Proprioceptive Weighting Ratio for Balance Control in Static Standing Is Reduced in Elderly Patients With Non–Specific Low Back Pain

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Study Design. A cross-sectional, observational study.

Objective. The aim of this study was to determine a specific proprioceptive control strategy during postural balance in elderly patients with non-specific low back pain (NSLBP) and non-LBP (NLBP).

Summary of Background Data. Proprioceptive decline is an important risk factor for decreased balance control in elderly patients with NSLBP. The resulting reduction in proprioception in the trunk or lower legs may contribute to a reduction in postural sway. This study aims to determine the specific proprioceptive control strategy used during postural balance in elderly patients with NSLBP and NLBP and to assess whether this strategy is related to proprioceptive decline in NSLBP.

Methods. Pressure displacement centers were determined in 28 elderly patients with NSLBP and 46 elderly patients with NLBP during upright stances on a balance board without the benefit of vision. Gastrocnemius and lumbar multifidus muscle vibratory stimulations at 30, 60, and 240 Hz, respectively, were applied to evaluate the relative contributions of the different proprioceptive signals (relative proprioceptive weighting ratio, RPW) used in postural control.

Results. Compared to elderly patients with NLBP, those with NSLBP had a lower RPW at 240 Hz and significantly higher RPW at 30 Hz. A logistic regression analysis showed that RPW at 240 Hz was independently associated with NSLBP after controlling for confounding factors.

Conclusion. Elderly patients with NSLBP decreased their reliance on ankle strategy (RPW at 240 Hz) and hip strategy (RPW at 30 Hz) proprioceptive signals during balance control. The inability to control hip and ankle strategies indicates a deficit of postural control and is hypothesized to result from proprioceptive impairment. Moreover, elderly patients with NSLBP are at higher risk for lower leg proprioceptive decrease (240 Hz) through the NSLBP exacerbation.

Key words: ankle strategy, balance control, hip strategy, non-specific low back pain, relative proprioceptive weighting ratio.

Level of Evidence: 4

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Postural stability is essential for performing daily activities. Healthy persons normally maintain postural stability using a multisegmental control strategy.1,2 Reweighting of sensory signals has recently been shown to be based on location rather than being intrinsic to the proprioceptive system in healthy persons and in persons with low back pain (LBP).3 Postural instability is observed in patients with LBP and in older persons.4,5 Mok et al6 reported that the quality of balance control is decreased in patients with LBP and that this deficit is associated with poor use of spinal function for postural control. An analysis of center-of-pressure motion has demonstrated that people with LBP are unable to use a hip strategy.7 Brumagne et al5 reported that people with LBP control their postural balance using a more rigid strategy involving the ankle strategy. These impairments lead to pain and declines in postural strategy, muscle function, and proprioception.9 Patients with LBP also have decreased lumbosacral proprioception, which might cause instability in postural sway.10,11 Therefore, postural control abilities in patients with LBP may affect coordination. Several proprioceptive systems are likely to affect postural control related to hip and ankle strategies. If input from particular parts of...
the body decreases because of injury, LBP, or aging, proprioception might increase the weighting of input from other locations that provide information for maintaining stable posture.

However, the mechanisms of such a response and postural instability in elderly patients with LBP are not yet clear. Muscle vibration, known to be a strong stimulus for muscle spindles and Vater-Pacini corpuscles, has been used to elucidate the role of proprioception.\(^1\)\textsuperscript{14} These studies suggest that pain is a possible cause of decreased variability in postural strategy. However, the role of each proprioceptor (Meissner corpuscle, muscles spindles, and Vater-Pacini corpuscles) in patients with non-specific LBP (NSLBP) was not evaluated in these studies.\(^1\)\textsuperscript{14}--\textsuperscript{16} Moreover, the differences in proprioceptive information created in the trunk and lower leg in patients with and without NSLBP have not yet been investigated. Investigating the specific role of proprioception through stimulation is essential for gaining insight into the variability of postural control strategies in NSLBP, and the possible role of impaired proprioception and trunk function decline.

This study aimed to investigate the relationship between NSLBP and proprioception which is related to hip strategy or ankle strategy in people with NSLBP and non-LBP (NLBP).

**MATERIALS AND METHODS**

**Participants**
This study was carried out during a period of 22 months (November 2012–September 2014) in tandem with general clinical practice. Written informed consent was obtained from all participants before inclusion in the study. All investigations were conducted according to the principles expressed in the Declaration of Helsinki. The Ethics Committee of the National Center for Geriatrics and Gerontology approved the study (IRB approval number: 586).

The subjects were patients with spinal column stenosis (53 patients) and spondylitis deformans (21 patients) who presented for conservative treatment of their symptoms. Seventy-four elderly patients (age ≥65 years: age range 65–85, averaged 74.4 ± 5.3; sex ratio: 36 women/38 men), including 28 individuals (18 women, 10 men) with NSLBP lasted >3 months who visited the National Center for Geriatric and Gerontology for orthopedic treatment. Forty-six individuals with NLBP (18 women, 28 men) were also recruited for the study. Control subjects were individuals with NLBP, defined as no history of disabling NSLBP. Patients with the following characteristics were excluded: paralysis, ataxia, spinal cord tumor, spinal infection, and history of spinal surgery.

**Measurements**

**Physical Assessment**
We measured each subject’s height (to the nearest 0.1 cm) and weight (to the nearest 0.1 kg). All patients were assessed by an orthopedic surgeon before entering the study. The assessment measures were performed by an experienced doctor and a physiotherapist.

**NSLBP Assessment**
Pain was assessed using the visual analogue scale (0–10) and the Roland–Morris disability questionnaire.\(^17\) All participants were asked to complete a pain questionnaire.

**Muscle Vibration**
The center of pressure (COP) was recorded using a Balance Board (Wii, Nintendo Co., Ltd., Kyoto, Japan).\(^18\)\textsuperscript{20} A vibratory stimulus was applied alternately to the gastrocnemius (GS) and the lumbar multifidus (LM) muscles by fixing two vibrators connected with the vibration device as shown in Figure 1A and B. The vibration device was developed in our previous work. The device consists of a laptop computer, an audio amplifier, and four vibrators. A sine wave signal with an arbitrary frequency generated on the laptop computer provided the input to the audio amplifier. The range of amplitude of the vibrators was 0 to 1.0 mm, and the frequency range was 20 to 300 Hz. Mechanical vibration is commonly used to test externally induced balance control. This method has been widely used to investigate the role of proprioception in research focusing on postural sway.\(^21\)\textsuperscript{24} The subjects stood barefoot on the Balance Board with their

![Figure 1. Experimental setup: (A) Lumbar multifidus vibration device setup. (B) Gastrocnemius muscles vibration device setup.](https://www.spinejournal.com)
feet together and their eyes closed. They were instructed to remain still and relax in the standing position with their arms hanging loosely at their sides. The amplitude of the vibration was 0.8 mm of a sinusoidal wave, with frequencies of 30, 60, and 240 Hz. Each subject’s COP was measured under six conditions in the two muscles with three frequencies of vibratory stimulation: 30 Hz on GS, 30 Hz on LM, 60 Hz on GS, 60 Hz on LM, 240 Hz on GS, 240 Hz on LM. The measurement time was 30 seconds, which was divided into two intervals of 15 seconds each. Vibratory stimulations were applied during the last 15 seconds. We labeled the first 15 seconds as “Pre” and the last 15 seconds as “During.” The participants rested on a chair for 60 seconds between each measurement. To obtain additional information regarding proprioceptive dominance of location, the relative proprioceptive weighting ratio (RPW) was calculated using the following equation:

$$\text{RPW} = \frac{(\text{Abs GS})}{(\text{Abs GS} + \text{Abs LM})} \times 100$$

where Abs GS and Abs LM were the absolute values of the mean COP displacement during GS and LM vibrations, respectively. The mean COP displacement was defined as follows:

$$\Delta Y = Y \text{ (During)} - Y \text{ (Pre)}$$

Y (Pre) and Y (During) were the mean values of the COP of the Y-coordinate for the first and last 15 seconds, respectively.

A value of 100% on the RPW meant perfect reliance on GS input (“lower limb-focused strategy”), whereas a value of 0% on RPW meant perfect reliance on LM input (“multi-segmental strategy”).

These values were calculated using Matlab (MathWorks, Inc., Natick, MA) in a blinded manner with respect to the presence of NSLBP.

Statistical Analysis

The data were analyzed using the Statistical Package for Social Sciences version 19.0 for Windows (SPSS Inc, Chicago, IL). In the statistical analyses, $P < 0.05$ was considered statistically significant. Data are expressed as mean values and standard deviations for NSLBP and NLBP.

Variable data for NSLBP and NLBP were compared using the independent $t$ test. Stepwise logistic regression analysis was carried out to examine whether the RPW was independently associated with NSLBP. In this analysis, the presence or absence of risk of NSLBP was the dependent variable (NLBP = 0, NSLBP = 1) and significant RPWs were set as the independent variables and adjusted for age and sex (women = 0, men = 1).

RESULTS

Table 1 shows the demographic and baseline clinical characteristics of the study participants. There were no significant differences in RPW at 60 Hz between the NLBP and NSLBP groups. Compared with NLBP controls, elderly persons with NSLBP showed a lower RPW at 240 Hz ($P < 0.01$), and higher RPW at 30 Hz ($P < 0.05$) (Table 2). Table 3 shows the RPW associated with NSLBP in the stepwise logistic regression. Multivariate logistic regression analyses for NSLBP after adjustment for age and sex among the significant variables, including RPW at 30 Hz and RPW at 240 Hz, indicated that only RPW at 240 Hz (odds ratio [OR], 0.97; 95% confidence interval [CI], 0.95–0.99; $P < 0.05$) was the most significant factor. No correlation was observed between the RPW at 30 Hz. The model was well-calibrated between decreases in the observed and expected risk (Hosmer-Lemeshow $\chi^2 = 10.3$, $P = 0.24$) (Table 3). Representative case of proprioceptive disorder is provided in Figure 2 based on patient characteristic, as well as each RPW result.

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<thead>
<tr>
<th>TABLE 1. Demographic Characteristics and Functional Outcomes of the Patients</th>
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<tr>
<td>Age, y</td>
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<tr>
<td>Sex (men)</td>
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<td>Height, cm</td>
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<td>Weight, kg</td>
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<td>BMI, kg/m$^2$</td>
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<td>VAS, cm</td>
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<td>RDQ (score)</td>
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<th>TABLE 2. Mean RPW Values with standard deviations for postural stability trials while standing on a balance board</th>
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<td>Variables</td>
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<tr>
<td>RPW 30 Hz (%)</td>
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<tr>
<td>RPW 60 Hz (%)</td>
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<tr>
<td>RPW 240 Hz (%)</td>
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NLBP, non-low back pain; NSLBP, non-specific low back pain; RPW, relative proprioceptive weighting values.

Data are presented as the mean ± standard deviation or n (%).

All $P$ values were generated using the independent $t$ test.
DISCUSSION

To our knowledge, this is the first study to clarify the effects of NSLBP on reduced postural stability through proprioceptive postural control strategies in elderly patients with spinal column stenosis and spondylitis deformans. Our main finding was that patients with NSLBP decreased their reliance on proprioceptive signals from the lower leg during the 240 Hz vibratory stimulus to the lower leg in the standing position. Therefore, those in the NSLBP group tended to display greater hip strategies during the 240 Hz vibratory stimulation of the trunk as compared with NLBP group. Also, during quiet standing trials and 30 Hz vibratory stimulus, the NSLBP group presented greater ankle strategy than NLBP group. Previous studies have suggested that a hip strategy is required for postural adjustments on short bases or during sudden perturbations, whereas an ankle strategy is adequate for maintenance of upright stance. According to other studies, although the hip and ankle strategies are stereotypical, a continuum of mixed strategies is used under most circumstances. Kiers et al reported that co-contraction increases stiffness and damping, which directly attenuates the effects of perturbations. Moreover, previous studies have suggested that stiffness through co-contraction may be the main strategy of postural control in static standing. Based on this, it has been suggested that elderly patients with NSLBP use a stiffening strategy to increase the robustness of the trunk in response to mechanical perturbations during a 30 Hz vibratory stimulus. Meanwhile, elderly patients with NSLBP are thought to use a stiffening strategy to increase the robustness of the lower leg in response to mechanical perturbations during a 240 Hz vibratory stimulus. This result indicates that patients with NSLBP who use more hip strategy for postural control in standing are likely to lose postural stability through the proprioceptive postural control strategy compared to those without NSLBP. However, this decline in sensitivity was not apparent at RPW 60 Hz. This result conflicts with that of a previous report of decreased reliance on lumbar muscle proprioceptive (muscles spindles) inputs for standing postural control.

In addition, trunk predominance through RPW 240 Hz was demonstrated to be a risk factor for instability in the

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<th>Variables</th>
<th>OR</th>
<th>95% CI</th>
<th>P</th>
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<tr>
<td>RPW 30 Hz</td>
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<tr>
<td>RPW 240 Hz</td>
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<td>0.95–0.99</td>
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<tr>
<td>Sex</td>
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<td>0.13–1.04</td>
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CI indicates confidence interval; NSLBP, non-specific low back pain; OR, odds ratio; RPW, relative proprioceptive weighting ratio.

Figure 2. Representative case of proprioceptive disorder. A 76-year-old woman with a history of LBP persists 48 months indicated 8.0 in VAS and 10 in RDQ. Bar graph representing ankle strategy and hip strategy in different conditions of frequencies of vibratory stimulation in representative case. RPW = (Abs GS)/(Abs GS + Abs LM) × 100 (%). Abs GS and Abs LM represent anteroposterior directions, respectively of COP positions. RPW 30 Hz: 75.1 = (0.500071)/(0.500071 + 0.166218) × 100; RPW 60 Hz: 55.9 = (0.342368)/(0.342368 + 0.270362) × 100; RPW 240 Hz: 28.0 = (0.122881)/(0.122881 + 0.316177) × 100. COP indicates center of pressure; GS, gastrocnemius muscles; LBP, low back pain; LM, lumbar multifidus; RDQ, Roland–Morris disability questionnaire; RPW, relative proprioceptive weighting ratio; VAS, Visual analogue scale.

TABLE 3. Factors Associated With NSLBP in a Stepwise Logistic Regression
NSLBP group. High frequency vibration stimulates Type II fast-adapting skin receptors, known as Vater-Pacini corpuscles. Previous studies have reported that proprioception and vibration sensation in the lower limbs decrease during normal aging, and that postural instability has been observed in patients with LBP. Therefore, patients with NSLBP may have even greater postural instability as the sensitivity of GS at 240 Hz continues to decline. Taken together, the reduction in RPW at 240 Hz stimulation with respect to lower leg proprioception suggests an inability of patients with NSLBP to switch to a more appropriate proprioceptive postural control strategy, possibly causing postural instability. The tendency toward an unstable postural sway with reduced lower leg sensitivity in patients with NSLBP was in line with the preceding study on high frequency vibration. Despite the evaluation of the proprioceptive control strategy through the values of RPW at 30 Hz, only a trunk-steered proprioceptive control strategy (RPW at 240 Hz) was identified as a clear risk factor for causing NSLBP. Thus, a higher frequency vibratory test for muscles may provide a more sensitive clinical test of proprioception loss in this population. Accordingly, relying on hip strategy to control posture may lead to a risk of NSLBP with the decreased proprioceptive signals adapting to high frequency vibratory stimulations.

There were several limitations to this study. First, only elderly patients with spinal column stenosis and spondylitis deformans were surveyed. Second, this study was a cross-sectional study. The assessment of postural control strategy was limited to vibratory stimuli to LM and GS, and the muscle activities of the LM and GS were not examined. Despite the specific evaluation of the proprioceptive system by means of muscle vibration, it remains unclear whether these proprioceptive control changes are based on changed peripheral inputs or changed sensory processing at the brain level or a combination of both. However, the findings of this study might shed additional light on the mechanism of trunk predominance through RPW at 240 Hz observed in elderly patient with NSLBP.

CONCLUSION
To our knowledge, no previous studies have investigated high vibration frequencies in elderly patients with spinal column stenosis and spondylitis deformans in patients with NSLBP and NLBP. Therefore, high-frequency vibration (Vater-Pacini corpuscles) is a stiffening strategy at the ankle in elderly patients with NSLBP as compared to low-frequency vibration (Meissner corpuscle) is a novel finding observed in this study. Increased reliance on proprioceptive inputs of hip strategy during standing on a stable surface slightly increases the risk of future NSLBP in elderly patients with spinal column stenosis and spondylitis deformans. These findings show that an RPW affecting postural control under 240 Hz proprioceptive stimulation might be a good indicator of NSLBP.

Key Points
- To our knowledge, this is the first study to clarify the effect of NSLBP on the reduction in postural stability through proprioceptive postural control strategies in elderly patients with NSLBP.
- The inability to use an ankle strategy indicates a deficit of postural control and is hypothesized to result from lower leg proprioceptive (240 Hz) impairment.
- Elderly patients with NSLBP are at higher risk of proprioceptive decreases (240 Hz) in the lower leg.

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References


