RESEARCH ARTICLE

Sensory Organization and Postural Control Strategies During Quiet Standing in People with Acute Low Back Pain: A Case-Control Study

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Abstract

Objectives: This study aimed to compare posturographic measures between acute low back pain patients (LBP) and healthy controls.

Methods: A total of 20 participants with acute LBP were compared with a group of matched, healthy participants. Sensory organization, standing balance, and motor control strategies were assessed with the Neurocom Smart Balance Master posturography platform.

Results: The MANOVA indicated significant between-group differences in equilibrium ($F = 5.58$, $p < 0.001$) and strategy scores ($F = 3.98$, $p = 0.006$) across the six conditions of the sensory organization test. The equilibrium scores were significantly lower in participants with acute LBP compared to controls in all conditions except conditions 1 and 2 ($p < 0.001$). Similarly, strategy scores were significantly reduced in the acute LBP group compared to the control group in all conditions except condition 1 ($p < 0.05$). Visual and vestibular ratios were significantly lower in the acute LBP group than in controls ($p < 0.05$), whereas no significant difference was observed in somatosensory ratios between the two groups ($p = 0.07$).

Conclusion: Patients with acute LBP exhibit impaired postural control and altered movement strategies under sensory challenges, highlighting the importance of early assessment and rehabilitation targeting sensorimotor deficits to reduce the risk of recurrence.

Level of evidence: III

Keywords: Balance, Low back pain, Postural control, Proprioception

Introduction

Low back pain (LBP) is a significant health problem and a leading cause of work absenteeism and activity limitation.[1] Approximately 39% of the population experiences at least one episode of LBP during their lifetime.[2] Acute LBP is defined as pain lasting less than 12 weeks, located between the costal angles and the gluteal folds, and potentially radiating to one or both legs.[3] Although some patients recover within 4–6 weeks, pain becomes recurrent or persistent in about 40% of cases.[4] Evidence has identified environmental, psychological, and biological risk factors—such as poor coping strategies and ineffective interventions—that contribute to long-term pain, disability, and unfavorable outcomes.[5,6] Consequently, further research into associated problems, including impaired proprioception and its postural consequences, may be valuable for developing effective intervention strategies.

Evidence has demonstrated that physical impairments in patients with acute LBP include pain, reduced range of motion, and strength deficits.[7] Alterations in both peripheral and central somatosensory functions have also been reported in these patients.[7] According to the bottleneck effect, the central nervous system (CNS) cannot process all sensory inputs received from the periphery; therefore, it prioritizes relevant information. When individuals focus on their pain, it is processed as more

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salient than proprioceptive input, resulting in reduced proprioceptive acuity.[8] The International Association for the Study of Pain defines pain as “an unpleasant sensory and emotional experience associated with, or resembling that associated with, actual or potential tissue damage.”[9] Such pain-related beliefs can promote protective behaviors and avoidance of daily activities. These symptoms may ultimately lead to impaired postural control, negatively affecting quality of life and functional abilities.[10]

Postural control, encompassing both stability and orientation, is a fundamental component of daily activities. Stability refers to the ability to maintain the center of mass within the base of support during quiet standing, whereas orientation describes the alignment of body segments relative to gravity, the support surface, and the surrounding environment.[11] Postural control requires the integration of sensory information from the visual, vestibular, and somatosensory systems to generate appropriate motor responses that maintain equilibrium and prevent falls while minimizing energy expenditure.[12] The visual system provides the brain with feedback about the environment and the body’s relationship to surrounding objects. Visual input influences postural stability, as demonstrated by changes that occur when the eyes are opened or closed, or when moving visual scenes are presented. The vestibular system contributes to equilibrium by responding to both self-generated and externally induced forces. Once transmitted to the brain, vestibular input supports head orientation in the vertical position and regulates eye movements. Together with cervical proprioceptive input, these signals help estimate the body’s orientation in space. The somatosensory system provides information about the relative position of body segments and contributes to the perception of verticality through visceral graviceptors and tactile afferents from the soles of the feet. Proprioception supplies both static and dynamic information regarding the spatial position and orientation of joints, particularly those of the lower limbs and ankles.[13]

There is limited evidence regarding postural control in individuals with acute LBP. One study reported that experimentally induced pain, achieved by injecting hypertonic saline into the paraspinal muscles of healthy subjects, increased the overall instability index during static postural control tests.[14] However, to the best of our knowledge, no study has investigated the ability of individuals with acute LBP to effectively process sensory inputs required to maintain postural control during changing tasks and environmental conditions.

One of the most widely used methods to assess sensory integration in postural control is the computerized dynamic posturography sensory organization test (CDP-SOT). In this protocol, body sway is measured. At the same time, the subject stands under six different conditions that manipulate the availability and accuracy of visual and somatosensory inputs, thereby assessing the individual’s ability to adapt sensory information for postural orientation and control. The test also evaluates the motor strategies recruited to maintain postural stability under each sensory condition. The CDP-SOT is considered a novel outcome measure of postural control, and its reliability has been confirmed in healthy individuals, older adults, and patients with LBP.[15,16] Nevertheless, to date, postural changes in individuals with acute LBP have not been examined using SOT conditions.

Postural strategies are reactive responses that prevent falls and contribute to the stabilization of body posture. Horak and Nashner identified three primary strategies for maintaining balance during quiet standing: the ankle, hip, and stepping strategies.[17] Ankle and hip strategies are most commonly employed to maintain upright balance during both static and dynamic activities. These postural strategies do not rely solely on automatic processes but increasingly involve higher-level cortical and cognitive mechanisms. They are highly context-dependent and influenced by a variety of factors, including intrinsic factors (e.g., fear of falling, arousal, neurological or musculoskeletal disorders, aging), extrinsic factors (e.g., support surface size, limited ankle torque, perturbation magnitude and direction), and concurrent cognitive or motor activity. In individuals with acute LBP, delayed activation of the erector spinae, transversus abdominis, and multifidus muscles in response to unexpected perturbations has been reported.[18,19] However, to the best of our knowledge, no study has assessed motor control strategies for re-establishing postural stability in patients with acute LBP. Therefore, the present study had two main objectives: (1) to compare postural control between individuals with and without acute LBP when relying on somatosensory, visual, and vestibular inputs, and (2) to compare the motor control strategies employed by these two groups.

Materials and Methods

Research design

This cross-sectional study was approved by the Ahvaz Jundishapur University of Medical Science (Approval number: IR.AJUMS.REC.1399.600) and conducted between May and November 2023.

Participants

Twenty individuals with acute LBP were recruited from patients attending a local hospital. Inclusion criteria were: a primary complaint of LBP, with or without lower extremity symptoms, of less than three months’ duration, and age between 18 and 45 years. Exclusion criteria included neurological or respiratory disorders, previous spinal surgery, uncorrected visual impairment, vestibular disorders, pregnancy, diabetes, alcoholism, lower extremity injuries, or the use of medications affecting balance (e.g., muscle relaxants or analgesics). A control group of twenty healthy subjects, matched for age, sex, and body mass index, was also recruited. All participants provided written informed consent before enrollment in the study.

Procedures and measures

Demographic characteristics, pain intensity (measured with the Visual Analog Scale), and disability level (assessed with the Oswestry Disability Index)[20] were documented at baseline. Postural control was then evaluated under normal, reduced, or conflicting sensory conditions using the computerized dynamic posturography (CDP) system (Smart EquiTest CRS®, NeuroCom® International, Clackamas, OR, USA). This system consists of two movable force plates that can translate in the anterior–posterior direction, a movable visual surround, and eight sensory channels for the assessment of postural control.[21] Before the primary evaluation, participants were familiarized with the test procedure. Each subject wore a safety harness and stood barefoot on the force plate. According to the NeuroCom standard protocol, the medial malleoli were aligned with a horizontal reference line on the platform. The lateral calcanei were positioned on the S, M, or T lines relative to the participant's height [Figure 1]. The Sensory Organization Test (SOT) protocol consists of six conditions, created by systematically altering visual input and support surface, to evaluate participants' ability to optimally utilize visual, vestibular, and proprioceptive inputs for maintaining postural stability in standing. In the first condition (control), the individual stood on the force plates with all sensory information available. In condition 2, participants stood with their eyes closed, and in condition 3, the eyes remained open while the visual surround was sway-referenced (i.e., the visual environment moved). In condition 4, the support surface was sway-referenced by moving the force plates in the anterior–posterior direction, rendering proprioceptive information inaccurate. In condition 5, participants stood with their eyes closed while the support surface was sway-referenced, thereby isolating vestibular inputs for postural control. In condition 6, both proprioceptive and visual inputs were rendered inaccurate, as the support surface was sway-referenced and the visual surround moved [Figure 2]. Each condition was repeated three times, with each trial lasting 20 seconds and a 60-second rest period between trials. Participants were instructed to maintain balance, focus on a screen in front of them, and remain silent throughout the test. Trials were repeated if the participant took a step or lost balance. The posturography system provided four primary outcome measures: the equilibrium score, composite score, strategy score, and sensory ratios. The equilibrium score was calculated by comparing the angular difference between a participant's maximum anterior–posterior center of gravity (COG) displacement and the theoretical maximum displacement for each trial. The score is expressed as an inverse percentage ranging from 0 to 100. ϴmax represents the maximum anterior–posterior COG sway angle, and ϴmin represents the minimum value (Eq. 1).[22] Lower postural sway corresponds to a higher equilibrium score, indicating greater postural stability.

$$Equilibrium = \frac{12.5^{\circ} - (\theta\max - \theta\min)}{12.5^{\circ}} * 100$$

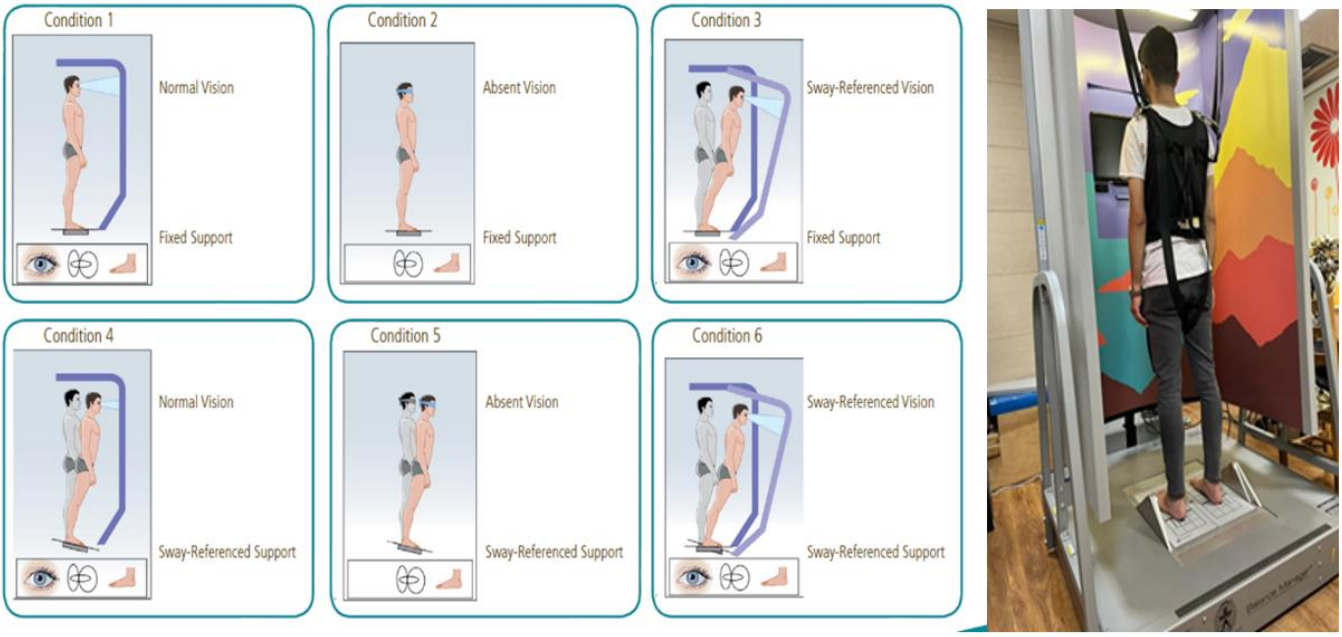

Figure 1. Conditions of the sensory organization test

Ratio	Comparison	Functional Relevance
somatosensory	Condition 2/condition 1	Patient's ability to use input the somatosensory system to maintain balance
Visual	Condition 4/condition 1	Patient's ability to use input the visual system to maintain balance
Vestibular	Condition 5/condition 1	Patient's ability to use input the vestibular system to maintain balance

Figure 2. Analysis of sensory ratio

The composite equilibrium score required at least two successful trials for each condition. It was calculated by averaging the equilibrium scores of SOT-1 and SOT-2, adding these to the equilibrium scores from each trial of SOT-3 through SOT-6, and dividing the total by the number of completed trials. The strategy score reflects the relative contribution of ankle versus hip and upper body movements used by participants to maintain balance in each sensory condition. It is expressed as a percentage, with higher scores indicating greater reliance on ankle strategies compared to hip strategies. The score was calculated as the difference between the maximum shear force (Shmax) and the minimum shear force (Shmin) generated (Eq. 2).[22]

$$MovementStrategy = \left[1 - \frac{SH_{\max} - SH_{\min}}{25} \right] * 100$$

The sensory ratio reflects the ability to effectively utilize specific sensory inputs for maintaining balance. Higher scores indicate greater reliance on, and more effective use of, a particular sensory modality in postural control.

Statistical analysis

Data were analyzed using SPSS version 24.0 for Windows (IBM Corp., Armonk, NY, USA). The normality of distributions was assessed with the Shapiro–Wilk test. Between-group comparisons of demographic variables were performed using independent-samples t tests or Mann–Whitney U tests, as appropriate. Multivariate analysis of variance (MANOVA) was conducted to compare equilibrium scores, strategy scores (across SOT conditions 1–6), and sensory ratios between the two groups. When the overall multivariate test was significant, univariate analyses were performed for each outcome measure. The Mann–Whitney U test was additionally used to compare composite scores between groups. A significance level of $p < 0.05$ was adopted for all analyses. Effect sizes were estimated using partial eta squared (η^2), with values of 0.0099, 0.0588, and 0.1379 considered small, medium, and large effects, respectively.[23] The required sample size was estimated using GPower software, version 3.1.9.2 (Franz Faul, Universität Kiel, Germany). A total of 38 participants (19 per group) was calculated to achieve 90% power at a type I error rate of $\alpha = 0.05$.*

Results

The demographic and clinical characteristics of participants are presented in [Table 1]. No statistically significant differences were observed between the groups in terms of age, height, weight, or body mass index.

Table 1. Demographic and clinical characteristics of low back pain and control groups

Characteristics	Low back pain patients (N=20)	Controls (N = 20)	*p*-value
Age (years)	36.85(7.16)	34.30(11.30)	0.20
Sex	Female =15/ Male = 5	Female = 15/ Male = 5	0.64
Body mass index (kg/m2)	27.83(4.40)	24.23(4.94)	0.39
Oswestry Disability Index (percent)	31.10 (11.81)	N/A	-
Visual Analog Scale (point)	6.84 (1.50)	N/A	-
Duration (mon)	36.85(23.61)	N/A	-

Standing balance

The composite equilibrium score, representing the weighted average of all SOT conditions, was significantly lower in the acute LBP group compared with healthy controls ($p < 0.001$). MANOVA revealed a significant overall between-group difference in equilibrium scores across the six SOT conditions ($F = 5.58$, $p < 0.001$). Follow-up one-way ANOVAs for each condition showed that equilibrium scores were significantly lower, with large effect sizes, in participants with acute LBP compared to healthy controls for all conditions except SOT-1 and SOT-2 [Table 2].

Strategy scores

Significant multivariate effects were observed for strategy scores between the two groups ($F = 3.98$, $p = 0.006$). Univariate analyses indicated that strategy scores were significantly lower in the acute LBP group compared with the control group across all conditions, except SOT-1, with large effect sizes [Table 2].

The contribution of the sensory systems to postural control

MANOVA results revealed a significant overall difference in sensory ratios between the two groups ($F = 7.40$, $p = 0.001$). Tests of between-subject effects showed that visual and vestibular ratios were significantly lower, with large effect sizes, in the acute LBP group compared with the control group. In contrast, no significant difference was observed between groups for the somatosensory ratio [Table 2].

Discussion

The objective of this study was to investigate differences in sensory organization and postural control strategies between individuals with acute LBP and healthy controls during quiet standing. The results demonstrated that participants with acute LBP exhibited reduced postural stability compared with healthy controls in SOT conditions 3–6. In contrast, performance was comparable between groups in the less challenging conditions (SOT-1 and SOT-2). Greater postural sway in the acute LBP group was observed when somatosensory and/or visual inputs were disrupted or absent.

To the best of our knowledge, previous studies on postural control have primarily focused on individuals with chronic

LBP.[24,25] Only limited research has examined postural control in acute LBP, particularly under varying task difficulties involving visual conditions.[10] Several mechanisms may explain the differences in postural control between patients with LBP and healthy individuals. First, somatosensory alterations have been reported in individuals with acute LBP compared with healthy controls.[26,27] Thus, the loss of reliable somatosensory input may limit the ability to effectively integrate sensory information for postural orientation. Second, patients with acute LBP have demonstrated delayed onset and reduced electromyographic activity of the abdominal and paraspinal muscles during postural perturbation tasks. These neuromuscular deficits likely contribute to the greater sway observed in the acute LBP group under SOT conditions compared with controls.[28,29] According to the theory proposed by Hodges and Tucker, pain leads to a redistribution of activity within and between muscles, resulting in altered movement patterns and increased stiffness to protect the painful region from further pain or injury. Consequently, individuals with acute LBP may adopt different postural control strategies than healthy controls.[30] Third, psychological factors such as anxiety and depression associated with acute pain may also influence postural control performance.[31]

Table 2. Comparison percentage of stability (%) and strategies (% of ankle strategy) used under the conditions of the SOT between the groups:

	Group			
	Low back pain (n=20)	**Control (n=20)**	***p*-value**	**Effect size**
Equilibrium score				
Condition 1	93.78(1.48)	93.84(1.79)	.906	.001
Condition 2	88.02(9.87)	92.21(1.56)	.068	.085
Condition 3	85.63(5.69)	89.80(3.87)	<.001	.162
Condition 4	62.54(18.05)	75.81(9.80)	<.001	.180
Condition 5	40.68(19.31)	64.03(9.67)	<.001	.380
Condition 6	30.56(16.74)	56.35(17.15)	<.001	.379
Composite ES	59.95(10.36)	72.30(6.25)	<.001	.354
Sensory ratio analysis				
Somatosensory ratio	0.93 (0.10)	0.98 (0.01)	.070	.084
Visual ratio	0.66 (0.19)	0.80 (0.10)	.006	.180
Vestibular ratio	0.43(0.20)	0.68 (0.10)	<.001	.375
Strategy score				
Condition 1	95.94(1.31)	96.31(1.77)	.727	.004
Condition 2	91.68(6.07)	95.53(1.50)	.023	.156
Condition 3	89.02(9.01)	93.72(2.58)	. 006	.109
Condition 4	80.94(7.02)	89.40(3.19)	<.001	.372
Condition 5	75.75(8.14)	82.18(6.86)	.022	.159
Condition 6	71.28(14.13)	81.72(4.73)	. 012	.194

Analysis of strategy scores revealed that the movement patterns used for postural correction in individuals with acute LBP differed from those of healthy controls as postural demands increased across the six SOT conditions. This may represent an adaptive strategy adopted by patients due to altered proprioceptive acuity and changes in central processing of nociceptive information. The lower strategy scores observed in the acute LBP group suggest a hip-dominant movement strategy. Greater reliance on hip strategies may increase both the risk of falling and the energetic cost of maintaining postural control. These differences may be related to inhibited muscle activity and delayed trunk muscle reflex responses in patients with acute LBP, which could lead to faster and larger amplitude compensatory movements following perturbations.[32,33] These results contrast with the motor strategies typically reported in individuals with chronic LBP, who often rely on an ankle strategy during quiet standing. Patients with chronic LBP appear to adopt a trunk- and body-stiffening strategy due to restricted lumbar range of motion, while reweighting proprioceptive inputs by increasing reliance on ankle proprioceptive signals for postural control. This tighter regulation of the center of mass through ankle strategies may be associated with trunk muscle co-contraction, as well as anxiety and fear of pain in chronic LBP patients.[34,35] However, based on the findings of this study, patients with acute LBP appear to adopt looser postural control and reduced spinal motor control, which may contribute to lumbar instability and greater reliance on hip movements compared with healthy controls. Further research is warranted to clarify these mechanisms.

In addition, the findings of this study showed no significant between-group differences in the somatosensory ratio. In contrast, visual and vestibular ratios differed significantly between patients with acute LBP and healthy controls. This suggests that individuals with acute LBP have an impaired ability to utilize visual and vestibular inputs to maintain standing balance. However, further research is needed to clarify the specific contributions of the visual and vestibular systems to postural control in this population. Moreover, future studies should explore the role of active physiotherapy interventions in acute LBP management, with a focus on resetting postural strategies within a multidisciplinary framework. Such approaches should incorporate both targeted exercises to improve proprioceptive deficits (peripheral) and interventions addressing psychological factors (central).

Limitation

This study has several limitations. First, postural control in patients with acute LBP was not assessed during complex tasks. Future research should evaluate postural control in such individuals during functional movements, such as lifting and carrying groceries to a countertop. Second, no functional balance tests were included in this study; therefore, future investigations should provide a more comprehensive assessment of postural control at different levels of the International Classification of Functioning, Disability and Health (ICF) in patients with acute LBP. Third, the relatively small sample size limits the generalizability of our findings. Finally, this study did not address whether differences in postural control between groups persist under fatigue conditions or during more complex motor tasks. Future studies should therefore examine these factors in larger samples and in the context of fatigue protocols and ecologically valid movement tasks.

Conclusion

Individuals with acute LBP demonstrated greater postural sway than healthy controls in SOT conditions 3–6 and adopted different postural strategies, with an excessive reliance on hip strategies under increased sensory challenges. The presence of subclinical deficits in sensory organization and motor control during the acute phase of LBP may contribute to cycles of recurrence and chronicity. These findings underscore the importance of early assessment and targeted rehabilitation to address sensorimotor deficits in patients with acute LBP.

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Declaration of Informed Consent: There is no information (names, initials, hospital identification numbers, or photographs) in the submitted manuscript that can be used to identify patients. Written informed consent was obtained from all participants prior to entering the study.

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