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Deficits in foot skin sensation are related to alterations in balance control in chronic low back patients experiencing clinical signs of lumbar nerve root impingement

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ABSTRACT

Chronic low back pain (LBP) patients with radiculopathy, or sciatica, experience pain, tingling or numbness radiating down their leg due to compression of the lumbar nerve root. The resulting reduction in somatosensory information from the foot sole may contribute to deficits in standing balance control. This work was designed to investigate the relationship between foot skin sensitivity and standing balance control in chronic LBP patients with associated radiculopathy. Patients ($n = 9$) and matched healthy controls ($n = 9$) were recruited to the study, and were tested for balance control in both quiet standing as well as during rapid arm raise perturbation trials on a force plate. Foot skin sensitivity was tested bilaterally for vibratory threshold (3, 40 and 250 Hz) and touch (monofilament) threshold.

Results demonstrate that patients had reduced sensitivity to 250 Hz vibration in their affected compared to unaffected foot (at the great toe and heel), as well as compared to controls (at the great toe), but there were no differences with lower frequency vibratory testing or with monofilament testing. While there were no significant between-group differences in balance measures, moderate statistically significant correlations between 250 Hz sensitivity and quiet standing balance parameters were uncovered. Thus, patients demonstrate reduced high-frequency vibratory sensitivity at the foot sole, and correlations with quiet standing balance measures indicate a connection between these foot skin sensitivity deficits and alterations in balance control. Clinically, this identifies high frequency vibration testing as an important measure of skin sensitivity in patients with radiculopathy.

1. Introduction

Chronic low back pain (LBP) is a debilitating musculoskeletal disorder, affecting nearly 80% of adults at some point in their lifetime [1]. A subset of LBP patients suffer from associated lumbosacral radiculopathy, or sciatica. LBP-associated radiculopathy (LBP-R) is characterized by pain, tingling or numbness radiating down the affected leg, and is the most commonly occurring form of neuropathic pain [2]. Chronic compression of the affected lumbar nerve root and the resulting inflammation can compromise motor signals and sensation to the lower leg and foot, within the respective myotome and dermatome [3]. We were motivated to study potential skin sensory deficits on the affected foot, and to probe whether these may be related to compromised balance that has previously been reported for groups of LBP patients [4].

Prior research investigating foot skin sensation within the affected dermatome of LBP-R patients has focused on clinical assessments of skin sensitivity, such as touch detection [5], monofilament (MF) testing [6,7], heat or cold detection [6], and vibration [5,8]. Vibratory testing can be conducted across a spectrum of frequencies to target specific types of skin mechanoreceptor [9], and has never been completed comprehensively in a LBP-R population. In contrast, MF testing for mechanical touch threshold is thought to be mediated by fast-adapting afferents, and is a commonly used clinical tool for quickly measuring cutaneous sensation threshold [10,11]. Somatosensory information gained from skin on the foot sole is known to contribute to balance and stability [12,13].

Some evidence suggests that LBP patients have balance deficits in both quiet standing [4,14,15] and in perturbed standing [16,17]; although this is not a universal finding [18]. Specific mechanisms behind balance deficits in this population have not yet been

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defined, although proposed mechanisms include reduced lower back proprioception [19,20], alterations in hip control strategies [14], and reduced lumbar motion [21]. In healthy young adults, experimentally-induced plantar cutaneous somatosensory loss at the feet has been shown to result in increased centre of pressure (COP) deviations in quiet standing [22]. The role of foot skin somatosensory information in balance in LBP-R participants has not yet been investigated. The purpose of this work was to investigate the relationship between foot skin sensitivity and standing balance control in chronic LBP-R patients. It was hypothesized that decreases in foot skin sensation would be found in response to specific vibratory stimuli in LBP-R patients, and that these decreases would correlate with altered balance control apparent in this population.

2. Methods

2.1. Participants

Nine participants with LBP and associated unilateral lumbar radiculopathy (LBP-R) and 9 healthy controls (matched for age, sex, height and mass) were tested (Table 1). Chronic LBP-R patients had clinically diagnosed lumbar intervertebral disc herniation or bulge resulting in LBP and associated unilateral radiculopathy for a minimum of 3 consecutive months, and had no history of spine surgery or other chronic musculoskeletal or neurologic disorders. LBP-R patients completed a medical questionnaire detailing LBP-R duration and symptoms, and all reported at least one of pain, tingling or numbness down one leg and into the foot. The Oswestry Disability Index (ODI) and the Visual Analogue Scale of pain (VAS) were completed at the initiation of testing (VASi) and again after testing was finished (VASf). All participants signed informed consent, and the study was approved by the University Research Ethics Board.

2.2. Balance tests

First, all participants completed tests of whole body balance while standing barefoot on a force plate (sampled at 100 Hz; AMTI model MC3A-6, USA). Two 60-s quiet standing balance trials were conducted with eyes closed, one with a self-selected foot width and the other with narrow foot width (inter-malleolus distance of 1 cm). In addition, internal balance perturbation recovery was tested via bilateral arm raise trials completed with eyes open, repeated three times in both self-selected and narrow width stance. In these trials participants began with their arms by their side and were instructed to bilaterally flex their arms 90° at the shoulder, as rapidly as possible.

2.3. Skin sensitivity tests

Foot skin sensitivity was tested bilaterally at four sites, in randomized order. On the plantar surface: centre of the heel (He), centre of the great toe (GT), and 5th metatarsal head (5Met); on the dorsal surface (DS): webbing between first and second toes. Dynamic skin sensitivity was tested at each site using a Bruel and Kjaer Mini-shaker (Denmark, model 4810) with a 2 mm probe indented to a pre-load of 1 N. The Mini-shaker applied a 2 s vibratory stimulus at a specified frequency (3, 40 or 250 Hz), and the participant responded with a hand held trigger if they detected the stimulus. These specific frequencies were used because they are believed to isolate the activation of specific skin mechanoreceptors [10]. During threshold testing, vibratory stimuli were separated by 1–5 s, and a binary search method was used to determine the smallest detectable peak-to-peak displacement of vibration (vibratory threshold) at each site and for each frequency [23]. Displacement was recorded with a custom-made displacement sensor (sampled at 1000 Hz; model RGH24Z (0.5 μm resolution), Renishaw, UK). Static skin sensitivity was tested bilaterally using Semmes-Weinstein Monofilaments (MF) at the same sites. MF threshold was determined using an approximate 4-2-1 staircase method, and catch trials were included [11]. For all foot sensitivity tests participants were positioned in prone (for plantar surface sites) or supine (for DS site), with eyes closed, and wore headphones playing white noise. Skin temperature was recorded at each site using an infrared thermometer (THS841-065, ThermoWorks, USA) to ensure it remained consistent throughout testing.

2.4. Data analysis

Vibratory threshold was determined, as described above, at each foot site and frequency, and the average of three tests was recorded as vibratory threshold. Monofilament threshold was recorded as the grams of pressure associated with the smallest monofilament that was felt at least two thirds of the time.

Force plate data from the balance trials were lowpass filtered at 6 Hz (4th order dual pass Butterworth). The quiet standing balance outcome measures were root mean square (RMS) centre of pressure (COP) excursion (cm) and mean rectified COP velocity

Table 1
Detailed characteristics of LBP-R participants ($n = 9$) and mean (SD) characteristics of matched healthy controls ($n = 9$).

	Age (years)	Sex	Height (cm)	Mass (kg)	ODI[a] (%)	VASi[b]	VASf[c]	Duration (months)	Aff side	Disc level[d]	Symptoms[e]
LBP-R	21	F	175.3	63.5	8.9	0.9	1.2	24	R	L3-L4	Tingling, tightness
	46	F	160.0	68.0	22.2	1	3	7	R	L5-S1	Pain, numbness
	23	F	165.0	59.0	6.7	0	0.3	23	R	L4-L5	Pain, numbness
	31	F	167.6	81.6	41.1	4.9	4.9	11	R	L4-L5, L5-S1	Pain, tingling, numbness
	47	F	160.0	53.5	37.8	1.4	4.6	180	L	L2-L3, L4-L5, L5-L6	Pain, tingling, numbness, burning
	45	F	170.8	133.3	42.2	1.9	4.3	48	L	L5-S1	Pain, tingling
	46	M	178.0	100.0	13.3	0.9	0.9	6	R	L4-L5, L5-S1	Numbness
	20	F	175.0	65.0	44.4	2.1	6.8	24	L	L4-L5	Pain, tingling
	55	M	180.0	97.5	8.9	2.0	0.67	240	L	L4-L5	Numbness, pain
LBP-R average	37 (13.4)	2:7 (M:F)	169.6 (7.8)	78.0 (27)	25.9 (16)	1.8 (1)	3.4 (2)	62.6 (86)			
CONTROL average	37 (12.7)	2:7 (M:F)	174.7 (5.5)	76.1 (13)							

[a] ODI is Oswestry disability index; 0–20% indicates minimal disability, 20–40% indicates moderate disability, 40–60% indicates severe disability.
[b] VASi is Visual Analogue Scale of pain (0–10) recording at the initiation of testing.
[c] VASf is Visual Analogue Scale of pain (0–10) recorded after testing was finished.
[d] Disc level of herniation or bulge, determined from MRI ($n = 7$), CT ($n = 1$), or physician diagnosis ($n = 1$).
[e] Symptoms were recorded in a health questionnaire requiring patients to describe their radiculopathy.