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ORIGINAL ARTICLE

Decreased variability in postural control strategies in young people with non-specific low back pain is associated with altered proprioceptive reweighting

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Abstract Optimal postural control is an essential capacity in daily life and can be highly variable. The purpose of this study was to investigate if young people have the ability to choose the optimal postural control strategy according to the postural condition and to investigate if non-specific low back pain (NSLBP) influences the variability in proprioceptive postural control strategies. Young individuals with NSLBP ($n = 106$) and healthy controls ($n = 50$) were tested on a force plate in different postural conditions (i.e., sitting, stable support standing and unstable support standing). The role of proprioception in postural control was directly examined by means of muscle vibration on triceps surae and lumbar multifidus muscles. Root mean square and mean displacements of the center of pressure were recorded during the different trials. To appraise the proprioceptive postural control strategy, the relative proprioceptive weighting (RPW, ratio of ankle muscles proprioceptive inputs vs. back muscles proprioceptive inputs) was calculated. Postural robustness was significantly less in individuals with NSLBP during the more complex postural conditions ($p < 0.05$). Significantly higher RPW values were observed in the NSLBP group in all postural conditions ($p < 0.05$), suggesting less ability to rely on back muscle proprioceptive inputs for postural control. Therefore, healthy controls seem to have the ability to choose a more optimal postural control strategy according to the postural condition. In contrast, young people with NSLBP showed a reduced capacity to switch to a more multi-segmental postural control strategy during complex postural conditions, which leads to decreased postural robustness.

Keywords Postural control · Multi-segmental strategy · Ankle strategy · Sensory reweighting · Variability · Low back pain

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Introduction

Optimal postural control is an essential capacity in daily activities and can be highly variable. For example, the maintenance of quiet stance can be performed through adjustments at the ankles, knees, hips and spine (Allum et al. 1998). When postural conditions change, the central nervous system (CNS) must identify and selectively focus on the most reliable sensory inputs to provide optimal control. Inputs from the vestibular, the visual and the proprioceptive system are weighted by the CNS. As a result of this weighting, muscle forces can be produced to control the center of mass efficiently to maintain a good equilibrium (Brumagne et al. 2004; Carver et al. 2006). Previous studies described different models and strategies to maintain optimal postural control in the sagittal plane during standing (Horak and Nashner 1986; Runge et al. 1999). Within the 'inverted pendulum' postural control model, where the body pivots as a rigid segment around one joint, two strategies can be distinguished. An ankle strategy restores the equilibrium by moving the body primarily around the ankle joints (Horak and Nashner 1986). While this strategy could be sufficient in simple postural conditions such as standing on a flat surface, in more complex postural tasks it might fail. To achieve optimal stability in more difficult postural conditions, according to the inverted pendulum model, the resulted motion to maintain balance is primarily generated at the trunk and the hips (i.e., hip strategy) (Horak and Nashner 1986). In contrast, according to the 'multi-segmental' postural control model, postural control is achieved not only by corrections at one joint but also by multiple corrections at different joints coordinated by the CNS (Morasso and Schieppati 1999; Schieppati et al. 2002; Kiemel et al. 2008).

One factor that could disturb the optimal multi-segmental postural control is non-specific low back pain (NSLBP). Individuals with NSLBP have been observed to have decreased postural robustness during standing, particularly when the standing task becomes more difficult such as standing on an unstable support surface (Mientjes and Frank 1999; Mok et al. 2004; della Volpe et al. 2006). Furthermore, individuals with NSLBP have shown poorer postural control during sitting (Radebold et al. 2001; O'Sullivan et al. 2006; Dankaerts et al. 2006). Both during standing (Mok et al. 2004) and during sitting (Radebold et al. 2001; Van Daele et al. 2009), impaired proprioception has been suggested as a possible mechanism causing the impaired postural control, although a specific assessment of the impaired proprioception was not performed in these studies.

Several studies already evaluated proprioceptive changes in people with NSLBP by determining the lumbosacral position sense. Larger repositioning errors in people with NSLBP suggest proprioceptive impairments (Newcomer et al. 2000; Brumagne et al. 2000; Descarreaux et al. 2005; Dolan and Green 2006), while other studies could not demonstrate larger repositioning errors and associated impaired proprioception (Koumantakis et al. 2002; Silfies et al. 2007). However, these studies did not evaluate repositioning errors in combination with postural sway characteristics. Hence, it remains unclear if proprioceptive impairments are associated with reduced postural robustness. Moreover, an evaluation of postural sway characteristics in combination with muscle vibration evaluates the subconscious proprioceptive control, while repositioning tasks are more an evaluation on a conscious level (e.g., rely more on memory) and therefore less representative of normal proprioceptive control.

Within the proprioceptive system, reweighting of sensory signals has already been demonstrated in both healthy controls and in individuals with NSLBP (Brumagne et al. 2004). Another study investigating two postural standing conditions (standing on stable and unstable support) in a larger test population already suggested decreased variability of postural control strategy in people with NSLBP (Brumagne et al. 2008a). These studies only evaluated standing postural conditions, so the role of proprioceptive reweighting as a characteristic of variability in postural control strategies (during standing as well in sitting conditions) was not evaluated specifically. Variability, as a fundamental property of biological systems, means that the person has multiple options to perform one task based on adaptive strategies, rather than on rigid programs (Harbourne and Stergiou 2009). To have more insight into the variability of postural control strategies and its changes in people with NSLBP, it is recommended to investigate this under a variety of different postural conditions (e.g., standing on a stable and on an unstable surface as well as sitting).

A decrease in variability of anticipatory adjustments (APAs) during postural control has been observed in an experimental-induced acute NSLBP and in recurrent NSLBP (Moseley and Hodges 2006; Jacobs et al. 2009). Pain-related beliefs have been suggested as a possible mechanism for this decreased variability in postural strategy in both studies (Moseley and Hodges 2006; Jacobs et al. 2009), but the role of proprioception was not evaluated in these studies. Furthermore, subjects were only tested during one condition (standing), so it remains unclear if the persons had the variability to choose the optimal strategy upon different postural conditions. To get more insight into the selection variability of postural control strategies upon the condition and the possible role of impaired proprioception, investigating the specific role of proprioception during diverse postural conditions is essential.

Therefore, this study had two aims. The first aim of this study was to investigate if healthy people show variability in their proprioceptive postural control strategy to ensure postural robustness during increased postural complexity. To investigate this first aim, different postural conditions (standing on a stable and unstable surface and sitting) were chosen. Furthermore, muscle vibration, known as a strong stimulus for muscles spindles (Roll and Vedel 1982), was used to more specifically appraise the role of proprioception. The second aim was to investigate if age-matched people with NSLBP show a similar variability in postural strategy. It was hypothesized that healthy persons regulate their proprioceptive postural control strategy depending on the postural demands and that individuals with NSLBP demonstrate less variability by selecting the same ankle-steered strategy independent of the postural condition.

Materials and methods

Subjects

One hundred fifty-six students (47 men, 109 women) volunteered in this study. All subjects were included or excluded in the study by an experienced musculoskeletal physical therapist. Exclusion criteria were a history of vestibular disorders, neurological or respiratory disease, previous spinal surgery, structural spinal problems, acute radiculopathy, serious neck problems and recent musculoskeletal problems (<6 months). All subjects had to fill out four questionnaires: a physical activity questionnaire (Baecke et al. 1982), the Oswestry disability index (ODI-2) (Fairbank and Pynsent 2000), the fear avoidance beliefs questionnaire (FABQ) (Waddell et al. 1993) and the Tampa scale of Kinesiophobia (Vlaeyen et al. 1995). In addition, they had to score the pain at the moment of testing on a numerical rating scale (NRS). Subjects were included in the NSLBP group if they reported a NRS > 0 and if they scored ODI-2 > 6 at the moment of the test. The healthy controls did not report any pain (NRS $= 0$) and had an ODI-2 score of 0. Characteristics of all subjects are presented in Table 1.

All subjects gave their written informed consent and all test procedures were approved by the Medical Research Ethics Committee of K.U.Leuven with respect to the declaration of Helsinki (Ethical Principles for Medical Research Involving Human Subjects).

Movement analysis

Postural sway characteristics were measured using a six-channel force plate (Bertec Corporation, Ohio, USA). Force plate data were sampled at 500 Hz using a Micro 1401 data-acquisition system and Spike2 software (Cambridge Electronic Design, UK) and low pass filtered with a cutoff frequency of 5 Hz. To evaluate trunk position in space, two piezo-resistive accelerometers (ICSensors, UK), also connected with the data-acquisition system, were placed on the spinous processes of thoracic (T1) and sacral (S2) vertebra in upright posture.

Muscle vibration

In six trials, the role of proprioception in postural control was directly examined by means of muscle vibration, known as a powerful stimulus of Ia afferents (Roll and Vedel 1982). Therefore, two muscle vibrators (self-manufactured with Maxon motors, Switzerland) were used. Vibration was applied bilaterally to triceps surae muscles or to lumbar multifidus muscles, respectively. These muscles were selected, based on previous studies to represent

Table 1 Characteristics of the test population

	Healthy controls ($N = 50$)		Persons with NSLBP ($N = 106$)		p
	Mean	SD	Mean	SD	
Male	17		25		
Female	33		81		
Age (years)	19.6	1.6	18.5	0.5	NS
Height (cm)	171.4	7.9	170.9	9.1	NS
Weight (kg)	64.3	8.9	63.2	8.5	NS
BMI	21.89	2.3	21.63	2.4	NS
PAI (5–15)	8.5	1.4	7.9	1.9	NS
NRS (0–10)	0	0	2	2.2	
ODI (0–100)	0	0	8.8	2.0	
FABQPA (0–24)	4.4	5.8	7.9	5.3	NS
FABQW (0–42)	3.0	6.0	4.6	7.6	NS
TSK (17–68)	31.1	5.5	33.1	4.9	NS

The values are mean with standard deviations

BMI body mass index, *PAI* physical activity index (work index + sport index + leisure-time index, max. score: 5 + 5 + 5 = 15), *NRS* pain at the moment of the test scored on a numeric rating scale (0–10), *ODI* score on the Oswestry disability index (min. 0–max 100), *FABQPA* fear avoidance beliefs questionnaire physical activity (min. 0–max. 24), *FABQW* fear avoidance beliefs questionnaire work (min. 0–max. 42), *TSK* Tampa scale for Kinesiophobia (min. 17–max. 68), *NS* not significant, *NSLBP* non-specific low back pain

$p < 0.05$ means significant difference

the muscles used in an ankle-steered strategy or a multi-segmental strategy, respectively (Brumagne et al. 2008b). Muscle vibration was initiated 15 s after the start of the trial for duration of 15 s. Activation and deactivation of the vibrators were manually controlled. The frequency of the vibration was set at 60 Hz and the amplitude was approximately 0.5 mm. These characteristics of vibration were chosen to induce maximal illusory joint movement and were demonstrated to induce a significant muscle lengthening illusion in healthy individuals (Roll and Vedel 1982; Cordo et al. 2005). When the CNS is using the signals of the vibrated muscles for postural control, larger directional sways are expected. When triceps surae muscles are vibrated in a healthy subject during standing, a postural sway in backward direction is expected; when lumbar multifidus muscles are vibrated during standing, a healthy subject is expected to show a postural sway in a forward direction. The effect of lumbar multifidus muscle vibration will be different depending on the reference frame the CNS is using (Gurfinkel et al. 1995; Paulus and Brumagne 2008). During standing, the sacrum-pelvis will be considered as the 'mobile' body part compared to the 'stationary' trunk. So, the resulting illusion of lumbar multifidus muscle lengthening during vibration corresponds with a posterior pelvic tilting and thus a posterior center of pressure (COP) displacement. Therefore, the subject will compensate this illusion with a forward COP displacement. During sitting, however, the trunk will be considered as the 'mobile' body part compared to the 'stationary' sacrum-pelvis which is connected to the stool. Consequently, the illusion during lumbar multifidus muscle vibration corresponds with a trunk flexion and thus an anterior COP displacement. Hence, the subject will compensate this kinesthetic illusion with a backward COP displacement during sitting.

Test procedure

To appraise postural stability and proprioceptive postural control in quiet stance, two test conditions were used: (1) an upright standing condition on a stable support surface and (2) an upright standing condition on an unstable support surface ("foam"), respectively. To appraise proprioceptive postural control in sitting, subjects sat on a stable stool with the feet stable. The sitting condition was chosen to evaluate the possibility to switch to a more appropriate postural control strategy when the postural condition changes (e.g., from standing to sitting). Table 2 gives an overview of all postures and the different trials.

In all standing conditions, subjects had to stand barefoot on the force plate (Trials 1, 2, 3, 4) or on the "foam" (Trials 5, 6, 7, 8) with the arms loosely hanging along the body, both heels 10 cm separated and the forefeet in a free splayed out position. Feet position is standardized in all trials using a transparency sheet to mark off both feet. The "foam" condition is used to create a postural condition in which ankle proprioceptive signals are less reliable and therefore the CNS should rely more on other proprioceptive signals to control posture (Ivanenko et al. 1999).

In all sitting trials (9, 10, and 11), subjects sat on a stable stool with height adjusted to create a rectangle between the greater trochanter (lateral femoral condyle line) and the lateral femoral condyle (lateral malleolus line), respectively. Feet position was standardized using the same transparency sheet from the standing trials. Subjects were asked to adopt a usual sitting posture with the arms loosely hanging along the body.

In all trials, vision was occluded and subjects were asked to remain as immobile, but relaxed as possible in upright standing or usual sitting posture, respectively (Fig. 1).

Table 2 The experimental trials to evaluate postural stability and proprioceptive postural control

Posture: quiet standing	
Condition 1: stable support surface	
Trial 1	Quiet standing
Trial 2	Quiet standing, ballistic shoulder flexion at 30 s
Trial 3	Quiet standing, bilateral triceps surae vibration
Trial 4	Quiet standing, bilateral lumbar multifidus muscle vibration
Condition 2: unstable support surface (foam)	
Trial 5	Quiet standing
Trial 6	Quiet standing, ballistic shoulder flexion at 30 s
Trial 7	Quiet standing, bilateral triceps surae vibration
Trial 8	Quiet standing, bilateral lumbar multifidus muscle vibration
Posture: stable sitting	
Trial 9	Sitting
Trial 10	Sitting, bilateral triceps surae vibration
Trial 11	Sitting, bilateral lumbar multifidus muscle vibration

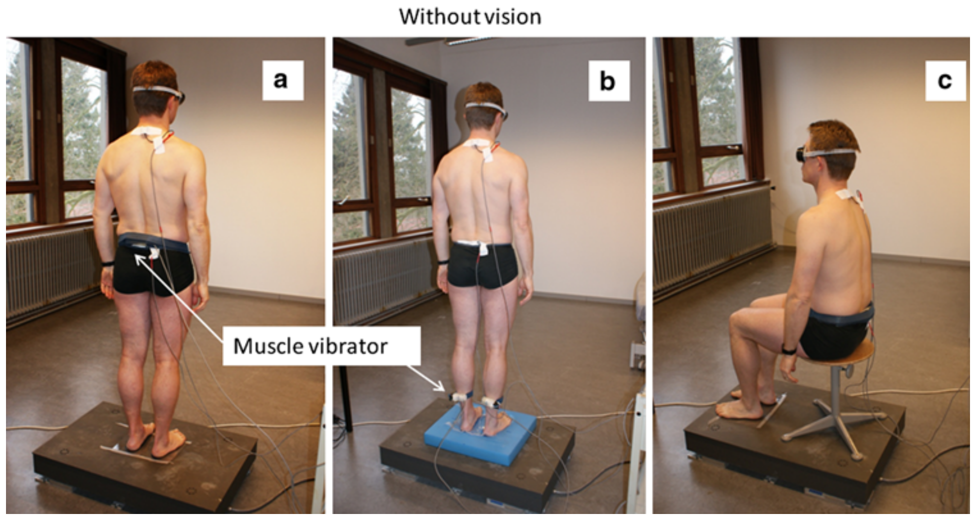

Fig. 1 Experimental set-up: **a** standing on a stable support; **b** standing on an unstable support ('foam') with application of muscle vibration on triceps surae muscles; and **c** usual sitting on an adjustable stool

Data reduction and statistical analysis

Postural sway characteristics from the force plate readings were collected and calculated using Spike2 (CED, Cambridge, UK) and Microsoft Excel software, for all trials of both groups. Displacements of the COP in anterior–posterior (AP) direction were estimated from the raw force plate data using the equation:

$$\mathrm{COP} = \frac{\mathrm{Mx}}{\mathrm{Fz}}.$$

Further data reduction was performed by calculating the root mean square (RMS) values of the COP displacements for the stability trials (1, 2, 5, 6,) and the mean values for the muscle vibration trials in order to appraise the directional effect of muscle vibration on COP displacement. The COP displacements in the muscle vibration trials were analyzed over two epochs: the 15 s preceding and the 15 s during muscle vibration. Positive values correspond to forward COP displacement, negative values correspond to backward displacement. Furthermore, proprioceptive control strategy or relative proprioceptive weighting (RPW) was appraised using the equation:

$$\mathrm{RPW}\frac{\mathrm{TS}}{\mathrm{LM}} = \frac{\mathrm{abs\,TS}}{\mathrm{abs\,TS} + \mathrm{abs\,LM}}$$

where abs TS is the absolute value of the mean COP displacement during triceps surae muscle vibration and abs LM is the absolute value of the mean COP displacement during lumbar multifidus muscle vibration. A score equal to 1 corresponds to 100% reliance on triceps surae muscle afference. A score equal to 0 corresponds to 100% reliance on lumbar multifidus muscle afference.

Differences in RMS and mean values of COP displacement between the conditions, between the trials, and between the NSLBP and healthy group were compared, based on repeated measures analysis of variance (ANOVA/MANOVA). Where a significant main and interaction effect was found, post hoc tests (Tukey's unequal N HSD) were performed to further analyze the detailed effects. All data are presented as mean ± standard deviations (SDs). The level of statistical significance was set at $p \leq 0.05$. The statistical analysis was performed with Statistica 9 (Statsoft, Oklahoma, USA).

Results

Postural robustness

In the usual standing trial on a stable surface, the subjects with NSLBP showed significantly less sway compared to the healthy group (Trial 1; $p < 0.0001$). However, the individuals with NSLBP showed significantly larger sways when standing on a foam support (Trial 5; $p < 0.0001$) and while performing a ballistic arm movement on an unstable support surface (Trial 6; $p < 0.0001$). Figure 2 illustrates the results of the stability trials.

Proprioceptive postural control strategy expressed as RPW

When standing on a stable support surface, individuals with NSLBP performed significantly more backward sway during triceps surae muscle vibration (Trial 3; $p < 0.0001$) compared to the healthy group. Muscle vibration on lumbar multifidus muscles showed no significant differences between the two groups (Trial 4; $p > 0.05$). In the foam conditions, however, larger forward sways were observed by the healthy control group compared to the individuals with NSLBP when vibration is applied on the lumbar multifidus muscles (Trial 8; $p < 0.0001$). In addition,

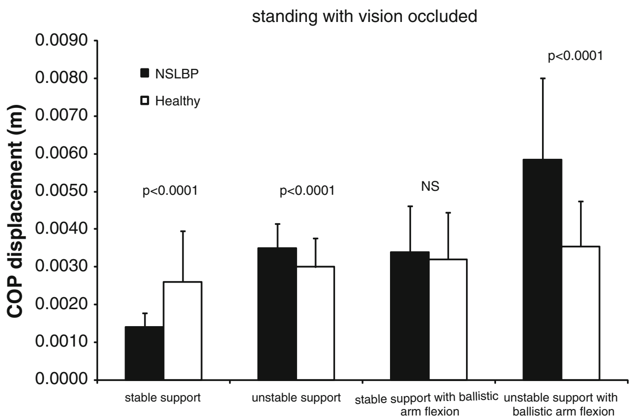

Fig. 2 RMS values of the center of pressure (COP) displacement for the 'baseline' and 'ballistic arm movement' trials in the stable support surface and foam condition (*NSLBP* non-specific low back pain, *NS* not significant)

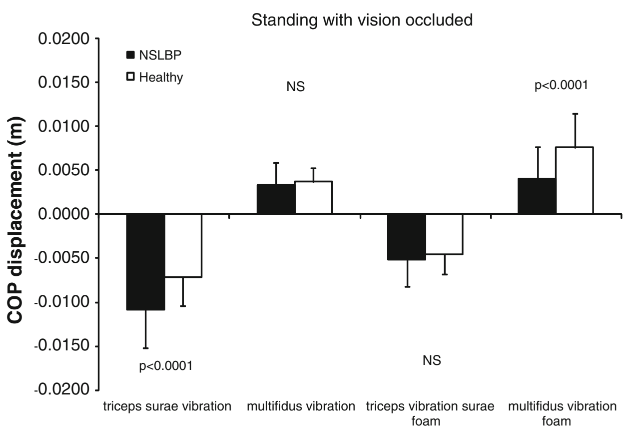

Fig. 3 Mean displacements of the center of pressure (COP) during the vibration trials for both groups when standing on a stable support surface and on 'foam', respectively (*NSLBP* non-specific low back pain, *NS* not significant)

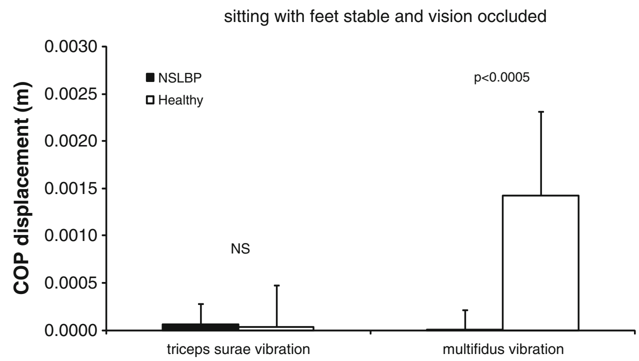

Fig. 4 Mean displacements of the center of pressure (COP) during the vibration trials for both groups during sitting (*NSLBP* non-specific low back pain, *NS* not significant)

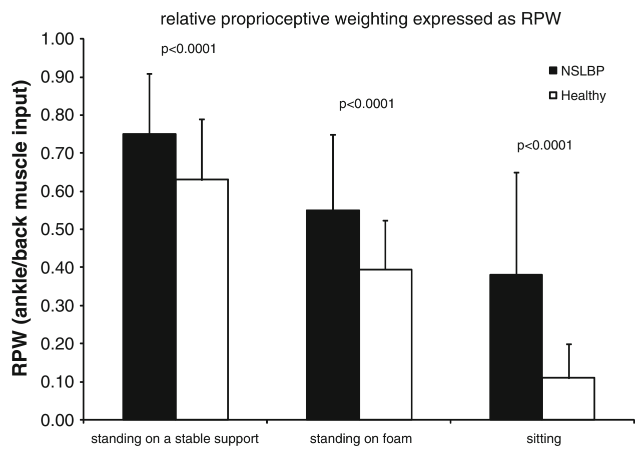

Fig. 5 Relative proprioceptive weighting (RPW) values of both groups during standing on stable support surface and on foam and during sitting. Higher RPW values mean more reliance on proprioceptive inputs of ankle muscles (*NSLBP* non-specific low back pain)

during sitting, significantly larger sways were recorded when vibration was applied on lumbar multifidus muscle in the healthy group compared to the people with NSLBP (Trial 11; healthy: 0.0010 m. vs. NSLBP: 0.0000 m.; $p < 0.0001$). Figure 3 illustrates the results of the vibration trials during standing on a firm support surface and standing on foam. Figure 4 illustrates the results of the vibration trials during sitting.

Subjects with NSLBP showed significantly higher RPW values compared to healthy individuals both during standing on a stable support surface and on an unstable support surface ($p < 0.0001$). Also, during sitting, significantly higher RPW values were demonstrated in the NSLBP group ($p < 0.0001$). Figure 5 displays the RPW values for both groups during the different postural conditions.

Discussion

The main finding of this study is that young people with NSLBP (compared to healthy controls) show a stronger ankle-steered proprioceptive postural strategy during standing on a stable support surface and in a condition, where this strategy is less appropriate (i.e., standing on an unstable support surface). This may lead to decreased postural robustness during standing. Furthermore, in a condition where lumbar proprioceptive afference is expected to be crucial (sitting), persons with NSLBP are not able to rely on this afference to control posture.

Postural robustness

Results of this study demonstrate greater AP sways of the COP when standing on an unstable support surface and when performing a ballistic arm movement on an unstable support surface in people with NSLBP (Fig. 2). These findings are in agreement with the results of previous research, where larger AP sways were found when the postural task became more difficult and vision was occluded (Mientjes and Frank 1999; Mok et al. 2004; Henry et al. 2006; Popa et al. 2007). Moreover, our findings are in agreement with earlier results where the integration of somatosensory signals during postural control of a young healthy population was tested (Isableu and Vuillerme 2006). They found that the less the subjects swayed in a stable condition, the more they swayed in an unstable support surface (foam) condition. Our results show that in an easy postural condition (e.g., standing on a firm surface), the NSLBP group demonstrated less sway than the healthy group where the healthy group was more robust in all other (more complex) postural conditions. These findings might indicate that the adopted postural strategy of persons with NSLBP is effective for easy postural conditions; however, this postural strategy seems to fail in more complex postural conditions leading to decreased postural robustness.

Proprioceptive postural control strategy or RPW

In the present study, we used muscle vibration, known as a powerful stimulus of muscle spindles, to evaluate the role of proprioception in postural control directly (Roll and Vedel 1982; Cordo et al. 2005). It is demonstrated that (1) people with NSLBP demonstrate larger backward sways during triceps surae muscle vibration when standing on a stable support compared to the control group and (2) healthy people demonstrate significantly more forward sway during multifidus muscle vibration when standing on a foam support. These findings illustrate clearly that proprioceptive differences are an influencing factor in this strategy selection. Previous studies already demonstrated more reliance on ankle signals during stable standing conditions in people with NSLBP (Brumagne et al. 2004, 2008a).

The higher RPW values in the group with NSLBP compared to healthy controls when standing on a stable or an unstable support and during sitting indicate that the NSLBP group relies less on back muscle proprioceptive inputs independent of the postural condition. This reduced multi-segmental strategy seems to be adequate in stable support conditions, but leads to decreased postural robustness in unstable support conditions. Lumbosacral proprioceptive deficits were suggested as a possible reason why people with NSLBP could not switch to a more appropriate postural control strategy upon the condition (Mok et al. 2004), but a specific evaluation of the proprioceptive system did not occur.

These results are in accordance with previous studies showing that people with NSLBP used a more ankle-steered strategy to maintain upright position while healthy controls predominantly use a hip strategy when tested on a translational platform (Henry et al. 2006) or on a rotational platform (della Volpe et al. 2006). In contrast, Isableu and Vuillerme 2006 demonstrated that some healthy people use an ankle strategy in all conditions. These findings suggest that there might be differences in strategy selection in young healthy people, based on different central or peripheral proprioceptive processing. It may be possible that these people are at higher risk to get NSLBP in the future, due to impaired proprioception of the lumbosacral area. It is hypothesized that these proprioceptive changes may cause less fine-tuned control of the spine during postural control which may increase the risk to induce more mechanical stress on the spinal column causing (recurrent) NSLBP (Hodges and Moseley 2003). Prospective studies investigating the role of reduced variability caused by altered proprioceptive inputs in postural control strategies are needed to clarify the role of reduced variability as a causing factor for NSLBP.

Furthermore, during sitting, people with NSLBP also show higher RPW values compared to the healthy controls. This suggests that they use less afferent signals from the back muscles in a condition where these signals are expected to play a predominant role in postural control. These results underscore the hypothesis that in NSLBP lumbosacral proprioceptive impairment is associated with decreased postural control variability. This finding is in accordance with earlier results where greater AP sways of the COP during unstable sitting without vision are shown in people with NSLBP (Radebold et al. 2001).

The underlying mechanism causing the altered proprioceptive steering in people with NSLBP remains still unclear. Morphological, histochemical and neurophysiological changes are already shown in the lumbar multifidus in people with NSLBP (MacDonald et al. 2006). However, the relation between these changes and altered proprioceptive steering remains unclear. A possible mechanism underlying the decreased reliance on back muscle proprioception in patients with NSLBP might be a different muscle spindle density in the paraspinal muscles. Muscle spindles tend to concentrate mainly where oxidative muscle fibers predominate, often in the deeper and central portions of muscles (Kokkorogiannis 2004). Individuals with NSLBP have been observed to have more fatigable muscle fibers due to decreased oxidative capacity (Mannion et al. 1997) and therefore might have a decreased density of muscle spindles in their back muscles. Consequently, lumbar multifidus vibration might cause a smaller effect. This hypothesis warrants further investigation.

Variability in postural control strategies

Few studies demonstrated a reduced variability of anticipatory control in young healthy people and age-matched persons with NSLBP (Moseley and Hodges 2006; Jacobs et al. 2009). In these studies, fear of movement and pain-related beliefs were suggested as influencing factors. Brumagne et al. (2008b) demonstrated that only healthy persons show lower RPW values during standing on an unstable support surface compared to a firm surface condition, whereas people with NSLBP showed similar RPW values in both postural conditions. These earlier findings are in contrast with our findings demonstrating that healthy controls have lower RPW values in all postural conditions. Thus, our results demonstrated that both young people with NSLBP and healthy controls have the ability to make a proprioceptive switch, but this capacity to switch is observed to be reduced in people with NSLBP. When subjects are about 5 years older, this proprioceptive variability may be further reduced (Brumagne et al. 2008b). These findings suggest that age may be an important factor in the capacity of varying postural control strategies and the associated sensory reweighting variability. It might be possible that at a certain age, young people with NSLBP move from adaptive 'switchable' postural control strategies to more rigid postural control strategies based on less variability in somatosensory reweighting. Prospective studies in different age groups are necessary to further explore this hypothesis.

In addition, in this study, fear may be likely ruled out as a causing factor for the reduction in postural strategy variability as there were no significant differences in the scores on FABQ and TSK questionnaires between the NSLBP and the control group. Moreover, the people with NSLBP had a low mean pain score of 2/10 at the time of testing, so pain is probably not the predominant factor responsible for the reduction in proprioceptive postural strategy variability.

Limitations and future directions

Some limitations of our study warrant discussion. First, a very young population with minimal pain and disability scores was investigated. Therefore, the results of this study cannot be generalized to the average NSLBP patient population. Moreover, a sub-classification based on pain aggravating movements and postures was not made. It could be possible that the people with NSLBP are still robust in some pain-free postures, but less robust in the pain aggravating postures. Another limitation of this study is that only rather static postural conditions (sitting and standing) were tested. Investigating the role of proprioceptive adaptations during more dynamic tasks (e.g., sit-to-stand, lifting a weight, forward bending) could give more insights into the role of proprioception in postural control.

Muscle vibration, used to appraise the proprioceptive steering, could be influenced by skin thickness. However, in the current study there were no significant differences in height and weight between both groups. Moreover, body mass indexes of both groups were fairly low (Table 1). Therefore, differences in COP displacements between the two groups during multifidus muscle vibration are unlikely attributed to lumbar skin thickness.

While more optimal investigation of proprioceptive changes may optimize treatment of persons with NSLBP, it remains difficult in clinical practice to evaluate these changes without the use of precise and accurate instruments as in a laboratory setting. Therefore, based on the laboratory results, a functional clinical test battery should be developed and its concurrent validity should be assessed before wider integration into clinical practice.

In addition, it might be fruitful to pay more attention on increasing the variability in postural strategies in rehabilitation of NSLBP. A large amount of multi-segmental postural correction possibilities depending on the postural task should be included in exercise programs. Performing postural control exercises on different surfaces (e.g., stable, unstable) and in different postural conditions (e.g., standing, sitting) might optimize this proprioceptive variability.

Conclusion

Young healthy people have the ability to choose the optimal multi-segmental postural control strategy according to the postural condition. In contrast, young people with mild NSLBP exhibit a reduced variability in proprioceptive postural control strategies due to a decreased proprioceptive reweighting capacity. This loss of variability in strategy selection is associated with a decreased postural robustness. Prospective studies are needed to further clarify the relation between reduced variability of postural control strategies and the development, reoccurrences or maintenance of NSLBP.

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