Adaptation of muscles of the lumbar spine to sudden imbalance in patients with lower back pain caused by military training

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Objective: This study aims to investigate the effects of sudden load changes (expected and unexpected imbalance) on the activity of muscles of the lumbar spine and their central motor control strategy in military personnel with or without chronic low back pain (LBP).

Design: Bilateral sudden imbalance was examined (2 × 2 factorial design).

Setting: The 117th PLA Hospital, Hangzhou, China

Participants: Twenty-one male subjects with lower back pain and 21 male healthy control subjects were active members of the Nanjing Military Region land forces.

Outcome measures: Independent variables: LBP vs. healthy controls and imbalance anticipation (expected and unexpected imbalance). Dependent variables: rapid reaction time (RRT) and intensity of rapid reaction (IRR) of bilateral lumbar (L3–L4) erector spinae (ES), lumbar (L5–S1) multifidus (MF), and abdominal external oblique muscles.

Results: Under expected or unexpected sudden imbalance conditions, subjects with LBP demonstrated significantly greater IRR than healthy controls in ipsilateral and contralateral ES and MF, respectively ($P < 0.05$ for all). IRR of contralateral ES was significantly larger than that of the ipsilateral ES. A significant group effect of RRT of both ipsilateral and contralateral ES muscles and a significant time expectation effect on RRT of contralateral MF muscles were also observed. RRT of the contralateral ES muscles was significantly lower than that of the ipsilateral ES muscles ($P < 0.001$).

Conclusions: Sudden imbalance prolonged RRT of selected trunk muscles in patients with chronic LBP. The activation amplitude increased. The results may provide a theoretical basis for a study on the pathogenesis of chronic LBP.

Keywords: Back pain, Muscle response, Sudden load

Introduction

Lower back pain (LBP) can result from a variety of factors, including mechanical factors. Mechanical factors also contribute to an increased risk of recurrence in individuals with LBP.¹ A delay in reaction time after sudden loading in the muscles of the lumbar spine has been observed in patients with LBP. Muscle recruitment and the timing of muscle activation play an important role in maintaining lumbar spine stability. An association between sudden and unexpected movements, or

loading, and low back injuries has been reported.^{2–4} These factors may cause LBP or aggravate preexisting pain by increasing the risk of recurrence. LBP can occur from the application of a sudden, unpredictable external load on the lumbar spine.⁵ Sudden events including slips, stumbles, falls, and poor body mechanics while lifting heavy objects have been shown to be primary causative factors of acute lower back pain.⁶ Such circumstances arise accidentally during recreational activities, and at a high rate among professionals whose responsibilities include intense physical exertion and stress upon the low back, including military personnel.

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Patients with LBP may demonstrate differential trunk muscle response strategies compared with that of healthy people. In response to a sudden load, muscle activity of the trunk can increase the stability of the spine; however, the spine is concurrently subject to increased pressure load which may lead to soft tissue injury in the lumbar region of the lower back. In response to a sudden external force, greater load strength, muscular fatigue, and an extended latent muscle response, an increased spinal load has been shown to occur, thereby increasing the risk of waist injury.⁷

Electromyography (EMG) analysis provides a high level of precision in exploring the information associated with the neural commands and mechanical behavior in response to externally applied loads.⁴ Previous studies of sudden load showed lower EMG amplitude in response to unexpected loads compared with expected loads in healthy subjects and those with back pain. Under the condition of unexpected loading, the mean muscle activation has been demonstrated to be greater than twice as large as for the expected loading, and peak muscle activation was an average of 70% greater.^{3,4} Leinonen *et al.*⁸ reported that visual expectation shortens the latency and decreases the magnitude of the paraspinal muscle response to sudden upper limb loading. The effect of anticipation (expected loading) on trunk muscle reaction time seems to be more stable than its effects on the average EMG amplitude.⁸

In recent years, the effects of sudden load changes on the activity of muscles of the lumbar spine and their central motor control strategy have attracted extensive attention from researchers. The primary objective of this study was to investigate the effects of sudden load changes on the activity of muscles of the lumbar spine and their central motor control strategy. The reaction characteristics of lumbar stability muscles to sudden load reduction stimulation in patients with military training-induced lower back pain and healthy controls were examined. This study utilized a self-developed sudden load reduction apparatus in order to test the hypothesis that subjects with a history of chronic LBP would demonstrate extend muscle reaction time in response to sudden imbalance, as well as impaired central motor control strategy. The results may provide a theoretical basis for the study on the pathogenesis of chronic LBP and rehabilitation treatment. The subjects in this study were members of the Nanjing Military Region land forces, which is of relevance given a previous report suggesting that LBP may be experienced by approximately 26% of individuals in the Chinese military.⁹

Methods

Subjects

A total of 42 male subjects, 21 with lower back pain and 21 healthy control subjects participated in the current investigation. All subjects were active members of the Nanjing Military Region land forces. Chronic LBP was diagnosed by an orthopedic surgeon. Subjects in the LBP group had reported LBP for >6 months, while healthy controls had never reported LBP for >3 days. Neither functional defects of the nervous system, structural deformation of the lumbar spine nor hereditary spinal disorders were found in any study subject. Subject characteristics were obtained using a personal information questionnaire, visual analog scale (VAS),¹⁰ and the Oswestry Low Back Pain Scale.¹¹ For the VAS, subjects were asked to place a mark on a horizontal line with a scale ranging from 0 to 10 cm, where a mark at 0 cm indicated no pain and a mark at 10 cm indicated the worst pain imaginable. The Oswestry scale comprises 10 sections (Pain Intensity, Personal Care, Lifting, Walking, Sitting, Standing, Sleeping, Sex Life, Social Life, and Traveling). Each section is scored from 0 to 5, with 0 indicating no effect of pain and 5 indicating maximal effect of pain.

The study was approved by the Institutional Review Board of Zhejiang University. All subjects were recruited from 117th PLA Hospital and signed an informed consent prior to study onset.

Experimental design

A 2×2 factorial design was currently used: sudden imbalances on the left and right side of subjects were studied, respectively. Grouping factor (the LBP group and the healthy control group) and imbalance anticipation (expected and unexpected imbalance) were independent variables, respectively. Rapid reaction time (RRT) and strength of bilateral lumbar erector spinae (ES; L3–L4), lumbar multifidus (MF; L5–S1), and abdominal external oblique (EO) muscle were dependent variables, respectively. Imbalance was achieved using a novel, self-developed imbalance device (Fig. 1) that has been previously validated.¹² Before the experiments, subjects completed at least five imbalance exercises to become familiar with the device.

All experimental procedures were explained to study subjects before the start of the experiment. Briefly, electrodes were placed on the bilateral lumbar (L3–L4) erector spinae (ES), lumbar (L5–S1) multifidus (MF), and abdominal external oblique muscles (EO) according to Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM) international standards.¹³ Subjects stood on the pedals of the imbalance

Figure 1 Sudden imbalance device. When a subject stands on the pedal, a wireless switch is used to control the internal magnetic lock. A rod connecting to the base from each pedal detaches, resulting in a sudden fall of the pedal and the sudden imbalance of the subject.

device and were asked to look straight ahead with arms dropped naturally to the sides (Fig. 2). Subjects completed the left-side and right-side imbalance experiments with and without anticipation, respectively. The researcher verbally forewarned the subjects as part of the anticipation arm (expected imbalance: as “A”) 3 seconds before imbalance initiation – subjects then operated the wireless switch to start the imbalance experiment. The researcher operated the switch for non-anticipatory experiments (unexpected imbalance as “B”) and pressed the button to initiate the imbalance device randomly within 1–10 seconds. The sequences of the experiments were A–B–B–A. Experiments were repeated three times under each condition (i.e. a total of 12 experimental sequences were completed under the aforementioned 4 conditions). Subjects rested approximately 10–20 seconds between the two conditions (expected and unexpected imbalance).

This study developed a program for personal computers via the Visual Basic platform based on Krishnan *et al.*'s approach.¹⁴ A pulse signal is output in EMG channels when the wireless switch is pressed, and the strength of that signal is far greater than the normal myoelectric value. The time of that value is used as the starting time

Figure 2 Subject starting position on the sudden imbalance device

of the sudden imbalance. That program can automatically determine the starting point of the activation of the target muscle and calculate the RRT and intensity based on the mean baseline surface EMG (sEMG) signal ± 3 standard deviations (SDs). RRT is the time difference between the starting point of activation and the starting point of sudden imbalance. The absolute intensity of rapid reaction (IRR) is the mean sEMG collected after 80 ms post-activation. After standardization processing, relative IRR values were obtained (i.e. the ratio of IRR to the mean baseline sEMG signal).

EMG activity was recorded with six surface electrodes (left lumbar ES, right lumbar ES, left lumbar MF muscles, right lumbar MF muscle, left abdominal EO, and right EO muscles) using an MC6000 recording device (Mega Electronics, Kuopio, Finland). The EMG signals were band-pass limited between 10 and 500 Hz, common mode rejection ratio (CMRR) > 130 dB, with a total gain of 1000, noise < 1 μ V, and analogue/digitally (A/D) (12-bit resolution) converted at 1024 Hz. Raw sEMG signals were read using Mega-Win software (Biomation, Almonte, ON, Canada).

Statistical analysis

Descriptive results are presented as the mean $\pm$ SD. Subjects' demographics and characteristics were

compared using two-sample *t*-test. The two-way analysis of variance (two-way ANOVA) to determine significant effects of group, time expectation and interaction of group, and time expectation on the activation amplitude (AA) and RRT. If the interaction was not significant, only the main effects of group and time expectation were considered, respectively. The term ipsilateral was defined as the right muscle activity during trunk imbalance to the right and the left muscle activity during trunk imbalance to the left. Similarly, the contralateral muscle activity was defined. Furthermore, the difference of AA and RRT between LBP and healthy subjects in different muscle were represented as mean $\pm$ SD and compared using two-sample *t*-test; the difference of AA and RRT between ipsilateral and contralateral for given muscles, ES, MF, and EO were represented as mean $\pm$ SD and compared using two-sample *t*-test. All statistical assessments were two-sided and considered significant when $P < 0.05$. Statistical analyses were performed using SPSS 15.0 statistical software (SPSS Inc., Chicago, IL, USA).

Results

In this case-control study, baseline demographics and subject characteristics for the LBP group and healthy controls are presented in Table 1; no differences

Table 1 Baseline demographic and patient characteristics

	Low back pain (<i>n</i> = 21)	Healthy subject (<i>n</i> = 21)	<i>P</i> value
Age (years)	31.1 $\pm$ 5.1	31.7 $\pm$ 5.2	0.708
Height (cm)	174.1 $\pm$ 5.8	177.8 $\pm$ 7.4	0.079
Body mass (kg)	75.8 $\pm$ 9.7	74.1 $\pm$ 9.0	0.559
VAS	4.56 $\pm$ 0.48	3.11 $\pm$ 0.51	<0.001*
Oswestry disability index	20.13 $\pm$ 3.27	10.87 $\pm$ 1.91	<0.001*

Data were summarized as mean $\pm$ SD by group and compared using two-sample *t*-test.

*Significant difference between the two groups, $P < 0.05$.

between groups were observed, suggesting subjects were well matched for age, height, and body mass. Subjects with LBP had significantly higher VAS and Oswestry disability index scores than healthy subjects ($P < 0.001$ for both).

Results of two-way ANOVA for IRR of ES, MF, and EO muscles are shown in Table 2. Main effects (group and time expectation) were considered due to a lack of significant interaction effects between group and time expectation on IRR for each muscle ($P > 0.05$), respectively. Significant differences were observed between IRR of ipsilateral ES, ipsilateral MF, contralateral ES, and contralateral MF muscles in the LBP and healthy control groups, respectively ($P < 0.05$).

Subjects with LBP demonstrated significantly greater IRR than healthy controls (2.90 ± 1.68 vs. 1.77 ± 0.75 , $P = 0.001$ in ipsilateral ES (Fig. 3A); 5.18 ± 7.35 vs. 2.00 ± 1.00 , $P = 0.010$ in ipsilateral MF (Fig. 3B); 5.02 ± 4.80 vs. 2.14 ± 0.87 , $P = 0.001$ in contralateral ES (Fig. 3C); 5.38 ± 9.96 vs. 1.96 ± 1.06 , $P = 0.037$ in contralateral MF (Fig. 3D)). No differences were observed between IRR of ipsilateral and contralateral MF and EO (3.74 ± 5.68 vs. 3.78 ± 7.47 , $P = 0.924$ in MF; 6.55 ± 4.34 vs. 6.43 ± 4.82 , $P = 0.875$ in EO), whereas IRR of contralateral ES was significantly larger than that of the ipsilateral ES (3.73 ± 3.87 vs. 2.41 ± 1.46 , $P = 0.010$) (Fig. 4). A significant RRT group effect of both ipsilateral and contralateral ES muscles and a significant time expectation effect on RRT of contralateral MF muscles was observed ($P < 0.05$).

RRT of ipsilateral ES muscles was significantly lower in healthy subjects compared with subjects with LBP (Fig. 5A: 182.50 ± 51.02 vs. 210.28 ± 48.10 ms ($P = 0.027$)). RRT of contralateral ES muscles was also significantly lower in healthy subjects compared with subjects with LBP (Fig. 5B: 148.34 ± 30.89 vs. 180.55 ± 35.86 ms ($P < 0.001$)). In addition, RRT of contralateral

Table 2 Significance^a of IRR and RRT for given ipsilateral and contralateral spinae

	Ipsilateral			Contralateral		
	ES	MF	EO	ES	MF	EO
Intensity of rapid reaction						
Group	0.001*	0.017*	0.051	0.001*	0.047*	0.451
Expectation	0.150	0.971	0.118	0.093	0.228	0.121
Group $\times$ expectation	0.638	0.611	0.140	0.444	0.424	0.610
Rapid reaction time						
Group	0.028*	0.610	0.927	<0.001*	0.369	0.994
Expectation	0.430	0.532	0.585	0.072	0.023*	0.216
Group $\times$ expectation	0.900	0.476	0.881	0.285	0.602	0.577

ES, erector spinae; MF, multifidus; EO, external oblique.

^a*P* values were represented via two-way ANOVA.

* $P < 0.05$.

Figure 3 Relative intensity of rapid reaction (IRR) between subjects with LBP and healthy subjects. (A) Ipsilateral ES; (B) Ipsilateral MF; (C) Contralateral ES; (D) Contralateral MF. *Significant difference, $P < 0.05$.

MF muscles were significantly lower in subjects with time expectation compared with those subjects without time expectation (Fig. 5C: 145.95 ± 37.1 vs. 171.57 ± 55.26 ms ($P = 0.022$)). Furthermore, no differences were observed between ipsilateral and contralateral RRT of MF and EO muscles (167.90 ± 52.96 vs. 158.59 ± 48.37 ms, $P = 0.265$ in MF; 118.92 ± 22.01 vs. 127.14 ± 28.02 ms, $P = 0.053$ in EO), while RRT of the contralateral ES muscles was significantly lower

than that of the ipsilateral ES muscles (162.81 ± 36.70 vs. 194.52 ± 51.31 ms, $P < 0.001$) (Fig. 6).

Discussion

The pathogenesis and pathological mechanisms underlying military training-caused LBP are complex. Any lumbar structures, intervertebral discs, muscles, ligaments, and nerve roots innervated by nerve endings are likely to become the origin site of the pain. In this study, we used surface EMG signal measurement to analyze and compare trunk muscle activity under expected and unexpected sudden imbalance conditions in subjects with chronic LBP caused by military training and healthy controls. We aimed to explore the differences in the neural control strategies between these subjects. We found that under sudden imbalance conditions, subjects with chronic LBP had significantly prolonged RRT of some trunk muscles compared with healthy controls. This study demonstrates, for the first time, the neural control strategy of subjects with military training-associated chronic LBP and healthy controls in response to sudden imbalance due to vertical and lateral deviations of the body.

The relationship between sudden loading, LBP, paraspinal muscles, and reaction time have been described in several reports.^{3,4,15} Increased RRT and AA in trunk

Figure 4 Relative intensity of rapid reaction (IRR) between ipsilateral and contralateral muscles of the lumbar spine. *Significant difference, $P < 0.05$.

Figure 5 Rapid reaction time between ipsilateral and contralateral muscles of the lumbar spine. (A) Ipsilateral ES; (B) Contralateral ES; (C) Contralateral MF. *Significant difference, $P < 0.05$.

muscles (e.g. rectus abdominis, abdominal EO muscle, abdominal internal oblique muscle, latissimus dorsi, chest ES, and lumbar ES) when the load is suddenly removed in the directions of forward flexion, backward extension, and lateral flexion in patients with LBP has been reported.¹⁵ Magnusson *et al.*³ similarly reported longer reaction time and lower EMG amplitude in patients with LBP compared with age-matched

controls.³ These observations are consistent with our own regarding RRT and AA in muscles of the lumbar spine. Muscle responses can be mediated by several factors, including fatigue, posture, expectation, and rehabilitation.³ We speculate that the observed reduction in rapid reaction in response to sudden load may be due to soft tissue injury proximal to the spine in soldiers with LBP and the consequent impact on nociception and proprioception.

Reaction time in response to a sudden load has been commonly reported in the LBP literature. Different to the majority of previous reports, we examined the AA using EMG analysis. This is a relatively novel variable that provided additional insight to the results, specifically regarding the AA of contraction in the muscles of interest. The findings from studies examining the positive impact of rehabilitation training on patient responses to sudden loads support the EMG data reported herein. Specifically, with appropriate rehabilitation training (rehabilitation duration ranged from 2 weeks to 3 months), these studies have demonstrated that patients with chronic LBP have been able to improve their response to sudden load.^{3,4,16–27}

The current study also included imbalance in the vertical direction, thus not allowing for obvious forward flexion or backward extension. This experimental

Figure 6 Rapid reaction time between ipsilateral and contralateral muscles of the lumbar spine. *Significant difference, $P < 0.05$.

variable may explain why we did not observe any differences between subjects with LBP compared with healthy controls in the RRT for the MF muscle. Of the muscles of interest in the current investigation, the direction of imbalance does not affect the response of the lumbar MF or abdominal EO muscles, which are rapidly activated to stabilize the spine.

Anticipation of an impending load change has been previously reported to be associated with muscle activity occurring before a sudden load.² Awareness of an impending load change can significantly increase the RRT of lumbar stabilization muscles and reduce the muscle activity IRR, thereby enabling an overall appropriate and adequate response. Increased awareness may therefore help prevent injuries caused by late or excessive muscle activity as suggested by the findings from previous studies.^{3,28,29} Consistent with these previous findings, we found that subjects without time expectation had significantly lower RRT of contralateral MF muscles than subjects with time expectation. Anticipation of a sudden load creates a state of alertness, and increases the excitability of motoneurons, resulting in a more rapid postural response.³⁰

Our study has several limitations that warrant mention. First, the use of sudden imbalance to study the motion control strategy of trunk muscles is well documented; however, we do believe our study has several novel features as already outlined. Secondly, although the sudden imbalance device developed for the current study is capable of initiating unilateral imbalance in the vertical direction, it can only induce one episode of imbalance per experiment. Therefore, we were not able to explore the neural control strategy of trunk muscles under dynamic imbalance conditions.

Conclusions

Under unilateral sudden imbalance conditions, patients with chronic LBP associated with military training had significantly increased reaction time latency and AA of the lumbar ES compared with healthy individuals. Sudden imbalance prolonged RRT of selected trunk muscles in patients with chronic LBP and increased AA. Our results may help provide a scientific basis for exploring the physiological mechanisms underlying military training-caused central motor control deactivation, lower back discomfort, and pain.

Disclaimer statements

Contributors YG: guarantor of integrity of the entire study, study concepts, study design, definition of intellectual content, literature research, experimental studies, data analysis, statistical analysis, manuscript

preparation, manuscript editing, manuscript review. J-GS: study concepts, study design, data analysis, manuscript editing. HY: study concepts, literature research, clinical studies, data analysis. Z-RL: study design, literature research, clinical studies, data analysis, statistical analysis, manuscript editing. L-BZ: study design, definition of intellectual content, literature research, clinical studies, data analysis. Z-MN: definition of intellectual content, literature research, clinical studies, data acquisition, data analysis, statistical analysis. L-QF: definition of intellectual content, literature research, clinical studies, experimental studies, data acquisition, statistical analysis. JW: study concepts, study design, experimental studies, data acquisition. Z-HH: guarantor of integrity of the entire study, study concepts, study design, definition of intellectual content, literature research, clinical studies, experimental studies, data acquisition, manuscript preparation, manuscript editing, manuscript review.

Conflicts of interest None declared.

Ethics approval The study was approved by the institutional review board (IRB) of Zhejiang University. All subjects were recruited from 117th PLA Hospital and signed an informed consent prior to study onset.

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