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Hip Strategy for Balance Control in Quiet Standing Is Reduced in People With Low Back Pain

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Study Design. Quiet stance on supporting bases with different lengths and with different visual inputs were tested in 24 study participants with chronic low back pain (LBP) and 24 matched control subjects.

Objectives. To evaluate postural adjustment strategies and visual dependence associated with LBP.

Summary of Background Data. Various studies have identified balance impairments in patients with chronic LBP, with many possible causes suggested. Recent evidence indicates that study participants with LBP have impaired trunk muscle control, which may compromise the control of trunk and hip movement during postural adjustments (*e.g.,* hip strategy). As balance on a short base emphasizes the utilization of the hip strategy for balance control, we hypothesized that patients with LBP might have difficulties standing on short bases.

Methods. Subjects stood on either flat surface or short base with different visual inputs. A task was counted as successful if balance was maintained for 70 seconds during bilateral stance and 30 seconds during unilateral stance. The number of successful tasks, horizontal shear force, and center-of-pressure motion were evaluated.

Results. The hip strategy was reduced with increased visual dependence in study participants with LBP. The failure rate was more than 4 times that of the controls in the bilateral standing task on short base with eyes closed. Analysis of center-of-pressure motion also showed that they have inability to initiate and control a hip strategy.

Conclusions. The inability to control a hip strategy indicates a deficit of postural control and is hypothesized to result from altered muscle control and proprioceptive impairment. [Key words: balance, low back pain, postural control] **Spine 2004;29:E107–E112**

It has been shown that in normal adults, postural adjustments in bilateral stance on a flat surface are generally achieved using an "ankle strategy",[1] in which ankle torque maintains the center of mass (COM) over the base of support. In this strategy, muscle activity occurs in a distal to proximal sequence.[1] If the support surface is short in relation to foot length, this strategy is replaced by a "hip strategy" that involves generation of horizontal shear forces from torques at the hip, rather than shifting the center of vertical foot pressure by torques at the ankle.[1] This strategy involves motion at the trunk and hip, using a proximal-distal sequence of muscle activation.[1] While postural control strategies can be broadly categorized according to these definitions, postural control normally involves elements of both, although the emphasis will vary depending on the postural context.

The coordination of postural control may be affected in people with low back pain (LBP). Several factors associated with LBP are likely to affect postural control and the relative utilization of hip and ankle strategies.

First, studies of people with LBP have indicated changes in position of the center of pressure (COP) in quiet standing on a flat surface. For example, several authors report that the COP is more posterior in people with LBP than in pain-free control subjects, at least in some tasks.[2,3] This has been argued to be resulting from adoption of a lordotic posture to relieve pain.[2] Postural deviations such as this are likely to influence the relative utilization of ankle and hip strategies in quiet standing.

Second, several studies have reported changes in postural activity of the trunk muscles in people with chronic[4,5] and acute LBP.[6] Although several studies have identified a consistent deficit in the activity or morphology of the deep abdominal[5,7–9] and paraspinal muscles,[10–12] it has been debated widely that LBP is often accompanied by augmented activity of the superficial trunk muscles. For instance, Radebold *et al*[13] reported increased coactivation and delayed offset of activity in association with removal of a load from the trunk, and increased activity of the erector spinae muscles has been reported at the end range of trunk flexion[14–16] and during locomotion[17] compared with control subjects. Increased activity of the trunk muscles may limit trunk and hip motion, thus restricting the hip strategy. Thus, we hypothesized that people with LBP may have increased difficulty maintaining equilibrium when standing on a short base of support, which forces the use of the hip strategy.

Third, several studies have reported deficits in proprioception in the lumbar spine in people with LBP.[18–20] These changes may lead to compromised balance control.[4,21,22] However, this has not been directly evaluated. With impairment of the proprioceptive system, we hypothesized that it would be reasonable to deduce that control of the lumbar spine may be impaired in people with LBP. There may be a greater dependence on visual input to control balance and, therefore, less likely to keep their balance when visual input is altered or removed.

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Table 1. Characteristics of Back Pain and Matched Control Subjects

	Back Pain Subjects (n = 24)	Matched Controls (n = 24)	*P*
Age (yr)	36.6 ± 10.0	36.9 ± 10.5	0.934
Height (m)	1.71 ± 0.09	1.69 ± 0.08	0.481
Weight (kg)	71.2 ± 11.5	65.3 ± 11.6	0.036*
Body mass index	25.0 ± 4.3	22.7 ± 3.1	0.059
Habitual Physical Activity			
Work (scale 1–5)	3.2 ± 0.4	2.9 ± 0.5	0.088
Sports (scale 1–5)	2.4 ± 0.6	2.5 ± 0.8	0.901
Leisure (scale 1–5)	2.9 ± 0.5	3.0 ± 0.6	0.475
Duration of back pain (yr)	10.5 ± 8	N/A	
VAS score (scale 0–10)	2.0 ± 1.6	N/A	
Roland Morris Scale (scale 0–24)	3.2 ± 3.5	N/A	

Values are mean ± SD.
N/A = not applicable.
* $P < 0.05$.

In view of these factors, several studies have investigated balance control in people with LBP. However, there has been little agreement regarding which parameters are affected most. Although increased postural sway has been identified, there is disagreement regarding the most sensitive parameter.[2,3,21,22] For instance, while some authors report a reliable decrease in sway velocity in LBP,[23] others report either no change[24] or changes in only in unilateral stance.[25] We hypothesized that the differentiation between healthy and study participants with LBP may be augmented when quiet stance is challenged by placing them on a short base of support.

Thus, the aims of the present study were as follows: 1) to compare the postural control strategy between people with and without LBP while standing on short and long bases; 2) to compare the utilization of the horizontal shear forces (hip strategy) or displacement of center of pressure (ankle strategy) when standing on short and long bases; and 3) to compare balance control between conditions in which visual information is present, reduced, or absent.

■ Methods

Subjects. Twenty-four people with LBP (age range, 20–55 years) and 24 age- and gender-matched control subjects were recruited from nursing and allied health staff of a tertiary hospital *via* dissemination of information through seminars and flier posting within the hospital campus. Study participants were included in the LBP group if they had a history of LBP for more than 18 months, at least 1 episode of LBP in the last 6 months or pain that was semi-continuous nature with periods of greater and lesser pain, and LBP of the severity that required treatment or sick leave from work. Study participants were excluded if they had LBP with a nonmusculoskeletal etiology, any known sensory or neurologic disorders, previous surgery, structural damage or gross structural defect of the spine, or unresolved lower limb musculoskeletal pathology or if they were using any pain relieving medication or any substance that could affect balance. Study participants were included in the control group if they had no history of significant LBP (defined as episodes that required treatment or sick leave) and any conditions that would affect their balance. The same exclusion criteria were applied to the control subjects. All subjects were on full work duty, and none was undergoing regular medical treatment or physical therapy for their LBP at the time of testing.

Anthropometric measures including height, weight, and foot length were recorded from each participant before testing and a Habitual Physical Activity Questionnaire (HPA)[26] was administered. The study participants with LBP completed an additional questionnaire related to their back pain history, and severity of LBP was measured using a Visual Analog Scale and the Roland Morris Disability Questionnaire.[27,28] The characteristics of study participants are listed in Table 1. All procedures were approved by the Institutional Medical Research Ethics Committee.

Force Plate Measurements. A dual force platform system (9286A, Kistler) was used to detect the ground reaction forces (shear and vertical) during 12 quiet stance trials. Data were acquired at 100 Hz and low pass filtered at 10 Hz using Bioware 3.12 software (Kistler) and calculations made with Matlab 6.0 software (The Mathworks). Measurements used in this study were: the average anteroposterior shear force (aFy), maximum range of center-of-pressure excursion in anteroposterior dimension (rCOPy), and the average velocity of the center-of-pressure (aCOPV).

Experiment Protocol. Measurements were made in a closed room, free from external distractions and all procedures and instructions were standardized and conducted by one person. Subjects stood with bare feet, one on each force plate, with the feet placed so that the midpoint of the heels was separated by a distance equal to half the foot length and externally rotated a comfortably up to 15°. Foot position was marked on a plastic sheet on each force plate to enable standardization of the subsequent tasks. Twelve tasks were performed by each subject with different combinations of stance positions (bilateral, unilateral), anteroposterior support surface dimensions (flat, 9 cm), and visual conditions (eyes open, dim light, eyes closed).

For each visual and base condition, bilateral stance was tested before unilateral stance. Subjects were asked to hold each bilateral stance position for 70 seconds and each unilateral stance position for 30 seconds. The skill-dominant lower limb was selected as the stance limb for all the unilateral stance tasks. Two base conditions differentiated by anteroposterior dimensions were performed in a sequence of flat surface and 9

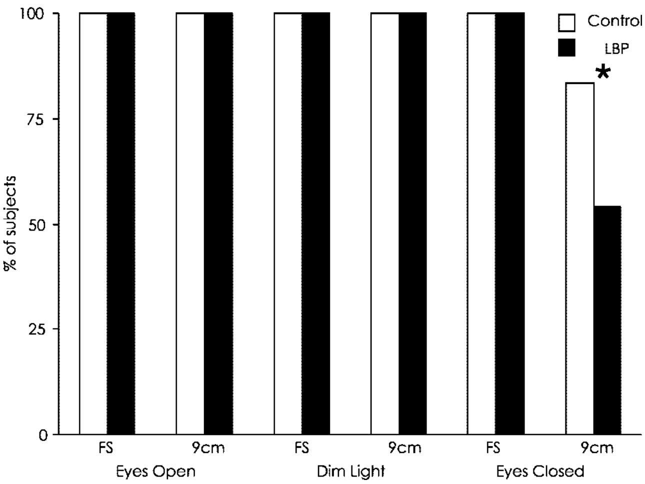

Figure 1. The percentage of successful bilateral tasks achieved in the control and LBP groups. Note the increased failure of LBP patients to maintain balance on a 9-cm base with the eyes closed. FS = flat surface; 9cm = 9-cm base. $^*P < 0.05$.

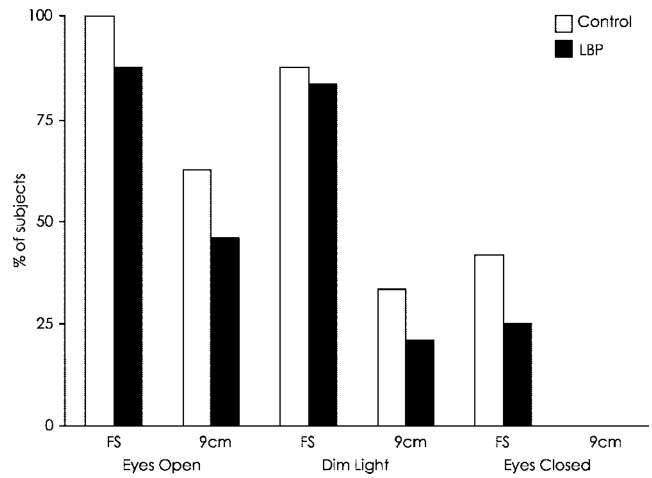

Figure 2. The percentage of successful unilateral tasks achieved in the control and LBP groups. Although there is no significant difference between the two groups, there was a trend for reduced success by the LBP across tasks. FS = flat surface; 9cm = 9-cm base.

cm. In the 9-cm base condition, two blocks were positioned with one on each plate. Study participants stood on the blocks with one foot on each block across the center of the sole of the feet. The visual conditions used in this study were eyes open, dim light, and eyes closed. In the dim light condition, overhead lights were turned off and only illumination from the computer monitor 1 m behind the subject was available. This resulted in a light intensity measured with a photographic light meter of <5 foot-candles (53.8 lux). The order of stance and base conditions remained the same for each study participant, the sequence of visual conditions was randomized.

Data Analysis. A task was considered to be successful if the subject could sustain a bilateral stance for 70 seconds and unilateral stance for 30 seconds. Between-group difference in ordinal data such as age, HPA, and number of successful tasks were analyzed with Wilcoxon's rank sum test. Differences in continuous data such as anthropometric measurements were analyzed with paired *t* tests. For data from the force platform, only successful trials were analyzed. To detect differences within and between groups in the three force platform measures (aFy, aCOPV, and rCOPy), a linear mixed model was used and significance was tested using the *F* statistic of the analysis of variance table. The factors involved in the model were group (2), base (2), and visual condition (3). As the spread of the residuals of this variable was not homogeneous, the analysis of variance was performed on the log-function of the data.

Results

Number of Successful Trials

When study participants stood quietly with both feet on the floor, people with LBP were able to complete fewer tasks (of possible 6) than the control subjects ($P = 0.029$, Figure 1). In bilateral stance, all subjects were able to complete the majority of tasks with the exception of standing on the short base with eyes closed. Although 83% of the control subjects could successfully complete 70 seconds of this task, only 54% of the study participants with LBP were successful ($\chi^2 = 4.7515$, $P = 0.029$), and were 4.23 times (odds ratio failure rate 95% confidence interval = 2.35, 7.60) more likely to fail than the control subjects. When the mean holding time of the 9 cm eyes closed condition was compared between groups, there was no significant difference.

When study participants stood on one leg, there was no significant difference in the number of successful unilateral stance tasks that could be completed between the control and the LBP groups. However, there was an overall trend for more subjects in the control group than the LBP subject group able to sustain the position for 30 seconds in every task (Figure 2). No significant difference was found between groups in the average holding time in any of the unilateral tasks.

Anteroposterior Shear Force (aFy)

Comparison of the mean amplitude of anteroposterior shear force between the control and LBP groups indicated that there was a significant main effect for group ($P = 0.04$) with a smaller aFy in the LBP group (3.14 ± 3.56) than the control group (4.35 ± 4.09) (Figure 3). As expected, the main effect for base ($P < 0.0001$), visual conditions ($P = 0.007$), and a condition × base interaction ($P = 0.008$) were all significant. Anteroposterior shear force was increased by reduced base length and availability of visual input for both groups. There was no interaction between groups with visual condition and base condition ($P = 0.416$). This indicates that, although the study participants with LBP had a consistently lower aFy than the control group, they responded similarly to the reduction of base size and visual input.

Velocity and Range of COP Motion (aCOPV, rCOPy)

The velocity of COP motion was significantly less in the LBP group (4.33 ± 2.17) compared with the controls (5.03 ± 2.83) ($P = 0.0005$). Similar to aFy, an increase in

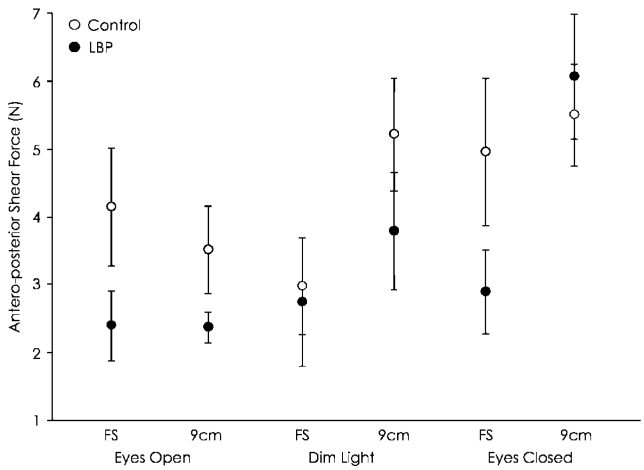

Figure 3. Group data for change of anteroposterior shear force in all tasks for both subject groups (mean ± SEM). Note that aFy is reduced for study participants with LBP compared with controls for most conditions and that a similar trend of increase in aFy in response to reduced base length and visual input in both groups. FS = flat surface; 9cm = 9-cm base.

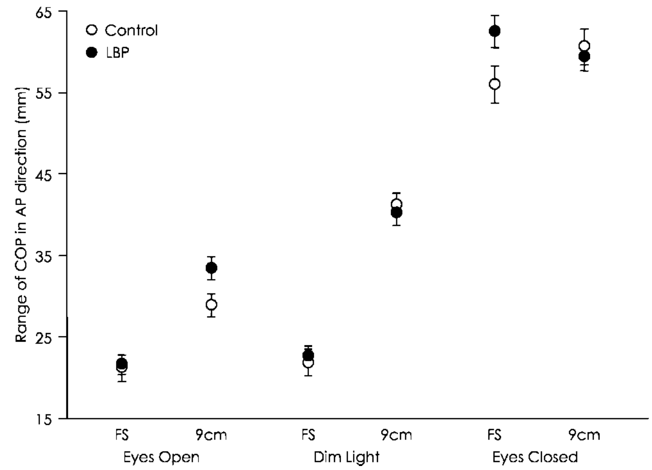

Figure 5. Group data for range of COP motion in the anteroposterior direction for the LBP subject and control group in all tasks (mean ± SEM). There is a weak but nonsignificant trend for COP range to increase with decrease in length of support surface in the LBP group compared with the control group. FS = flat surface; 9cm = 9-cm base.

aCOPV was associated with a decrease in supporting base and visual input (condition, $P < 0.0001$; base, $P < 0.0001$; condition $\times$ base, $P < 0.0001$) and both groups respond similarly to the change in base and visual conditions ($P = 0.176$) (Figure 4).

No significant difference between groups was identified in rCOPy. A decrease in base length and visual input induced significant increase in the anteroposterior postural sway (base, $P < 0.0001$; visual, $P < 0.0001$; base $\times$ visual, $P < 0.0001$) in both groups, but the study participants with LBP did not have a greater range of anteroposterior COP motion than the controls (Figure 5).

Discussion

The results of the present study suggest that subjects with LBP have poor balance. When compared with their age- and gender-matched pain-free controls, study participants with LBP achieved a smaller number of successful balance tasks. Among the bilateral stance conditions, study participants with LBP were more likely to fail tasks with decreased length of the supporting base and removal of vision. This supports previous studies, which have shown that study participants with LBP tend to fail balance tasks with a decreased size of the base of support[2,25] and altered sensory inputs.[3,4,21,22] It is unlikely that the reduced balance performance is due to deconditioning as all subjects were performing full job duty, there was no between-group difference in physical activity level, and the reported pain level in the LBP group was low at the time of testing (Visual Analog Scale ~2/10).

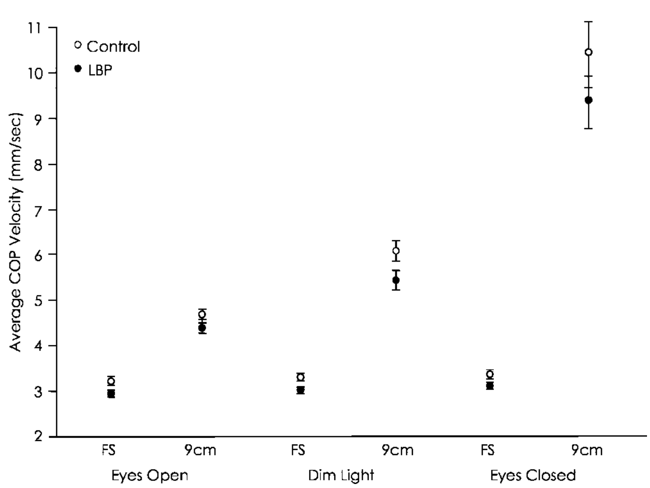

Figure 4. Group data for average COP velocity for all tasks and groups (mean ± SEM). Note the consistently reduced COPV for study participants with LBP across all conditions. FS = flat surface; 9cm = 9-cm base.

Study Participants With LBP Had Impairment of Hip Strategy

Horak and Nashner[1] suggested that while an ankle strategy is adequate for maintenance of upright stance on a flat surface, a hip strategy is required for postural adjustments on short base or during sudden perturbations on a flat surface.[29,30] While the ankle and hip strategies are stereotypical, a continuum of mixed strategies is used under most circumstances. Decision on predominance of strategy is made depending on factors such as experience, expectation of the perturbation, and environmental constraints.[29,31] By asking subjects to balance on a short base, we aimed to force subjects to use a hip strategy. Kinetically, a hip strategy is characterized by an increase in horizontal shear force in the anteroposterior direction.[1] In the present study, the consistently reduced anteroposterior shear force in the LBP group may indicate their difficulty in producing or controlling a hip strategy. This is in contrast to previous work,[2] which argued (on the basis of visual observation) that study participants with LBP use a hip strategy more frequently than the controls. This interpretation differs from our present data based on the characteristics of kinetic data, horizontal shear force, which is a well-accepted objective measurement.

The reduced utilization of the hip strategy may be due to reduced motion of the lumbar spine and hip as a result of increased activity of lumbopelvic muscles. Numerous studies have reported increased activity of trunk muscles in patients with LBP. Several EMG studies have reported increased activation of the erector spinae muscle in study participants with LBP during tasks such as trunk flexion,[14–16,32,33] and the absence of relaxation of the erector spinae at the end of range of trunk flexion (the "flexion-relaxation" phenomenon) has been shown to be associated with reduced intervertebral motion.[16] Increased activity of the erector spinae muscles has also been identified during the swing phase of gait in people with LBP.[17] Furthermore, Ng *et al* tested lumbar axial rotation of the trunk and reported reduced fatigability of obliquus externus abdominis in the LBP group.[34] Finally, when a load is unexpectedly removed from the trunk of people with LBP, Radebold *et al*[4,13] showed increased activation of the superficial trunk muscles in study participants with LBP.

In contrast to the increased activation of the superficial trunk muscles, activity of the intrinsic spinal muscles has been found to be either decreased or delayed in patients with LBP. In people with LBP, impairment of the lumbar multifidus muscle has been reported as decreased activity[11] and reduction in size.[10,35] Similarly, activity of the deep abdominal muscle, transversus abdominus, has been found to be delayed in study participants with LBP.[5,7,36] The association of impairment of intrinsic spinal muscle activity with hyperactivity of the lumbosacral muscle in study participants with LBP is still unclear. However, it is possible that the hyperactivity of the lumbosacral muscle could be a cause or a compensation for the deficiency of the intrinsic spinal muscle function. Regardless, increased activity of the lumbosacral muscles is likely to restrict the range and pace of trunk-on-hip motion in response to postural perturbation. The reduced hip strategy (*i.e.*, decreased anteroposterior shear force) identified when subjects stood on short base may be due to this mechanism. In support, there is preliminary evidence that LBP patients have changes in trunk superficial muscle activity and restricted trunk displacement in response to postural perturbation induced by translation of the support surface.[37] Other possible explanations for reduced hip strategy such as fear of movement cannot be excluded and require further investigation.

Increased Visual Dependency in LBP

Our results suggested that visual input is critical for postural control in people with LBP, as absence of visual inputs results in an increased likelihood of failing balance tasks on a 9-cm base. This visual dependence is supported by other studies, which have found that with the absence of visual input, balance impairment in study participants with LBP is greater. This is evidenced by increased loss of balance[2,4] or COP sway parameters.[2–4,21,22]

It has been argued that the balance dysfunction in patients with LBP may be due to altered proprioceptive feedback from the trunk. This is supported by recent studies, which show that lumbar proprioception is reduced in study participants with LBP.[18–20] If quality of proprioceptive feedback from one segment of the body is poor, the dependency on visual input is likely to be increased. As the ankle strategy involves less head movement,[38,39] this may be preferred by patients with LBP as it would assist with gaze stabilization when visual input is available. Furthermore, it has been argued that while position of the COM can be calculated by the central nervous system from ankle position when an ankle strategy is used, a more complex calculation is required for estimation of the COM position during the hip strategy due to its multisegmental nature.[40] This has been argued to require accurate information of the position of the lumbar spine and hip and visual cues.[40] Thus, when visual input is not available, execution of hip strategy and maintenance of the position of the COM over the base of support are dependent on accurate input of lumbar position.[40] As the proprioceptive input from this region has been argued to be reduced in LBP,[18–20] this calculation is likely to be erroneous, forcing people with LBP to avoid the hip strategy, particularly when visual inputs are reduced.

Methodologic Considerations

Results may have been affected by the number of trials that were of sufficient duration to be analyzed. Some of the unilateral stance tasks were too difficult even for control subjects to complete successfully and the COP motion of a bilateral stance task was only analyzed if the subjects could maintain their balance for 70 seconds. This data collection period was selected on the basis of previous data, which showed optimal reliability of COP motion with a sampling duration of more than 60 seconds.[41] Because of the exclusion of unsuccessful trials, we may have underestimated the extent of balance dysfunction in the LBP group because it is these trials that are likely to have the greatest balance deficit. However, analysis of fail trails not only yields results with less reliability, comparisons across trials with different sampling cannot be made. It is acknowledged that kinematic measurements would also allow direct measurement of postural strategies and may contribute further to the understanding of the difference between LBP and control subjects.

■ Conclusion

This study provides preliminary insight into the nature of balance impairment in persons with low back pain. It is important for the clinicians to consider the possible impairment in balance strategy during rehabilitation, and specific training of hip strategy in this particular population might be beneficial for full functional recovery.

■ Key Points

- Quiet standing balance performance was evaluated in 24 study participants with low back pain and 24 matched controls.
- Patients with low back pain showed poor standing balance with altered postural adjustment strategy and increased visual dependence.
- The increased failure rate of short base task and decreased horizontal shear force indicate reduced dependence on the hip strategy for postural control in study participants with low back pain.

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