Gait & Posture 29 (2009) 421–427

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Postural control during prolonged standing in persons with chronic low back pain

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ARTICLE INFO

Article history:
Received 16 June 2008
Received in revised form 24 October 2008
Accepted 29 October 2008

Keywords:
Low back pain
Center of pressure
Posturography
Prolonged standing
Postural changes
Balance

ABSTRACT

Prolonged standing has been associated with the onset of low back pain symptoms in working populations. So far, it is unknown how individuals with chronic low back pain (CLBP) behave during prolonged unconstrained standing (PS). The aim of the present study was to analyze the control of posture by subjects with CLBP during PS in comparison to matched healthy adults. The center of pressure (COP) position of 12 CLBP subjects and 12 matched healthy controls was recorded in prolonged standing (30 min) and quiet stance tasks (60 s) on a force plate. The number and amplitude of COP patterns, the root mean square (RMS), speed, and frequency of COP sway were analyzed. Statistical analyses showed that CLBP subjects produced less postural changes in the antero-posterior direction with decreased postural sway during the prolonged standing task in comparison to the healthy group. Only CLBP subjects were influenced by the prolonged standing task, as demonstrated by their increased COP RMS, COP speed and COP frequency in the quiet standing trial after the prolonged standing task in comparison to the pre-PS trial. The present study provides additional evidence that individuals with CLBP might have altered sensory-motor function. Their inability to generate responses similar to those of healthy subjects during prolonged standing may contribute to CLBP persistence or an increase risk of recurrent back pain episodes. Moreover, quantification of postural changes during prolonged standing could be useful to identify CLBP subjects prone to postural control deficits.

1. Introduction

In our daily activities, we frequently stand for long periods of time, waiting for a bus for example, or while performing other tasks, such as working or talking to somebody. Negative physical and psychological outcomes have been associated with prolonged unconstrained standing (PS). Gregory and Callaghan [1] reported that around 50% of healthy subjects perceived low back discomfort after 2 h of PS. The perception of discomfort associated with PS is commonly assessed in low back pain (LBP) disability questionnaires [2,3]. Prolonged periods of standing have been linked with the onset of LBP symptoms in working populations [4,5]. Magora [6] observed a higher incidence of LBP in people standing more than 4 h every day. To date, however, few studies have addressed postural control strategies during PS, and to the authors' knowledge, none has investigated them in LBP populations. So far, it is not appreciated how individuals with chronic low back pain (CLBP) behave during PS. On the other hand, we already know that postural control is altered during short periods of standing (<90 s) in LBP subjects [7–10]. In general, during quiet standing, CLBP subjects sway more in the antero-posterior (A-P) direction and show less postural control adaptability under balance constraints. It has also been demonstrated that LBP subjects have a reduced ability to shift their weight to achieve a single leg stance [11].

During periods of PS, we periodically alter postural position [12]. These changes are believed to be triggered by the postural control system to reduce musculoskeletal discomfort and fatigue [13]. The underlying causes of such postural modifications could derive from the need to enhance venous pump activity (venous pooling) or decrease pressure over joint tissues. Previous studies have characterized the postural alterations that occur during PS. Duarte and Zatsiorsky [13] exposed young, healthy subjects to different mechanical loading conditions and type of support surface to increase muscular activity and postural discomfort. Escalating constraints during PS did not influence the frequency or amplitude of postural changes in young, healthy subjects.

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doi:10.1016/j.gaitpost.2008.10.064

Compared to young subjects, elderly people made postural modifications of lower amplitude and swayed less during PS [14]. The authors concluded that the reduced sway in elderly subjects during PS could be attributed to a lack of mobility in this group.

Given that postural changes are responses to avoid discomfort and fatigue and the fact that CLBP patients commonly perceive discomfort during prolonged standing, we hypothesized that CLBP subjects would present a higher frequency of postural alterations and increased sway during prolonged standing compared to healthy controls. In addition, we also hypothesized that the control of posture deteriorates both at the end of the prolonged standing task and immediately after PS. Therefore, the aim of the present study was to analyze the control of posture in subjects with CLBP during prolonged standing in comparison to matched healthy adults, particularly looking at the postural changes during such a task.

2. Methods

2.1. Subjects

Twelve adult subjects with CLBP and 12 healthy controls without a history of musculoskeletal disorders were recruited and matched for age and gender (Table 1). The inclusion criteria for study participation in the CLBP group were LBP for at least 6 months, radiating pain no further than the buttocks, and normal neurological examination. Most CLBP subjects did not have a more specific diagnosis than mechanical LBP. The exclusion criteria were a history of neurological disease or vestibular affliction, a history of dizziness and medication with known effects on balance. All subjects gave their informed, written consent according to the protocol approved by the University Ethics Committee (CER-07-121-07.02).

2.2. Procedures

CLBP subjects were instructed to complete a French version of the Fear-Avoidance Belief Questionnaire [15] and the Oswestry Disability Index [3]. Prior to and after the PS period, CLBP participants were asked to rate their level of perceived low back discomfort on a 100-mm visual analogue scale (VAS). The experiment involved 32-min trials, consisted of two trials of quiet standing for 60 s immediately before and after the 30-min PS period, with no resting period between quiet standing trials and PS trial. All trials were performed on a force plate (OR6-2000, AMTI, Watertown, USA) in a quiet laboratory setting. For the PS trial, no specific instructions were given to the subjects except that they were warned not to step off the force plate. They were allowed to stand naturally throughout the 30-min PS, during which they watched a documentary about St. Lawrence River ecology on a television located 2 m away from the force plate. For the quiet standing trials, they were asked to stand on the force plate with their feet approximately at pelvis width, to look straight ahead and to keep their arms at their sides in a comfortable position. They were instructed to stand as still as possible for 60 s.

2.3. Data analysis

Ground reaction forces and moments were acquired from the force platform. Analogue signals were sampled at a frequency of 100 Hz and filtered with a zero-lag sixth-order Butterworth low-pass filter at 10-Hz cut-off frequency. Center of pressure (COP) displacements were computed in the A-P and medio-lateral (M-L) directions. Two different types of COP analysis were performed. First, structural analysis identified 3 COP postural patterns according to the methods proposed by Duarte and Zatsiorsky [12]: (a) *shifting*: fast displacement of the average COP position from one region to another (step-like); (b) *fidgeting*: fast and large displacement, followed by a return of COP to approximately the same position (pulse-like) and (c) *drifting*: slow, continuous displacement of the average COP position (ramp-like). A complete description of the algorithms appears elsewhere [12]. Criteria values of COP pattern analysis to classify the data as shifting, drifting and fidgeting were identical to those in other studies [12,14]. We also performed time and frequency domain analyses to obtain summary measures of COP signals in both the A-P and M-L directions: (a) root mean square (RMS); (b) mean COP speed; (c) mean COP power frequency (COP frequency) and (d) COP area. COP speed was defined as total COP displacement divided by the total period. COP frequency was calculated from power spectral density of the de-trended COP data estimated by the Welch periodogram method. COP sway area (COP area) was calculated using the principal component analysis [16], COP analysis algorithms were implemented in Matlab 7.1 (Mathworks Inc., Natick, USA).

The homogeneity of variance of COP variables was assessed by the Kolmogorov–Smirnov test. Non-parametric statistics were used to analyze COP pattern data. Mann–Whitney tests were applied to analyze the group effect (CLBP versus healthy subjects). Wilcoxon signed rank tests were undertaken to investigate the time effect (first 15 min versus last 15 min) on COP pattern variables. The number and amplitude of COP patterns are summarized as median values, with 25th and 75th percentiles. An independent t-test was performed to assess the group effect, and paired t-test served to evaluate the time effect (first 15 min versus last 15 min) on COP summary measures, expressed as mean and standard deviation. The statistical significance level was set at $P < 0.05$, and all statistical analyses were conducted with STATISTICA software, version 6.1 (Statsoft Inc., Tulsa, USA).

Table 1
Study subject characteristics.

	LBP	Healthy	P-value
Age (year)	41.5 (11.7)	40.0 (12.6)	0.826
Height (cm)	172.0 (10.6)	167.3 (9.8)	0.988
Body mass (kg)	74.6 (15.4)	68.5 (15.5)	0.790
BMI (kg/m^2)	25.0 (3.6)	24.3 (4.1)	0.678
VAS (mm)	24.7 (23.9)	–	–
ODI (%)	12.6 (7.3)	–	–
FABQ	20.4 (16.2)	–	–

Abbreviations: BMI = body mass index; VAS = visual analogue scale; ODI = Oswestry Disability Index; FABQ = Fear-Avoidance Belief Questionnaire. Data are mean (S.D.).

3. Results

3.1. PS task

All participants were able to stand for 30 min and made postural changes during that period. The total number of COP patterns was not significantly different between CLBP (median 55, 25th–75th percentile: 37–74) and healthy subjects (median 91, 25th–75th percentile: 48–128) ($Z(22) = -1.61$, $P = 0.11$). However, the number of shifting and drifting patterns in the A-P direction (shown in Fig. 1) were lower for the CLBP group compared to the healthy group (shifts: $Z(22) = -3.04$, $P = 0.002$; drifts: $Z(22) = -2.15$, $P = 0.03$). The amplitudes of drifting patterns in the M-L direction were greater for the healthy group in comparison to the CLBP group ($Z(22) = -2.04$, $P = 0.04$).

The number and amplitude of COP patterns in the A-P and M-L directions during prolonged standing (shown in Fig. 2) did not change significantly between 15-min periods for both groups. However, the number of shifting patterns were significantly greater in the healthy group than in the CLBP group during the first 15 min ($Z(22) = -2.87$, $P = 0.004$) and the second 15 min ($Z(22) = -2.85$, $P = 0.004$). Furthermore, the amplitudes of COP patterns were not different between groups and between periods in both the A-P and M-L directions.

Mean and standard deviation values of COP summary measures for the entire 30-min trial are presented in Fig. 3. COP speed of the LBP group was slower than that of the healthy group in the M-L direction ($t(22) = -5.99$, $P < 0.001$). COP RMS of the LBP group was smaller than that of the healthy group in the A-P direction ($t(22) = -2.07$, $P = 0.049$). The mean COP frequency was lower for the LBP group in comparison to the healthy group in both the A-P and M-L directions (A-P: $t(22) = -8.68$, $P < 0.001$; M-L: $t(22) = -7.43$, $P < 0.001$). COP area was not different between groups. As shown in Fig. 4, COP speed of the CLBP group in the M-L direction was slower than that of the healthy group for both 15-min periods (first: $t(22) = -6.76$, $P < 0.001$; last: $t(22) = -4.42$, $P < 0.001$). However, only CLBP subjects showed an increase in COP speed in the second 15 min compared to the first 15 min (M-L: $t(22) = -2.63$, $P < 0.03$). A significant between-group difference was observed for COP RMS during the last 15 min in the M-L direction only ($t(22) = -2.09$, $P = 0.048$). COP RMS increased during the last 15 min for CLBP subjects in the M-L direction ($t(22) = -2.41$, $P = 0.03$). In each direction, COP frequency for the

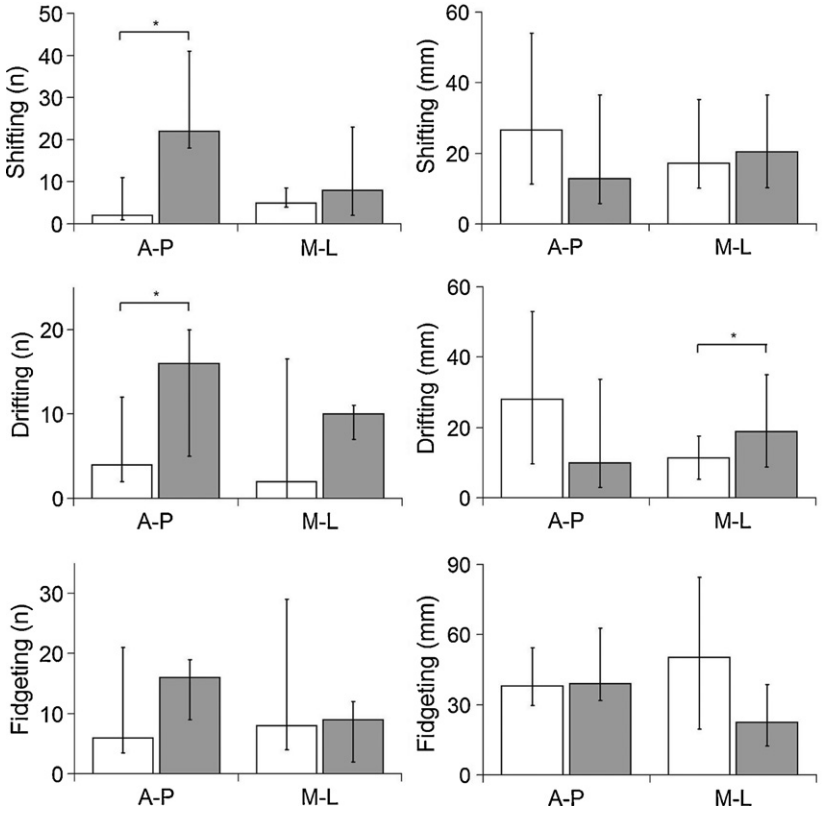

Fig. 1. Median and inter-quartile range values of COP pattern number and amplitude in chronic low back pain (○) and healthy (●) subjects in the antero-posterior (A-P) and medio-lateral (M-L) directions during the 30-min trial. *$P < 0.05$.

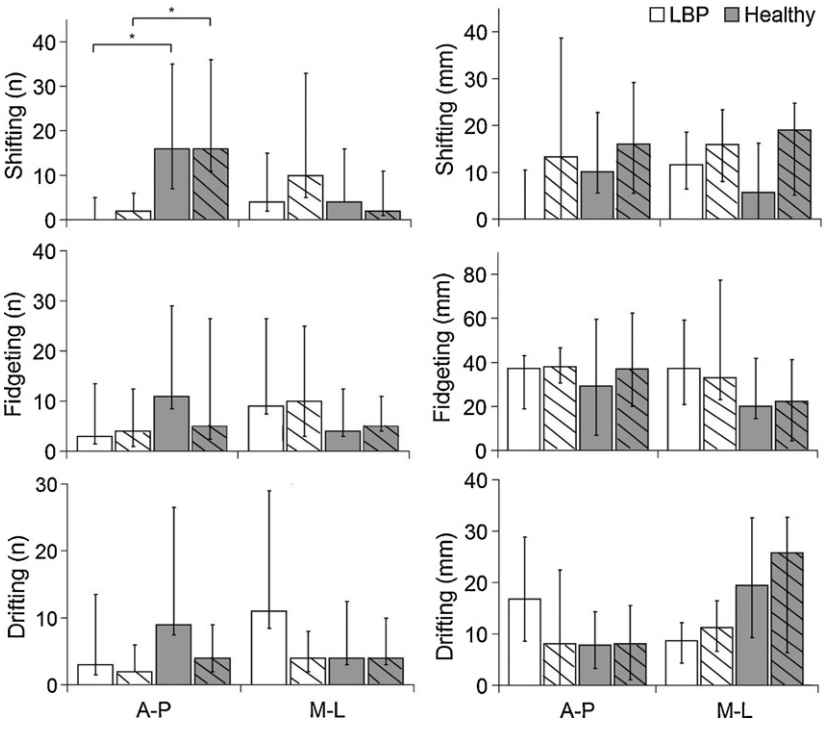

Fig. 2. Median and inter-quartile range values of COP pattern number and amplitude in chronic low back pain (○) and healthy (●) subjects during the first (blank) and the last (shaded) 15 min of PS. *$P < 0.05$.

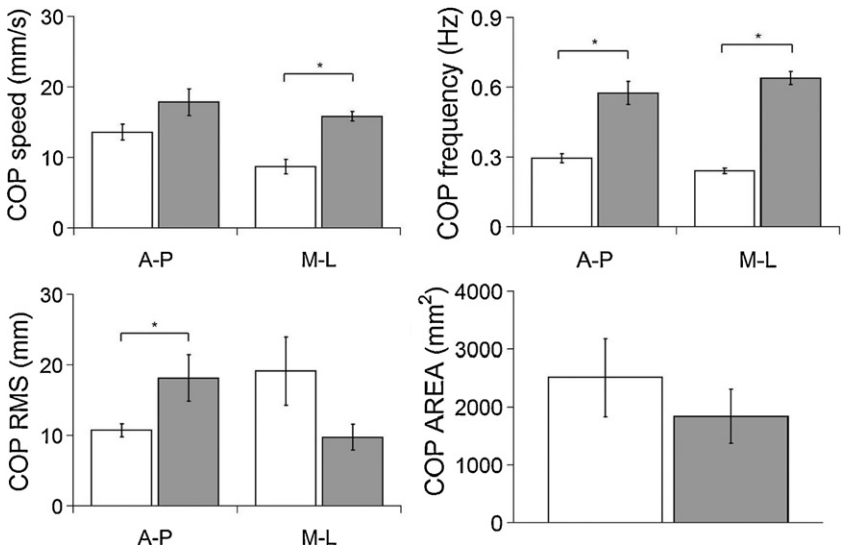

Fig. 3. Mean and standard deviation values of COP summary measures in chronic low back pain (○) and healthy (●) subjects during the 30-min trial. *$P < 0.05$.

CLBP group was lower during both the first and last 15 min than for the healthy group (first: A-P: $t(22) = -7.26$, $P < 0.001$; M-L: $t(22) = -7.16$, $P < 0.001$; last: A-P: $t(22) = -9.68$, $P < 0.001$; M-L: $t(22) = -6.65$, $P < 0.001$). COP area was not different between groups during both the first and last 15 min.

3.2. Quiet standing task

Mean and standard deviation values of COP summary measures during the 60-s quiet standing trials are presented in Fig. 5 for the CLBP and healthy groups. In the A-P direction, COP speed was greater before and after the PS period in the CLBP group than in the healthy group (before: $t(22) = 4.45$, $P < 0.001$; after: $t(22) = 3.78$, $P < 0.001$). CLBP subjects showed lower COP speed than healthy subjects in the M-L direction during both quiet standing periods (before: $t(22) = -6.40$, $P < 0.001$; after: $t(22) = -5.41$, $P < 0.001$). In the M-L direction, COP speed increased after the PS trial compared to the 60-s quiet standing period prior to PS in the CLBP group ($t(22) = 2.87$, $P = 0.017$). In the A-P direction, COP RMS of the CLBP group was higher after than before the PS trial ($t(22) = 2.33$, $P = 0.04$). In the A-P direction, COP RMS was greater before and after the PS period in the CLBP group compared to the healthy group (before: $t(22) = 6.43$, $P < 0.001$; after: $t(22) = 8.63$, $P < 0.001$). CLBP subjects had lower COP RMS than healthy subjects in the M-L direction during both quiet standing periods (before: $t(22) = -2.37$, $P = 0.027$; after: $t(22) = -3.01$, $P < 0.01$). In the A-P direction, the CLBP group showed lower COP frequency than healthy subjects during the quiet standing period prior to the 30-min PS and during the quiet standing period after the 30-min PS (before: $t(22) = -2.76$, $P = 0.01$; after: $t(22) = -2.97$, $P = 0.008$). In the A-P direction, COP frequency of the CLBP group was lower after than before the 60-s PS trial ($t(22) = 2.79$, $P = 0.02$). CLBP subjects presented greater COP area than healthy subjects during both quiet standing periods (before: $t(22) = 2.72$, $P = 0.01$; after: $t(22) = 2.69$,

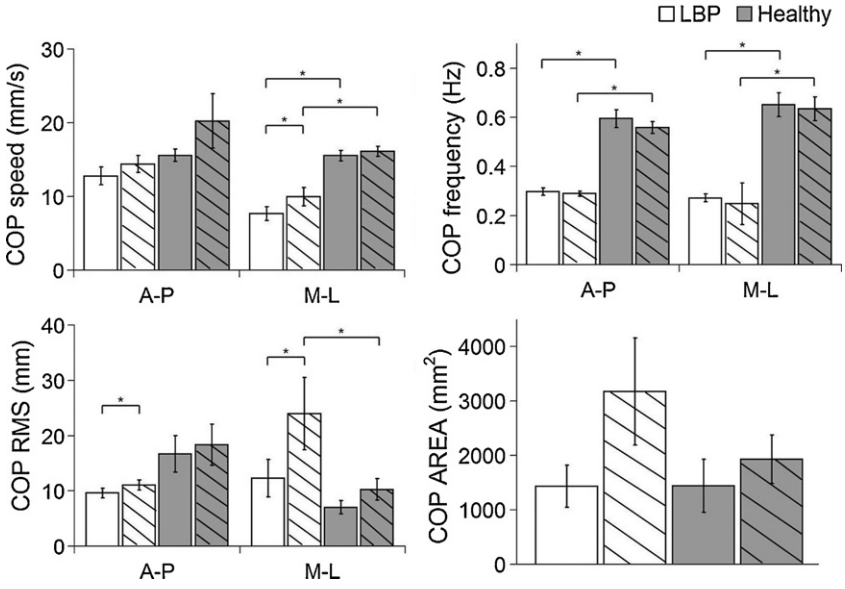

Fig. 4. Mean and standard deviation values of COP summary measures in chronic low back pain (○) and healthy (●) subjects during the first (blank) and last (shaded) 15 min of PS. *$P < 0.05$.

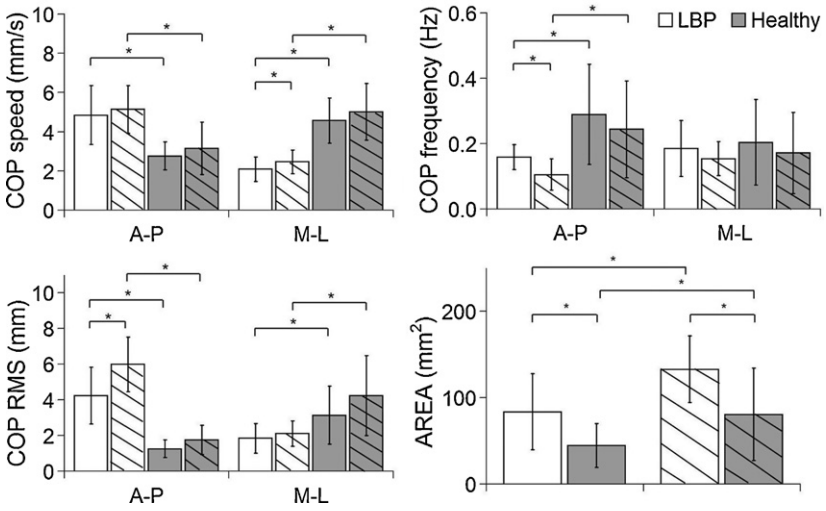

Fig. 5. Mean and standard deviation values of COP summary measures in chronic low back pain (○) and healthy (●) subjects during the quiet standing trial before (blank) and after (shaded) 30-min PS. *$P < 0.05$.

$P = 0.01$). COP area increased after PS in both the CLBP and healthy groups (CLBP: $t(22) = 3.27$, $P = 0.008$; healthy: $t(22) = 2.96$, $P = 0.01$).

4. Discussion

The purpose of this study was to analyze the control of posture in subjects with CLBP during prolonged standing. We expected that during prolonged standing, postural control variables (COP patterns and postural sway) would show more deterioration in CLBP than in healthy subjects. Three main findings emerged from our investigation. First, our results suggest that CLBP individuals tend to exhibit less postural changes during PS than healthy adults, particularly in the A-P direction. We also found that during prolonged standing, CLBP subjects swayed less than healthy adults. These two observations do not support our first hypothesis. We expected greater postural changes in LBP subjects compared to healthy subjects during PS. However, our second hypothesis was confirmed. During quiet standing trials, prior to and after the prolonged standing period, CLBP subjects presented greater postural sway than healthy subjects. Increased postural sway during quiet standing has been also shown in previous studies [7–10]. Indeed, only CLBP subjects demonstrated an influence of the PS task on postural control during quiet standing (60-s trial after PS).

The average number and amplitude of COP patterns in healthy individuals during PS were somewhat lower than the data reported in a previous study [14], although there was substantial variability across subjects. Nevertheless, under the same experimental conditions, we did observe expressive differences between healthy and CLBP subjects. CLBP subjects swayed more in the A-P direction during quiet standing with greater COP RMS and COP speed than healthy subjects, as reported in previous quiet standing experiments [8].

Due to the possible discomfort and fatigue induced by standing during a prolonged period, we initially expected to observe an increase in the number and amplitude of COP patterns across time during PS (comparison of the first and last 15-min periods). The results did not support our expectations. Furthermore, we anticipated increments in postural sway parameters during the quiet standing trial after PS in comparison to the pre-PS trial. The data confirmed this hypothesis only for CLBP subjects as COP speed and COP RMS during quiet standing were greater after the prolonged standing task. Increased postural sway during PS or during the quiet standing trial after PS could be viewed as a neuromuscular indication of fatigue or discomfort, since standing for prolonged periods has been shown to cause fatigue [17,18] and low back discomfort [1]. Although we did not report a direct measure of fatigue or discomfort in the present study, increases in sway parameters during the quiet standing trial after PS could indicate greater neuromuscular fatigability of the lower back muscles in CLBP subjects. Indeed, several investigations have demonstrated that CLBP subjects present a greater rate of fatigue and poorer performance in back endurance extension tests than healthy subjects [19–22]. The effects of lumbar extensor fatigue on postural sway and postural strategies have been studied recently [23–25]. Inducing low back fatigue has been observed to increase sway frequency [24].

Interestingly, we found that during PS, CLBP subjects swayed less than healthy subjects in both the A-P and M-L directions, whereas during quiet standing trials, CLBP subjects swayed more. During quiet standing trials, the subjects were instructed to stand as still as possible, while during PS, they were allowed to make voluntary movements. The nature of the two tasks is obviously different. Quiet standing protocols are designed to determine the amount of 'noise' in the postural control system and its related sensory sub-systems. During normal daily activities people do not usually stand quietly. In this study, we tried to imitate natural standing. In such experiments, no specific instructions are given to the subjects on how to stand; the subjects are allowed to change their posture naturally without considering any specific instructions on how to stand. Freitas et al. [14] concluded that reduced postural behaviour in elderly subjects during PS could be attributed to a lack of mobility. Our results supported this hypothesis of postural deficits related to the lack of mobility in CLBP subjects. Previous reports showed that weight distribution is not affected by back pain during quiet standing [7], but that CLBP subjects have a reduced ability to shift their weight to achieve a single leg stance [11]. Mok et al. [10] concluded that the hip strategy during balance challenge is impaired in CLBP subjects, which may indicate decreased lumbar proprioception or increased activity of the lumbo-pelvic muscles. CLBP subjects are less prone to generate movement during stance because they seem to present with a stiffened posture.

Horak [26] argued that postural control involves postural orientation and postural equilibrium sub-components. Another

hypothesis is that postural deficits observed in CLBP subjects could be related to postural orientation deficits as a consequence of altered proprioceptive input or sensory integration. Altered proprioceptive input or central processing has been related to balance dysfunction in CLBP subjects [27]. Some authors have reported an increase in visual dependency during quiet standing [8,10]. These observations are evidenced by poorer performance in repositioning tasks [28] or reduced effects of vibratory perturbations on postural control [29] in CLBP compared to healthy subjects. Madigan et al. [24] discerned forward leaning in healthy subjects after fatigue. By increasing gamma-motoneuron drive, this postural strategy could improve the sensitivity of muscle spindles to changes in muscle length and velocity. Such potential benefits are important, since localized muscle fatigue has been linked to losses of proprioceptive acuity [30].

Since postural changes are a likely response to reduce musculoskeletal discomfort, it is somehow initiated by proprioceptive information signalling such discomfort. According to this rationale, the decreased number of postural changes observed in CLBP compared to healthy subjects during prolonged standing might be caused by diminished proprioceptive information from the low back or altered sensory-motor integration in CLBP. As a consequence, the presence of a ''frozen'' postural strategy can be viewed as a symptom of an altered postural control system. In view of that, it might be clinically relevant to diagnose lack of mobility in CLBP subjects and address this condition with rehabilitation exercises that exploit the use of postural changes and improved perception of the state of body parts, particularly the low back. In addition, the quantification of postural changes during prolonged standing using a force plate might be useful as a simple method to identify subjects with CLBP among those, the one who might have more compromised their posture control and consequently.

One limitation of our study is that we did not assess the perception of low back discomfort, general fatigue, and alterations in proprioceptive input before and immediately after the prolonged standing period. Further experiments should evaluate these properties to better understand the altered behaviour of CLBP subjects during prolonged standing. Another limitation is that we did not monitor occupational or recreational activities prior posturography testing. However, we do not believe that such activities could explain between-group differences obtained in this study.

5. Conclusions

Whether it is during short-duration quiet standing tasks or in PS, the performance of CLBP subjects differs significantly from that of healthy subjects. The changes in postural control variables observed in the CLBP sample in the present study indicate that, as now believed by many researchers, individuals with CLBP might have altered sensory-motor function. These results, together with the growing body of knowledge pertaining to LBP and associated sensory-motor dysfunction, should be taken into consideration when patients are returned to work or daily activities as it may impact the course and prognosis of their condition.

Acknowledgements

This work was supported (DL) in part by the Fonds Institutionnel de la recherche-UQTR (3071081) and the Quebec Chiropractic Research Foundation. This study was in part supported by grants to M. Duarte and J.M. Prado [Fundação de Amparo a Pesquisa do Estado de São Paulo – Brazil (04/10917-0 and 06/52662-3)].

Contributors: MD (Martin Descarreaux) and DL participated in the study design, statistical analysis and writing of the manuscript. DL, AC and JDD performed the experiment and data analysis. Finally, JMP and MD (Marcos Duarte) helped in analyzing the data and drafting the manuscript. All authors have read and concur with the final manuscript.

Conflict of interest

The authors declare that they have no competing interest or conflicts of interest. None of the authors have any financial or personal relationships that could inappropriately influence their work.

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