Oswestry Questionnaire has been shown to be a reliable and valid questionnaire for assessing activity limitation [38]. Furthermore, a visual analogue scale (VAS) of a numerical rating scale of 0–10 was used to record pain for the previous week and current day. There were no significant differences in the values of VAS and ODIQ between the two LBP subgroups (P=0.05; Table 1). All the subjects signed an informed consent form approved by the Ethical Committee of the Ahvaz Jundishapur University of Medical Sciences.

The participants were asked to sit barefoot in their usual posture in a height-adjustable armless backless chair with their feet separated by a comfortable distance. The seat height was adjusted so that the participant's hip and knee joint formed a near right angle when sitting prior to performing an STS task. Overall, few constraints were placed on the procedure of sit-to-stand and stand-to-sit, the only restrictions being that the feet stayed on the floor. The participants were required to look forward with their arms crossed and folded on their chest. They were instructed to: follow a loud voice command ("OK"), rise freely at their comfortable speed, maintain a comfortable erect posture for around three seconds, and then intentionally, without a command, sit down on the chair at their own comfortable speed. There was no attempt to correct any deviations during the test. Each subject repeated the movements three times. There was a minute of rest period between trials. After the participants had practiced the movement (familiarization) three STS and STD movements were recorded, and the mean of two repetitions were chosen based on the recorded signal quality for data analysis.

The EMG parameters from four pairs of trunk stabilizer (internal oblique (IO), lumbar erector spine (ES)) and hip mobilizer (medial (MH) and lateral (LH) hamstring) muscles were recorded using a ME6000 (Mega Electronics, Finland), and the data were analyzed using a custom-written interactive program in MATLAB software (The MathWorks® Version R2012a, USA). After the electrode sites were shaved and cleaned with alcohol, disposable pre-gelled electromyography (EMG) Ag–AgCl electrodes with a 2-cm center-to-center interelectrode distance were applied over the muscles on the right and left sides. Refer to Appendix A for electrode site details [33, 39].

The EMG signals were bandpass filtered between 10 Hz and 500 Hz and then digitized at a sampling rate of 1000 Hz. The degree of muscle activity was assessed for every muscle by calculating the root mean square (RMS) of rectified and filtered (bidirectional digital Butterworth lowpass filter with a cutoff frequency of 250 Hz). The EMG onset time of each muscle was defined as the point at which the signal amplitude exceeded the mean amplitude plus two standard deviations (SD) of base line activity for at least 25 ms [40]. The interactive custom-written algorithm allowed visual inspection to confirm detected events or change the parameters (such as search starting point to bypass probable spikes due to signal disturbances) if necessary (Figure 1). The visual scrutiny of the EMG signal is an important aspect of studying EMG recordings [41]. Hodges and Bui [42] found that visual determination of EMG onset was highly repeatable. The EMG onset times were determined by a single blinded investigator.

In order to investigate the temporal firing pattern of all muscles during the task, the relative difference of the onset time between every muscle and the right IO was calculated; the IO was selected because normally one of the trunk stabilizer muscles should activate before the mobilizer muscles during a functional task. A positive value indicates the earlier activation of the right IO muscle.

The general characteristics and EMG parameters during the STS and STD tasks were analyzed using the SPSS software (Ver. 18). The differences among the three groups were tested by a one-way ANOVA, with the level of statistical significance set at P<0.05. Tukey's

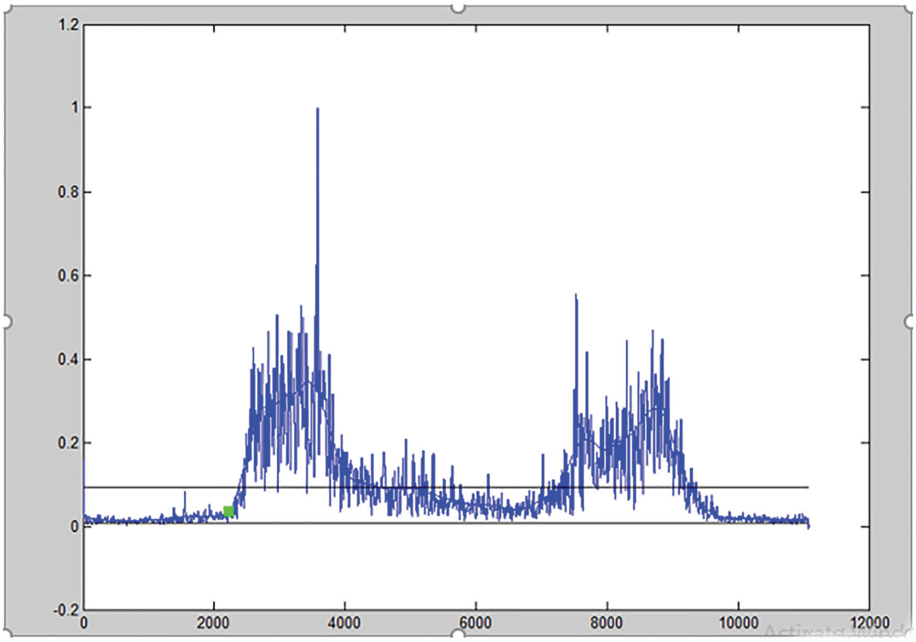

Figure 1: Example of EMG onset time determination method

Table 2: Average muscle onset time in relation to right internal oblique onset for each subject during sit-to-stand task

subject number in each group	Left LH			Left IO			Right ES			Left ES			Right MH			Left MH			Right LH		
	Cont.	ER	FR	Cont.	ER	FR	Cont.	ER	FR	Cont.	ER	FR	Cont.	ER	FR	Cont.	ER	FR	Cont.	ER	FR
1	690.5	444.5	-69	98	55	-435	246.5	243.5	-320	428.5	409.5	-369	582	77.5	-255.5	646	547.5	-163.5	672	144	-183.5
2	-287.5	202	282.5	619.5	-98.5	-124	-44	99	-72	337.5	-124	-27.5	-155	228	-37	-286	258.5	218.5	-41.5	116	260.5
3	548.5	163	1144	512	-31	1193.5	212.5	-105.5	743	448.5	122.5	-1241	333.5	137	991	311	128	984.5	716.5	305.5	934
4	326	-92.5	393.5	-352	-89	-138.5	-84	-24.5	-385	-98.5	-50	-819	94.5	-267.5	412.5	167	-142	105	121.5	-13	563.5
5	370	405.5	178.5	-106	-178.5	-31.5	372.5	137	-153	346	-16	-2551.5	490.5	383	167	131	-81	-54.5	528	328	147
6	-456	602.5	105	211	251.5	245	376	504.5	792.5	288	336.5	643	173.5	113.5	51	-10	122.5	26.5	131.5	586.5	111
7	735	-4080.5	127	267	-316.5	119	462	-172	-89.5	453	-149.5	-137	846	-261	92.5	752	-4080.5	159	919	-4080.5	96
8	57.5	810.5		-182	673.5		-133	1013.5		44.5	814.5		-31	844		80	339		25.5	1080.5	
9	-326.5	559		274	-287		-665	12		-512	-107.5		-327.5	487		-265.5	595.5		-293	503	
10	266	476		-452	-417		-453.5	252.5		-460	239		46.5	323.5		204	381		244.5	328.5	
11	430.5	52		-255	256		262.5	311		308.5	284		112	203		5.5	365.5		-44.5	155.5	
12	-328.5	359.5		-713.5	518.5		-482	204.5		-619.5	370.5		-368	715		-340.5	559.5		-329.5	649.5	
13	-674	-124.5		-769.5	-183.5		-964.5	-502.5		-1334.5	-332.5		-611.5	-61.5		-851	-200.5		-817	7.5	
14	1092.5	182		718	-384.5		854.5	-8.5		426	-38		106	120.5		1144.5	7.5		626.5	183.5	
15	-532	-66.5		47.5	-72.5		-1467	-594		-1214.5	-665.5		597	104		-712	-7.5		577.5	138.5	
MEAN	127.46	-7.166	308.78	-5.53	-20.23	118.35	-100.43	91.36	73.71	-77.23	72.90	-325.08	125.90	209.73	203.07	65.06	-80.46	182.21	202.46	322.39	275.50
SD	535.36	1159.79	395.75	455.32	320.90	520.47	611.58	386.70	488.07	610.55	354.72	655.11	399.23	310.74	401.92	529.04	1136.40	376.66	474.90	296.61	365.75

IO: Internal oblique; ES: Lumbar erector spine; MH: Medial hamstring; LH: Lateral hamstring; Cont.: Control group; ER: Extension rotation group; FR: Flexion rotation group

correction was used when making multiple comparisons. The differences in EMG onset time between the right and left sides among the three groups were tested using the one-way ANOVA as well; Tukey's correction was used for multiple comparisons and Shapiro–Wilks test was used to check for the normal distribution of data. For all variables, normal distribution was established.

Results

Table 1 shows the anthropometric data of the three participating groups of this study. No statistically significant differences were found among groups.

Sit-to-Stand

The results of onset muscle timing analysis during the sit-to-stand task revealed that there was no significant difference between the three groups. In the healthy group, the muscle firing sequence was right ES- left ES – right IO- left IO – left MH- right MH– left LH- right LH, respectively. In the LFRS group, the muscle order was approximately same as the healthy group so that, the trunk stabilizer muscles were activated before the hip mobilizer muscles: left ES - right IO - right ES- left IO - left MH- right MH- right LH- left LH. Although the muscle firing sequence showed no significant differences among the groups, some of the hip mobilizer muscles were activated before the trunk stabilizer muscles in the LERS group: left MH- left IO- left LH- right IO- right LH- left ES – right ES- right MH. Pairwise comparisons with the Tukey's correction showed that there was no statistically significant difference in side-to-side muscle onset timing (Table 3). It should be noted that while the averaging of EMG onset times were indicative for comparing the three groups together, the large range in onset times could result in skewed estimation (based on average data) suggesting an order of activation which is not typical to all subjects in their groups. Table 2 shows the EMG onset times in relation to right IO onset for each muscle examined during STD for all subjects in the three groups.

Stand-to-Sit

Given the results of onset muscle timing in the STS task, no consistent order of pattern was found even in the healthy group. In the LFRS group, left IO began to fire later than in both, the LERS group (mean difference: 506.33; CI: 71.03–941.63; P=0.023) and the healthy control group (mean difference: 515.46; CI: 80.16–950.76; P=0.021). In the LFRS group the relative difference of time between the right ES and right IO was smaller than in the healthy control. On the other hand, the right ES activated later in the LFRS group than in the healthy subjects (mean difference: 588.02; CI: 89.01–1087.04; P=0.022). In contrast, the left ES activated sooner in the LFRS group than in the control (mean difference: -1420.21; CI: -2380.32– -460.092; P=0.004) and LERS (mean difference: -1493; CI:-2453.42 – 533.19; P=0.003) groups. Moreover, the side to side muscle activation timing of IO (mean difference:

Table 3: Summary of significant asymmetry in bilateral onset muscle timing of each group (flexion rotation, extension rotation, and healthy control groups) during functional tasks

Task	**Muscles**	**Flexion rotation mean±SD**	**Extension rotation mean±SD**	**Control mean±SD**	**Tukey's correction pairwise comparison(post hoc)(P<0.05)**
STS	IO	*		P=0.021	
	ES	*		0.000	
	MH				
	LH				
STD	IO				
	ES				
	MH				
	LH				

IO: Internal oblique; ES: Lumbar erector spine; MH: Medial hamstring; LH: Lateral hamstring; STS: Stand- to- sit; STD: Sit- to- stand

-427.00; P=0.021) and ES (mean difference: 1964.57; P=0.000) showed a statistically significant difference in the LFRS group during the STS task (Table 3). Table 4 shows the EMG onset times in relation to right IO onset for each muscle examined during STS for all subjects in the three groups.

Discussion

The goal of the present study was to assess the recruitment patterns of the main muscles involved in STD and STS tasks of two common LBP subgroups based on the MSI classification and control group. The primary findings revealed that during the STD movement, there was no significant difference in the pattern of muscle activation among the groups. In the healthy and the LFRS groups, recruitment of the IO and ES muscles were the first to be activated. The trunk muscles (i.e. IO and ES) are likely to be the most representative muscles for lumbar stabilization [27, 43], and their function can be attributed to the necessary lumbar stability required to initiate the movement, thus creating useful conditions for pacing functional movements. The hamstring muscles are the task execution muscles of the STD task[27, 43]. Indeed, the IO and ES (iliocostalis lumborum) muscles were activated earlier than the MH and LH muscles in the control and LFRS groups. Therefore, the activation of trunk stabilizer muscles before the initiation of hip mobilizer muscle activation in the control and LFRS groups are in agreement with the muscle firing pattern reported during the performance of this task [43]. The LFRS group could be considered to possess a normal recruitment pattern in STD movement. However, there was an insignificant change in muscle activation sequence in the LERS group such that a small amount of delay was shown to occur before the onset of ES activity. Although the delayed onset of ES muscles and earlier onset of MH muscles can lead to disruption of lumbar stability (which may cause LBP), this finding for patients with lumbar extension rotation impairments contradicted the evidence that highlighted the susceptibility to early lumbopelvic motion in symptom-producing directions of LBP subgroups, based on the MSI classification, in activities of daily living [9, 11]. Hence, it was expected that in the LERS group the ES muscles were activated before the other muscles. The delay in onset of ES muscle activation, in comparison with the other muscles, would perhaps result in insufficient contribution of this muscle to lumbopelvic control during the STD task, thus causing a delay in the essential anterior pelvic tilt of movement initiation, and subsequently inducing an excessive trunk flexion in this movement [29]. A kinematic study of this population may be helpful to determine whether the LBP patient subgroups had different movement patterns during STD movement.

In the STS task, significant statistical differences were observed in the bilateral muscle activation timings of IO and ES muscles of the LFRS group. The lack of concurrence in onset timings of bilateral trunk muscles in patients with LFRS can disrupt lumbopelvic control in the sagittal plane during STS movement. This finding is in line with Kim et al. (2013) who found an imbalance in the muscle activation of ES in the LFRS group during standing trunk flexion, which is associated with inducing excessive lumbopelvic rotation [44]. However, the asymmetries in these studies are different. In the present study, we observed asymmetry in the timing of ES muscle's activation while Kim reported asymmetry in the level of ES muscle's activation. Tateuchi et al. (2012) maintains that altered balance of muscle activation level and muscle activation timing are important contributory factors leading to disrupted normal movement patterns with subsequent pain development [15].

Our results support the proposal that in people with mechanical LBP, repeated use of direction-specific, stereotypic movement patterns result in generalized strategies that affect their daily activity, and the continued use of these strategies contribute to changes in movement system elements such as variations in motor recruitment patterns [11]. Due to the magnitude of loading, the use of the same patterns is supposed to cause subfailure injuries and microtrauma to the lumbar region tissues that, over time, contributes to the development of LBP. The modification of specific patterns associated with the LBP classification can probably improve low back symptoms through a program of exercise and training created to alter the performance of direction-specific movement and alignment as associated with functional activities. Furthermore, our findings emphasize the importance of evaluating muscles recruitment parameters bilaterally, despite symmetry of the task. Imbalance in muscle recruitment pattern can contribute to pain problems.

Table 4: Average muscle onset time in relation to onset activation of right internal oblique for each subject during stand-to-sit task

Subject number in each group	Left LH			Left IO			Right ES			Left ES			Right MH			Left MH			Right LH		
	Cont.	**ER**	**FR**	**Cont.**	**ER**	**FR**	**Cont.**	**ER**	**FR**	**Cont.**	**ER**	**FR**	**Cont.**	**ER**	**FR**	**Cont.**	**ER**	**FR**	**Cont.**	**ER**	**FR**
1	8.5	114.5	-284	153	41	-290.5	-218.5	75.5	-341	805	-22.5	-349	-385.5	-45	-342.5	-135	18.5	-267.5	-334.5	99	-320.5
2	-576.5	-125.5	-53	704	477.5	118	-395.5	394.5	47	-552	32	31	-557	333.5	90	-560	365.5	49	-493	117.5	248
3	-718	-619	657.5	-4.5	731	2398	-688.5	-519	2080.5	-856	-553	-5116	-836	-505.5	2083	-827.5	-678	1865	-720.5	-178.5	2033
4	-673.5	-1307.5	-196.5	-495.5	-700	238	-786.5	-1118	-162	-836	-1273	-247.5	-790.5	-1253	303	-761.5	-1315.5	-613.5	-686	-1170	131.5
5	-979.5	307.5	609.5	-735.5	-376.5	-30	-1053	399	-866.5	-1231.5	371.5	-7348.5	-812.5	472.5	-414.5	-1058	518	-172.5	-1026.5	507	-606
6	-962.5	162.5	-596.5	-340	-442.5	541	-873.5	-96	-476	-914	-175	-447	-910.5	-377.5	-617.5	-1066	-514.5	-697	-1053	-189	-937
7	-167	-12105	-477	25	20	14.5	-341	-320	-345.5	-96	-935	-338.5	-230	-1330	-1655	-75	-12105	-554.5	-370	-12105	-528.5
8	-648.5	-1586		-334	-699		-977.5	-1416.5		-836.5	-1721		-933	-1638		-701.5	-1675.5		-686.5	-1609.5	
9	87.5	404		39	252.5		63.5	7.5		52.5	-99.5		-157.5	-196.5		-46	-50		51.5	21	
10	-823.5	-493		-589	-152.5		-943.5	-516.5		-756	-467		-608	-364		-642.5	-478		-639	-417.5	
11	-545.5	-624.5		95	-498		-389	-1045		-333	-869		-368	-1296		-524.5	-809		-541	-939.5	
12	-905	-696.5		-125	381		-1090	-351		-1223.5	-181		-1235.5	-523		-1379	-711.5		-1539	-822	
13	-397.5	-401.5		371.5	-188.5		-505	-551		-537.5	-512		1262	-977.5		-623.5	-412.5		86.5	-666.5	
14	-482	127.5		128	152		-247	109.5		-444.5	84		-322.5	44.5		-675	129		-182	120.5	
15	-357	-710.5		-219	-188		-511.5	-877.5		-542.5	-884.5		-459	-1009		-308	-1024.5		-589	-880.5	
MEAN	-542	-389.14	-48.57	-88.46	-79.33	98.50	-597.10	-388.30	-357.33	-553.43	-480.33	-270.20	-489.56	-577.63	-439.41	-625.5	-474.14	-55.85	-581.66	-389.14	-355.41
SD	331.52	594.94	498.78	377.147	427.64	279.47	348.85	551.87	308.34	521.93	569.41	182.59	570.94	646.49	685.68	3.379.04	629.11	887.85	422.87	594.94	454.09

IO: Internal oblique; ES: Lumbar erector spine; MH: Medial hamstring; LH: Lateral hamstring; Cont.: Control group; ER: Extension rotation group; FR: Flexion rotation group

Limitation

The main limitation of this study is that only women subjects were enrolled. Therefore, it is difficult to generalize these findings to the general population. Secondly, the cross-sectional design of study does not permit us to confirm whether the altered muscle recruitment or movement patterns caused LBP or whether the LBP caused altered patterns.

A kinematic examination was not included in this study concurrently with the muscle recruitment evaluation. Given that the STD and STS tasks has been divided into different movement phases [32], a simultaneous kinematic recording is very effective to investigate muscle firing pattern of different movement phases. We suggest that future studies consider this aspect.

Conclusion

The results of this study showed that motor recruitment pattern dysfunction during STD and STS tasks occur in women categorized as LFRS and LFRS subgroups based on the MSI model. We propose that neuromuscular changes could be contributing to the continuous cycle of movement impairment, and subsequently, the persistence of LBP. Given the high repetition of STS and STD functional tasks in daily activity, this information can be used to specifically identify and correct these recruitment pattern impairments in every subgroup of LBP; specific training of low back patients to modify how they perform everyday functional activities could prevent the persistent and recurrent course of LBP.

Acknowledgement

This study is part of the PhD thesis of Mrs. N.OrakiFar. Special thanks to the Ahvaz Jundishapur University of Medical Sciences for the financial support (PhD thesis Grant No: pht-9509). We thank Samira Hayati Samian (PhD student of TEFL) for improving the use of English in the manuscript.

Conflict of interest: None declared.

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Appendix A: Electrode sites

The internal oblique (IO) may have also picked up activity of the transversus abdominis muscle, which lies directly beneath it: 2 cm medial to the right anterior superior iliac spine, in the horizontal plane.

The lumbar erector spine (ES; iliocostalis lumborum): 3-cm distance lateral from the spinous process of level of the L3.

The medial hamstring (MH; semitendinosus): medial aspect of the thigh, 3 cm from the lateral border of the thigh and approximately half the distance from the gluteal fold to the back of the knee.

The lateral hamstring (LH; biceps femoris): 2 cm from the lateral border of the thigh, two-thirds the distance between the trochanter and the back of the knee.

Reference electrode for each muscle was attached on the closest bone landmark to electrode sites.