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The Role of Paraspinal Muscle Spindles in Lumbosacral Position Sense in Individuals With and Without Low Back Pain

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Study Design. A two-group experimental design with repeated measures on one factor was used.

Objectives. To investigate the role of paraspinal muscle spindles in lumbosacral position sense in individuals with and without low back pain.

Summary of Background Data. Proprioceptive deficits have been identified in patients with low back pain. The underlying mechanisms, however, are not well documented.

Methods. Lumbosacral position sense was determined before, during, and after lumbar paraspinal muscle vibration in 23 young patients with low back pain and in 21 control subjects. Position sense was estimated by calculating the mean absolute error, constant error, and variable error between six criterion and reproduction sacral tilt angles.

Results. Repositioning accuracy was significantly lower in the patient group than in healthy individuals (absolute error difference between groups = 2.7°, $P < 0.0001$). Multifidus muscle vibration induced a significant muscle-lengthening illusion that resulted in an undershooting of the target position in healthy individuals (constant error = −3.1°, $P < 0.0001$). Conversely, the position sense scores of the patient group did not display an increase in negative directional error but a significant improvement in position sense during muscle vibration ($P < 0.05$). No significant differences in absolute error were found between the first and last trial in the healthy individuals ($P \geq 0.05$) and in the patient group ($P > 0.05$).

Conclusions. Patients with low back pain have a less refined position sense than healthy individuals, possibly because of an altered paraspinal muscle spindle afference and central processing of this sensory input. Furthermore, muscle vibration can be an interesting expedient for improving proprioception and enhancing local muscle control. [Key words: low back pain, multifidus muscle, muscle spindle, neuromuscular dysfunction, pelvic tilting, proprioception, repositioning accuracy] **Spine 2000;25:989–994**

Neuromuscular dysfunction in the presence of low back pain (LBP) has been studied extensively in relation to trunk muscle strength and endurance.[1,2,34,46] However, trunk muscle strength and endurance does not guarantee the relief of painful symptoms.[7,46] Furthermore, inefficient muscular stabilization of the lumbar spine results in an increased risk of injury to the spine.[9,36] Recently, the focus has no longer been on the global trunk muscles but on the local system for controlling segmental spinal stability. The local muscles are capable of enhancing the inherent unstable condition of the motion segment.[10,29,42,51] However, a neuromotor dysfunction of the transversus abdominis[23,24] and the lumbar multifidus muscle[22] has been demonstrated in patients with LBP. Therefore, resolution of motor control problems in the local muscles of the lumbosacral spine is currently an important part of exercise therapy for patients with LBP.[43] The underlying mechanisms, however, are still poorly understood.

Reduced proprioception in the spine in patients with chronic LBP has been established for standing posture and four-point kneeling.[19] Possibly as a result of reduced proprioception, deficits in reaction time,[32,33] postural control,[33] and postural stability[31] have been shown in such patients. However, the specific structures responsible for a loss of proprioception were not identified.

Quint et al[42] stated that the importance of a neural control strategy in the stabilization of the spine cannot be overemphasized. The neural controller must not only select the appropriate muscles to activate, but must also decide on the appropriate activation level. Proprioception may be an important part of the neural controller, because it encompasses the sensation of position and movement of joints; the sensations of force, effort, and heaviness associated with muscle contractions; and the sensations of perceived timing of muscular contractions.[18]

Receptors in joint, skin, and muscle can theoretically contribute to these sensations. However, results in muscle–tendon vibration and microneurography studies have demonstrated a major role of muscle spindles in proprioception.[12,20,28,44] Muscle–tendon vibration is a powerful stimulus for muscle spindle primary afferents.[8,45] The effect of vibration is to introduce a bias into the muscle spindle output. The vibrated muscle is usually perceived to be longer than it actually is.[20,28,44] However, vibration frequencies lower than 40 Hz induce a shortening illusion in limb muscles.[12] Little is known about whether the cognitive effect of vibration of trunk muscles is the same as for peripheral muscles. In a previ-

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ous study,[5] healthy young individuals showed a significant muscle lengthening illusion during multifidus muscle vibration, which caused them to undershoot their target positions. This vibration-induced error demonstrated that multifidus muscle spindle input is critically important for lumbosacral repositioning accuracy during sitting. In addition, joint receptors have been shown to be mainly active at extreme joint angles,[21] whereas muscle spindles fire throughout the range of motion.[18,28]

The "neutral zone," a segmental region of low stiffness, is often expanded in patients with LBP,[37] and the stabilizing function of trunk musculature is especially important around the neutral spine posture.[10,36,42] If proprioceptive acuity in the lower back is decreased because of dysfunction of muscle spindles, local muscle control and thus segmental stability is at risk. Instability may make the spine more vulnerable to injury and recurrence of LBP. Accordingly, it can be hypothesized that muscle spindles are a causal factor in the association of muscle dysfunction with spinal instability.

In the current study, an active pelvic–sacral tilt repositioning task was used in combination with muscle vibration during sitting. The sitting posture was chosen, because it is a functional activity, and patients with LBP perform pelvic rotation easier during sitting than during standing. Position sense measurements have been shown to be more reliable in sitting[3] than in standing, and proprioception has not been assessed in patients with LBP when seated.[19] The authors tested the hypothesis that patients with LBP are less able to identify accurately muscle spindle afferent information from lumbar multifidus muscle than healthy persons, making it more difficult to reposition the lumbosacral spine accurately and consistently.

■ Methods

Subjects. Forty-four individuals participated in the study, including 23 patients (16 women, 7 men) with a history of LBP and 21 control persons (15 women, 6 men). The participants had an average physical activity level, and their ages ranged from 18 to 34 years. The patients were recruited from the Department of Physical Medicine and Rehabilitation, University Hospitals of Leuven. Most of these patients did not have a more specific diagnosis than mechanical LBP. Students or university staff served as healthy control subjects. Individuals with a recent history of inner ear infection with associated balance or coordination problem, a history of cerebral trauma with unresolved neurosensory symptoms, a recent history of vestibular disorder, previous spinal surgery, an involvement in specific balance or stabilization training in the 6 months before testing, and those taking pain medication were excluded. Table 1 gives the characteristics of both subject groups who took part in the study.

All participants gave their informed consent, and the study was approved by the local Ethics Committee of the Faculty of Physical Education and Physiotherapy, the Katholieke Universiteit Leuven, Belgium.

Preparatory Procedures. The participants filled out the LBP[16] and physical activity[39] questionnaires, and their height and weight were measured. They wore shorts to reduce sensory cues from clothing in contact with the skin, and they sat upright on a soft stool, with arms resting on the thighs. Before testing, each participant was instructed to tilt his or her pelvis 10 times as a warm-up procedure.

Table 1. Characteristics of the Control and LBP Groups, Mean and SD

	Control Group (N = 21)	LBP Group (N = 23)	*F*-value
Age (yr)	22.3 ± 3.8	21.8 ± 2.1	(NS)
Height (cm)	174 ± 8.3	173.7 ± 7.1	(NS)
Weight (kg)	63.2 ± 7	64.9 ± 7.2	(NS)
Activity Index			
Work	2.5 ± 0.5	2.7 ± 0.6	(NS)
Sport	3.3 ± 0.6	3.4 ± 0.5	(NS)
Leisure	3.5 ± 0.5	3.5 ± 0.5	(NS)
Oswestry Score	0	7 ± 6.8	
Pain 1	0	1.2 ± 1.5	
Pain 2	0	3.8 ± 1.7	

LBP = low back pain; NS = not significant; Pain 1 = LBP at moment of testing scored on visual analogue scale; Pain 2 = average LBP experienced in the last week before testing.

Position Sense Measurements. The general methods for measuring lumbosacral position sense have been described previously in detail[3,4] and will be only briefly reported in this section.

Sacral tilt position was electronically recorded by a piezoresistive electrogoniometer that was attached to the skin over the sacrum at spinous process S_2. Before testing, the range of motion of pelvic-sacral tilting was measured.

During testing, the participants were instructed to maintain a criterion position for 5 seconds and then tilt the pelvis completely forward. Subsequently, starting from this position of anterior pelvic tilt, they had to reproduce the criterion position. The participants were instructed to move only the pelvis and lower back during this task. After completion of each repositioning trial, the same sequence of events was repeated five more times. No feedback on accuracy was provided to the person. The criterion positions were pseudorandomly chosen by the examiner during the participants' active pelvic tilting; yet, they were based on the range-of-motion results that were previously assessed. These criterion positions were not situated at the extremes of range but are varied around the neutral position.

Repositioning accuracy was estimated by calculating the angular difference between six criterion and actual sacral tilt angles. Three measures of mean error were used: constant error (CE), variable error (VE), and absolute error (AE) (see Schmidt[47] for detailed description). In brief, the CE is a measure of angular bias, which represents accuracy. Negative CE represents a bias in the undershooting direction. The VE is a measure of variability based on the standard deviation of the CE and represents precision. The AE is the absolute value of the deviation between the person's responses and the target, which accounts for both bias and variability.

Muscle Vibration Protocol. A lightweight and silent proprioceptive muscle vibrator (VB100, Dynatronic, Valence, France) was attached with sports tape to the back at L5–S1 (Figure 1). The frequency of vibration was 70 Hz, and the amplitude was 0.5 mm. These characteristics of vibration were

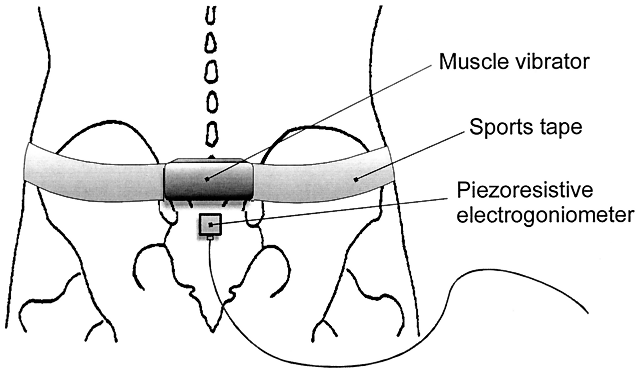

Figure 1. Experimental setup for position sense testing of the lumbosacral spine, with and without mechanical vibration.

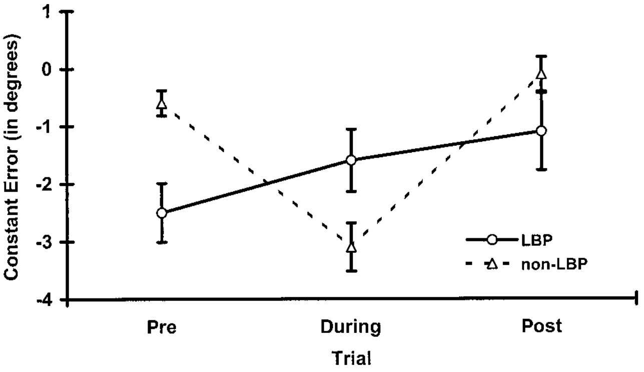

Figure 2. Comparison of mean constant errors in repositioning of the lumbosacral spine for patient and control group: previbration state, vibration state, and postvibration state (mean ± standard error). LBP=low back pain.

chosen to induce the maximal illusory joint movement[44] and were demonstrated to induce a significant muscle-lengthening illusion in the lumbar paraspinal muscles in healthy individuals.[5,6] Vibration was applied to the multifidus muscle bilaterally during the repositioning phase (approximately 3 seconds). Position sense was measured in separate trials before, during, and after muscle vibration in both groups.

Statistics. Differences in position sense measurements between baseline, vibration, and postvibration conditions and between patient group and control group were based on F-test analysis of variance, using one-way and two-way procedures with repeated measures on one factor (Statistical Analysis Systems, SAS Institute Inc., Cary, NC). The significance level was set at $P < 0.05$.

■ Results

Lumbosacral position sense (AE) was significantly degraded in patients with LBP compared with that in healthy controls (F[1,42] = 26.14, $P < 0.0001$). The mean difference in AE between the two groups was 2.7°. In the baseline condition (*i.e.,* no vibration), the healthy volunteers repositioned the back accurately to the target location, as shown by their average CE (−0.6 ± 1.0, $P > 0.05$). In comparison, the patient group had a significantly larger CE (−2.5 ± 2.5, F[1,42] = 39.5, $P < 0.0001$), because they tended to make smaller movements of the lumbar spine and undershoot the target position. The patient group also had a larger VE (3.3 ± 1.4, F[1,42] = 32.74, $P < 0.0001$) than the healthy control group (VE = 1.7 ± 0.7), showing that the patients were performing the task with less precision.

The two subject groups also responded differently to vibration of the paraspinal muscles. Figure 2 compares the CE for the two subject groups before, during, and after vibration. Vibration of the lumbar multifidus muscle in the control persons caused them to undershoot significantly the target position (CE = −3.1 ± 1.4, F[1,20] = 60.03, $P < 0.0001$), presumably because of an illusion of muscle lengthening.[20,28] In contrast, vibration of the multifidus muscle in the patient group significantly decreased the CE during muscle vibration (−1.6 ± 2.6, F[1,22] = 20.7, $P < 0.0001$), which could have been produced either by a muscle-shortening illusion or an improvement in the accuracy of proprioceptive perception.

Multifidus vibration influenced VE differently in the two subject groups. Figure 3 contrasts the VE for the two subject groups before, during, and after vibration. Vibration of the lumbar multifidus muscle in the control persons induced a slight increase in VE.[12] In contrast, vibration of the multifidus muscle in patients with LBP resulted in a decrease in VE (F[1,22] = 3.89, $P < 0.05$).

No significant differences in AE were found between the first and last trial in the normal participants (F[1,20] = 3.48, $P > 0.05$) and the patients with LBP (F[1,22] = 0.28, $P > 0.05$), showing that performance was stable (*i.e.,* learning did not occur) and that vibration did not induce any long-term changes in perception. Table 2 displays all the error measurements before, during, and after multifidus muscle vibration for the two subject groups, and the individual mean CE scores are presented in Table 3.

■ Discussion

In a previous study,[5] it was found that multifidus muscle vibration altered position sense significantly in young

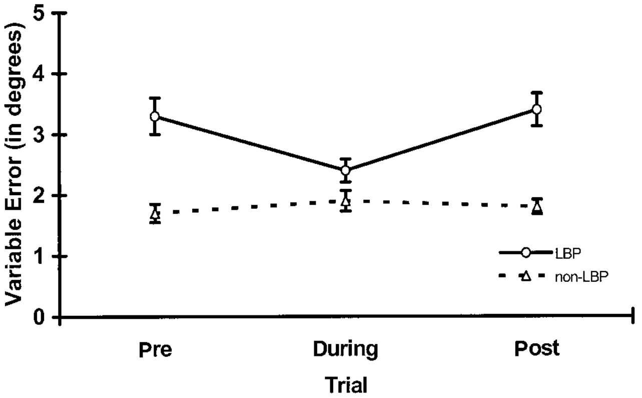

Figure 3. Comparison of mean variable errors in repositioning of the lumbosacral spine for patient and control group: previbration state, vibration state, and postvibration state (mean ± standard error). LBP=low back pain.

Table 2. Mean Absolute Errors (AE), Constant Errors (CE), and Variable Errors (VE) in Degrees Before Vibration, During Vibration, and Postvibration, and SD

	Control Group (N = 21)			LBP Group (N = 23)		
	AE	CE	VE	AE	CE	VE
Pre	1.6 ± 0.6	−0.6 ± 1.0	1.7 ± 0.7	4.3 ± 1.0	−2.5 ± 2.5	3.3 ± 1.4
During	3.2 ± 1.3	−3.1 ± 1.4	1.9 ± 0.8	3.2 ± 1.5	−1.6 ± 2.6	2.4 ± 0.9
Post	2.3 ± 2.3	−0.1 ± 1.5	1.8 ± 0.5	4.1 ± 1.1	−1.1 ± 3.2	3.4 ± 1.3

healthy individuals by inducing a significant muscle-lengthening illusion. The authors concluded that muscle spindles in the paraspinal muscles were likely to play an important role in lumbosacral position sense. In the current study, the lumbosacral position sense of healthy adults was compared with that of patients with LBP to investigate further the role of paraspinal muscle spindles in the origin and maintenance of LBP. Vibration was used in seated individuals to distort muscle spindle afferent information during an active pelvic–lumbosacral repositioning task.

The results show that the patients with LBP had a significantly lower proprioceptive acuity than the control healthy volunteers during sitting. Under control conditions (*i.e.*, no vibration), the patient group significantly undershot the target position, whereas the control subjects accurately repositioned the back to the target position. Moreover, compared with the control persons, the patients with LBP had a larger VE for the baseline condition. Thus, the accuracy and precision with which patients with LBP repositioned their backs were inferior to that of the control group. In support of this observation, Gill and Callaghan[19] also found a deficit in position sense in patients with LBP during standing and four-point kneeling compared with normal individuals.

These results provide clear evidence for a reduced sense of lumbosacral position in patients with LBP. However, the causality of this sensory deficit remains unclear. One possibility is that low back injury precedes sensory loss—that is, the painful sensory stimulation produced by mechanical injury to the back results in a proprioceptive deficit. The physiologic basis of such a cause and effect remains obscure, however, because nociceptive input seems more likely to enhance sensitivity to mechanoreceptor input than to reduce it.[50]

Alternatively, it is possible that reduced proprioceptive acuity in the lumbosacral spine is a precursor to back injuries and their sequelae. Poor perception of spine orientation may lead to more frequent excursions beyond the range of mechanical stability, thereby risking mechanical injury to spinal tissues.[9,37] Because sensory acuity in other sensory systems (*e.g.*, vision, hearing) varies widely among humans, it seems probable that the same type of diversity exists for proprioception, although this has yet to be systematically tested. If this hypothesis is correct, individuals whose normal proprioceptive acuity is relatively low may be at greater risk of development of LBP. Moreover, interventions in patients with LBP that enhance proprioceptive acuity may aid in recovery and reduce the likelihood of recurrence of chronic LBP.

The authors suggest that the higher CE in the LBP patient group is more likely to have originated from distortion in the central representation of lumbosacral spine posture[17,41] than from a bias in peripheral proprioceptive input. Rearrangement of the internal representation of the body has also been proposed as a cause of spinal disorders such as idiopathic scoliosis.[30] However, the higher VE in the LBP patient group may be related to noisier proprioceptive afference and the central processing of this sensory input.

Another possibility is that the lower proprioceptive acuity could be due to an abnormally high level of fusimotor activity of the lumbar multifidus muscle in patients with LBP. Under normal conditions, activation of the fusimotor system increases or decreases the sensitivity of the muscle spindles to length and change in length depending on the magnitude of fusimotor activation[25] and whether static or dynamic fusimotor input to muscle spindles is enhanced.[14]

Pederson et al[38] proposed that the fusimotor system is involved in the pathophysiologic mechanisms behind chronic musculoskeletal pain syndromes. They showed that increased intramuscular concentration of bradykinin increases the fusimotor drive (through reflex effects from chemosensitive muscle afferents) to muscle spindles in leg[15] and neck muscles of the cat.[38] The intramuscular

Table 3. Individual Measurements of Mean Constant Errors (CE) in Degrees Before Vibration, During Vibration, and Postvibration

Control group (N = 21)			LBP group (N = 23)		
CE Pre	CE During	CE Post	CE Pre	CE During	CE Post
1.0	−1.8	2.9	−3.5	−3.4	−0.5
−0.4	−1.6	−1.2	1.6	1.7	2.1
−1.1	−3.9	−1.9	−5.1	−3.3	−3.7
−1.1	−1.6	0.2	−5.3	−0.9	−5.0
0.6	−1.9	1.5	1.6	3.6	7.2
−0.3	−1.7	−1.2	−2.2	−2.1	−1.6
0.0	−1.7	−0.5	−2.3	−1.2	−1.4
−0.7	−2.1	0.3	−5.6	−6.5	−4.1
−2.8	−4.3	−2.7	−3.1	−3.2	−2.5
0.3	−2.7	2.0	−3.8	−1.5	1.0
−1.9	−2.8	−2.2	−2.7	−4.4	−2.8
−1.5	−4.4	−1.3	−5.7	−4.7	−5.2
−0.3	−2.5				

Each CE value is an average of six trials per session.

concentration of bradykinin has been shown to increase in a number of conditions (*e.g.,* during pain, inflammation, ischemia and static muscular contractions),[15,38] and bradykinin induces muscle pain in man.[38] Further, task and context (*e.g.,* fear of pain in the LBP patient group) could account for an increased fusimotor activity, also known as fusimotor set.[40]

Muscle vibration can induce two possible effects on the quality of muscle spindle afference. It can distort muscle's primary afference by introducing a bias signal in a parallel channel,[8,20,28,45] or it can change the sensitivity of proprioceptive afference to weak external signals.[13,35]

Vibration of the multifidus muscle induced a significant undershoot error in the healthy control group. The participants presumably perceived that the vibrated multifidus muscle was longer than it actually was,[20,28] leading to a perception of a more posteriorly tilted sacrum and pelvis. This increase in CE during vibration is comparable to the results of a previous study of multifidus muscle vibration in the spine[5,6] and with results in previous tendon vibration studies in which peripheral joints were studied during movement.[12,28,48]

In the LBP patient group, however, multifidus vibration had a different effect than in normal individuals: the CEs in the undershooting direction that occurred in the absence of vibration were reduced with vibration in LBP patients. Moreover, in patients with LBP, multifidus vibration also produced a significant decrease in VE. This apparently beneficial effect of vibration in patients with LBP has several possible explanations. It may be that vibration in this patient group produced a shortening illusion in the paraspinal muscles. Vibration-induced shortening illusions have been reported previously for low frequencies of vibration, particularly in the moving limb.[12] Alternatively, vibration may have reduced CE and VE because of a stochastic resonance-based enhancement of proprioceptive acuity.[13,35] However, any explanation must take into account the question of why the two subject groups responded differently to vibration.

In addition to higher level processes, LBP may also be caused by deficits in spinal reflexes. Indahl et al[26] have found that stimulation of low-threshold nerve endings in the disc and facet joints activates porcine paraspinal muscles. Solomonow et al[49] established similar results by stimulating supraspinous ligaments of cats and humans. Motion and stabilization of the spine are based on a complex reflex activation system in which the proprioceptive nerve endings in the anulus fibrosus of the intervertebral disc, the facet joints, supraspinous ligaments, and paraspinal muscles initiate various reflex patterns.[27,49] It can be hypothesized that deficits in proprioceptive input to the spinal cord may, in addition to changing perception, reorganize spinal reflexes so that these reflexes no longer protect spinal tissues from mechanical injury. Indahl et al[27] have suggested that restoration of the reflex system must be a focus of the LBP treatment regimen.

Finally, the sensitivity of muscle spindle afferents can change by the mechanical characteristics of the applied muscle vibration, *i.e.,* force, amplitude, and frequency.[11] A limitation of the study is that the force of vibration was not controlled. If muscle vibration is to be in a quantitative assessment of muscle spindle function, all the mechanical characteristics of muscle vibration must be controlled, to enable predicting the afferent response of vibration. Therefore, a new type of vibrator must be designed to independently control force and displacement of muscle vibration at different frequencies of vibration. In addition, the optimum frequency, amplitude, and duration of muscle vibration should be determined for patients with LBP adapted to the objectives of the treatment.

■ Conclusion

The findings indicate that precise muscle spindle input of the paraspinal muscles is essential for accurate positioning of the pelvis and lumbosacral spine in a sitting posture. Patients with LBP have a less accurate and precise position sense than healthy individuals, presumably because of an altered paraspinal muscle spindle afference and central processing of this sensory input. Additional studies are necessary to confirm the possible role of muscle vibration in improving proprioception and local muscle control.

■ Key Points

- Lumbosacral position sense was studied in individuals with and without LBP.
- The role of paraspinal muscle spindles is shown by means of muscle vibration.
- Patients with LBP have a less refined lumbosacral position sense than healthy individuals.
- This is possibly due to an altered paraspinal muscle spindle afference and central processing of this sensory input.

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