Postural control in individuals with and without non-specific chronic low back pain: a preliminary case–control study

Rene Rogieri Caffaro · Fábio Jorge Renovato França ·
Thomaz Nogueira Burke · Maurício Oliveira Magalhães ·
Luiz Armando Vidal Ramos · Amélia Pasqual Marques

Received: 19 June 2013 / Revised: 10 February 2014 / Accepted: 11 February 2014 / Published online: 26 February 2014
© Springer-Verlag Berlin Heidelberg 2014

Abstract

Study design A preliminary case–control study.

Objective To assess postural control in individuals with and without non-specific chronic low back pain (cLBP) during quiet standing.

Summary of background data cLBP affects 12–33 % of the adult population. Reasons for pain chronicity are yet poorly known. Change in postural control may be a risk factor for cLBP, although available studies are not conclusive.

Methods Sample consisted of 21 individuals with cLBP and 23 controls without cLBP. Balance was assessed using a force plate (Balance Master®, NeuroCom) by the modified clinical test of sensory interaction and balance, pain severity by the visual analogue scale, quality of life with the SF-36 Questionnaire, and functional disability with the Roland-Morris Questionnaire.

Results Groups were homogeneous for age, weight, height and body mass index. Relative to controls, participants in the cLBP group had deficits in the postural control, with greater postural sway in the quiet standing condition with closed eyes closed on unstable surfaces ($p < 0.05$) for the following parameters: total COP oscillation [cLBP 1,432.82 (73.27) vs CG 1,187.77 (60.30)], root mean

square sagittal plane [cLBP 1.21 (0.06) vs CG 1.04 (0.04)], COP area [cLBP 24.27 (2.47) vs CG 16.45 (1.79)] and mean speed of oscillation [cLBP 12.97 (0.84) vs CG 10.55 (0.70)].

Conclusion Postural control, as evidenced by increased oscillation of COP, is impaired in individuals with cLBP relative to controls. Differences are magnified by visual deprivation and unstable surface conditions.

Keywords Low back pain · Balance · Postural control · Quality of life

Introduction

Chronic low back pain (cLBP) may be defined as the persistence of lumbar and sacral pain for over 12 weeks [1]. It affects 12–33 % of the adult population, with a life time prevalence ranging from 11 to 84 % [2]. cLBP is a common reason for primary care consultation worldwide [3].

Studies suggest that individuals with low back pain (LBP) have abnormalities in the motor control of deep trunk muscles, characterized by delayed neuromuscular recruitment [4, 5], and changes in the lumbosacral proprioception. Taken together, these abnormalities may predispose to instability [6] and to the decreased postural control observed in some experimental situations.

Pain seems to influence motor response in individuals with LBP, delaying and reducing the amplitude of oscillation of the center of pressure (COP) on unstable surfaces [7], as well as increasing oscillation of the COP in the sagittal and coronal planes [8–10] when subjects have eyes closed [11] or when they stand on one foot [12].

R. R. Caffaro · F. J. R. França · T. N. Burke (✉) ·
M. O. Magalhães · L. A. V. Ramos · A. P. Marques
Department of Speech, Physical and Occupational Therapy,
School of Medicine, University of Sao Paulo, São Paulo, Brazil
e-mail: thomazburke@gmail.com

A. P. Marques
e-mail: pasqual@usp.br

A. P. Marques
FMUSP, Rua Cipotânea 51, Cidade Universitária, São Paulo,
SP 05360-160, Brazil

Abnormalities of the postural control at different conditions support the notion that LBP is associated with dysfunctions in the peripheral and central processing of proprioceptive information. Popa et al. [13] suggested that, in contrast to individuals without pain, subjects with LBP functionally adapt to decreased postural control due to impaired processing of sensory information. However, the theme is controversial, since studies of Kuukkanen and Malkia, and of Paalanen et al. [14, 15], found no differences in postural control as a function of presence or absence of LBP.

According to a systematic review [16], patients with non-specific LBP exhibit greater postural instability than healthy controls. Furthermore, only one study evaluated young individuals with cLBP. Participants had an average duration of LBP of 3.4 years, and were assessed on quiet standing condition with visual deprivation and unstable surface (foam). Therefore, the postural control knowledge remains unclear in cLBP patients.

The objective of this preliminary study was to assess postural control in adult individuals with and without non-specific cLBP during upright standing position.

Methods

Subjects

Sample consisted of 21 individuals, with age ranging from 30 to 57 years, with cLBP pain diagnosed by an orthopedist in 2010 and 2011, as well as of 23 controls without LBP. Inclusion criteria for the cLBP group were: history of non-specific LBP lasting at least 12 weeks. Controls had no history of significant LBP (defined as an episode that required treatment or that led to missed work or school days). Subjects with known sensory or neurological disorders, previous back surgery, active lower limb musculoskeletal pathology or using any medication that could affect the balance were excluded from the study. During the initial evaluation, participants were asked about medical history, including symptoms or diagnosis of vestibular disorders. The sample was recruited at the University Hospital of University of Sao Paulo (Sao Paulo, Brazil).

The required sample size was calculated using OPENPI software, assuming a 80 % statistical power to detect a 20 % difference between groups, with a 12.18 ± 1.2 mm/s (mean and standard deviation) of the COP speed of oscillation for the cLBP group, and 10.32 ± 0.6 mm/s for controls. Using this parameter, sample was defined as being 16 subjects per group. The significance level was established at 5 %. The speed of oscillation had demonstrated sensitivity when detecting instability related to other health conditions [8].

Demographic data

Prior to testing, anthropometric measures (age, height, weight and body mass index) and duration of pain were recorded. Pain intensity was assessed using the visual analogue scale (VAS—from 0 to 100 mm). Quality of life was assessed by the SF-36 Questionnaire, and functional disability was estimated using the Rolland Morris Disability Questionnaire.

Force plate measurements

NeuroCom International Balance Master[®] with four force sensors was used in order to obtain objective assessment of the sensory, postural control of balance with visual bio-feedback [17, 18]. Intraclass correlation coefficients showed high test–retest reliability for balance master measures of sway area with eyes opened (ICC [3, 4] = 0.91), eyes closed (ICC [3, 4] = 0.97), and with visual feedback (ICC [3, 4] = 0.94) in a healthy population with ages between 20–35 and 60–75 [19].

Procedures

Postural control was estimated using the modified clinical test of sensory interaction for balance (CTSIBm) [18], which measures static balance in four sensorial conditions, while participants stood on the force plate: condition 1, eyes opened and stable surface (participants are able to use the somatosensory, visual and vestibular systems); condition 2, eyes closed and stable surface (participants are able to use somatosensory and vestibular systems—visual system does not participate); condition 3, eyes opened and unstable surface (participants are able to use vision and vestibular systems—somatosensory is impaired); condition 4, eyes closed and unstable surface (participants are able to use the vestibular system—somatosensory is impaired and visual system does not participate). Each position was tested three times during 10 s each, at 100 Hz. The individuals maintained an upright position, barefoot, with arms along the body and the feet positioned in one of three standard positions recommended by the manufacturer, according to participants height. A person with 76–140 cm (cm) height should remain with their feet 22 cm apart; those with 141–165 cm height should remain with feet 26 cm apart, and those with 166–203 cm height should have their feet 30 cm apart. All participants completed the tests successfully. Unstable surface was obtained with a foam of 13 cm thickness and density of 5 kg/m³.

Ethics

The study protocol was approved by the Ethics Committee of the Clinical Hospital, and of the University Hospital of

Table 1 Demographic and clinical characteristics

	Low back pain (<i>n</i> = 21) Mean (SE)	Control (<i>n</i> = 23) Mean (SE)	Mean difference (CI 95 %)	<i>p</i> *
Male/female (<i>n</i>)	11/10	6/17	NA	NA
Age (years)	43.43 (1.74)	38.78 (1.85)	−4.65 (−9.75; 0.46)	0.073
Height (m)	1.69 (0.02)	1.65 (0.01)	−0.04 (−0.09; 0.02)	0.212
Weight (Kg)	73.52 (3.04)	65.85 (2.33)	−6.68 (−14.39; 0.93)	0.084
Body mass index (Kg/m ²)	25.71 (0.70)	24.48 (0.63)	−1.23 (−3.12; 0.66)	0.197
VAS (0–100 mm)	41.40 (0.33)	NA	NA	NA
Pain duration (months)	85.52 (17.05)	NA	NA	NA
SF36-physical aspects (0–100)	67.86 (8.65)	NA	NA	NA
SF36-emotional aspects (0–100)	79.36 (7.80)	NA	NA	NA
Rolland-Morris (0–24)	8 (0.87)	NA	NA	NA

Data expressed in centimeters

SE standard error, CI confidence interval, NA not applicable

* *t* Student test

Sao Paulo University (protocol no. 129/10). All participants signed informed consent forms.

Data analysis

Raw data from balance master (COP outputs) were treated for noise reduction using Matlab 7.0.1 software (The Mathworks, USA), using 4th order Butterworth filter, with cutoff of 8 Hz. Mean and trends of COP were also obtained (Detrend). Routine analyses using Matlab 7.0.1 software (The Mathworks, USA) were used in order to calculate the following variables:

Total oscillation (TO)

$$TO = \sum_{i=1}^N \sqrt{COP_{ap_i}^2 + COP_{ml_i}^2}$$

Root mean square (RMS)

$$RMS_{ap} = \sqrt{\frac{1}{N} \sum_{i=1}^N (COP_{ap_i})^2}$$

Mean speed of oscillation

$$\frac{1}{N} \sum_{i=1}^N \sqrt{COP_{ap_i}^2 + COP_{ml_i}^2} \times 100$$

Mean speed = Area: an ellipse representing 95 % of COP data.

Statistical analysis

All statistical tests were applied using software SigmaStat 3.5 (Systat Software, Inc., Germany). Normality was

assessed using the Shapiro–Wilk test. Demographic and clinical characteristics variables were compared with Student's *T* test. For groups and conditions comparisons, the Two-Way repeated measures ANOVA followed by the Holm-Sidak test were used. Confidence interval was established at 95 % and the significance level at 5 %.

Results

Characteristics of the sample are summarized in Table 1. The groups did not differ significantly regarding age, height, weight and body mass index. Men were overrepresented in the cLBP group (52 %) relative to the control group (26 %).

Table 2 describes the total oscillation of the COP by group, for the four conditions. Participants with LBP had significantly increased oscillation compared to controls in condition 4 ($p < 0.001$): closed eyes on unstable surface ($F_{(1,3)} = 16.00$). In intragroup analysis, values for condition 3 were significantly increased relative to conditions 1 and 2, while condition 4 had values significantly increased relative to all other conditions ($p = 0.02$), in both groups ($F_{(1,3)} = 3.22$).

Table 3 describes the anterior–posterior RMS of the COP by group, for the four conditions. Participants with LBP had significantly increased oscillation compared to controls in condition 4 ($p < 0.001$): closed eyes on unstable surface ($F_{(1,3)} = 20.01$). In intragroup analysis, values for condition 3 were significantly increased relative to conditions 1 and 2, while condition 4 had values significantly increased relative to all other conditions ($p = 0.2$), in both groups ($F_{(1,3)} = 1.23$).

Table 2 Total oscillation of COP comparing individuals with and without cLBP in the four tested situations

Group	Condition 1 Mean (SE)	Condition 2 Mean (SE)	Condition 3 Mean (SE)	Condition 4 Mean (SE)
Low back pain ($n = 21$)	276.11 ^{a,d} (26.46)	304.57 ^{b,e} (23.44)	671.50 ^{c,d,e} (19.42)	1,432.82 ^{*,a,b,c} (73.27)
Control ($n = 23$)	219.76 ^{a,d} (12.02)	221.23 ^{b,e} (17.57)	576.38 ^{c,d,e} (24.33)	1,187.77 ^{a,b,c} (60.30)
Mean difference (CI 95 %)	−56.35 (−113.30; 0.60)	−83.34 (−141.81; −24.86)	−95.12 (−158.72; −31.52)	−245.05 (−435.23; −54.86)
p value	0.255	0.159	0.165	<0.001

Data expressed in centimeters

SE standard error, CI confidence interval

* Groups are statistically different ($p < 0.05$)

^{a,b,c,d,e} In pairs, identify which values are statistically different between the four conditions, in each group, after multiple comparison test (ANOVA two way) and Post hoc Tukey test ($p < 0.05$)

Table 3 Anterior–posterior root mean square values of COP for the four tested conditions comparing individuals with and without chronic low back pain

Group	Condition 1 Mean (SE)	Condition 2 Mean (SE)	Condition 3 Mean (SE)	Condition 4 Mean (SE)
Low back pain ($n = 21$)	0.30 ^{a,d} (0.02)	0.34 ^{b,e} (0.03)	0.58 ^{c,d,e} (0.02)	1.21 ^{*,a,b,c} (0.06)
Control ($n = 23$)	0.24 ^{a,d} (0.01)	0.25 ^{b,e} (0.02)	0.50 ^{c,d,e} (0.02)	1.04 ^{a,b,c} (0.04)
Mean difference (CI 95 %)	−0.06 (−0.12; −0.002)	−0.09 (−0.15; −0.03)	−0.08 (−0.13; −0.02)	−0.17 (−0.31; −0.02)
p value	0.234	0.138	0.412	0.006

Data expressed in centimeters

SE standard error, CI confidence interval

* Groups are statistically different ($p < 0.05$)

^{a,b,c,d,e} In pairs, identify which values are statistically different between the four conditions, in each group, after multiple comparison test (ANOVA two way) and Post hoc Tukey test ($p < 0.05$)

Table 4 Area of COP oscillation contrasting the two groups in four tested conditions

Group	Condition 1 Mean (SE)	Condition 2 Mean (SE)	Condition 3 Mean (SE)	Condition 4 Mean (SE)
Low back pain ($n = 21$)	0.75 ^{a,d} (0.18)	0.72 ^{b,e} (0.11)	5.06 ^{c,d,e} (0.30)	24.27 ^{*,a,b,c} (2.47)
Control ($n = 23$)	0.36 ^a (0.05)	0.36 ^b (0.08)	3.80 ^c (0.30)	16.45 ^{a,b,c} (1.79)
Mean difference (CI 95 %)	−0.39 (−0.76; −0.03)	−0.36 (−0.63; −0.09)	−1.26 (−2.13; −0.38)	−7.82 (−13.91; −1.73)
p value	0.805	0.815	0.522	<0.001

Data expressed in squared centimeters

SE standard error, CI confidence interval

* Groups are statistically different ($p < 0.05$)

^{a,b,c,d,e} In pairs, identify which values are statistically different between the four conditions, in each group, after multiple comparison test (ANOVA two way) and Post hoc Tukey test ($p < 0.05$)

Table 4 illustrates the area of oscillation of COP in the four conditions for both groups. Participants with LBP had significantly increased oscillation compared to controls in condition 4 ($p = 0.002$), closed eyes on unstable surface ($F_{(1,3)} = 10.35$). In intragroup analysis, values for condition 3 were significantly increased relative to conditions 1 and 2, while condition 4 had values significantly increased

relative to all other conditions 3 ($p = 0.001$), in both groups ($F_{(1,3)} = 5.55$).

Mean speed of oscillation of the COP is displayed in Table 5. Participants with LBP had significantly increased oscillation compared to controls in condition 4 ($p = 0.01$), closed eyes on unstable surface ($F_{(1,3)} = 6.73$). In intragroup analysis, values for condition 3 were significantly

Table 5 Mean speed of oscillation of the center of pressure

Group	Condition 1 Mean (SE)	Condition 2 Mean (SE)	Condition 3 Mean (SE)	Condition 4 Mean (SE)
Low back pain ($n = 21$)	2.64 ^{a,d} (0.20)	2.72 ^{b,e} (0.19)	5.97 ^{c,d,e} (0.26)	12.97 ^{a,b,c} (0.84)
Control ($n = 23$)	2.57 ^{a,d} (0.21)	2.75 ^{b,e} (0.35)	5.18 ^{c,d,e} (0.20)	10.55 ^{a,b,c} (0.70)
Mean of the difference (CI 95 %)	−0.06 (−0.66; 0.53)	0.04 (−0.80; 0.87)	−0.79 (−1.45; 0.13)	−2.42 (−4.62; −0.22)
p value	0.925	0.957	0.312	0.004

Data expressed in centimeters per seconds

SE standard error, CI confidence interval

* Groups are statistically different ($p < 0.05$)

^{a,b,c,d,e} In pairs, identify which values are statistically different between the four conditions, in each group, after multiple comparison test (ANOVA two way) and Post hoc Tukey test ($p < 0.05$)

increased relative to conditions 1 and 2, while condition 4 had values significantly increased relative to all other conditions ($p = 0.02$), in both groups ($F_{(1,3)} = 3.32$).

Discussion

The objective of this preliminary study was to assess and contrast the postural control in individuals with and without cLBP. Our findings suggest that individuals with cLBP have impaired postural control, as evidenced by the increased amplitude and speed oscillation of the COP. Differences were amplified by visual deprivation and unstable surface condition.

Our results agree with previous studies that also found increased body sway in individuals with cLBP, relative to controls [7–11, 16]. This increase in the body sway may be caused by the fact that individuals with LBP have abnormalities in the motor control of deep trunk muscles, characterized by delayed neuromuscular recruitment [4, 5], as well as by changes in the neuromuscular receptors [6]. Gill and Callaghan [20] showed that proprioceptive receptors may be affected by LBP. Therefore, individuals with LBP may have poor postural control as a consequence of proprioceptive dysfunctions [6, 21–24]. Furthermore, some study has demonstrated the linearly correlated with pain intensity and postural sway in patients with LPB [24–26].

According to our results, individuals with cLBP showed impaired performance in condition 4 when compared to controls. This condition deprives the subjects of visual information and impairs proprioceptive inputs. In this test condition, the vestibular system is the main responsible for the maintenance of spatial orientation. Since both groups had no vestibular dysfunctions, attention should be given to the analysis of somatosensory (proprioceptive) and visual systems.

In conditions 3 and 4, we observed that intra-group significant differences only became evident when the

visual input was removed. Visual information reports position data and the movement of the head relative to surrounding objects, providing a reference for verticality, and assisting postural control [27]. This finding suggests that individuals with cLBP may give more importance to visual information at the expense of the somatosensory and vestibular systems, which differentiates them from individuals without LBP. This explanation does not exclude the possibility of a combination of proprioceptive information changes caused by the disease [6, 20–24], or personal preference for visual information in these individuals. Nonetheless, this finding translates into important implications for the treatment of patients with low back pain. Wand et al. [28] studied the effect of mirror visual feedback in other long-standing pain problems and suggested that similar lines of inquiry may be worth pursuing in the chronic nonspecific LBP population.

The data also suggests that the amplitude and speed of oscillation increase as a function of task complexity in both groups. This is in agreement with the study of Della Volpe et al. [8], who observed that, as the complexity of the task increased, the postural stability decreased in individuals with LBP relative to controls.

Another factor that may have contributed to postural control impairment in those with LBP relates to changes in the self-perception of body image secondary to pain [29]. Central modulation of information from neuromuscular spindles may be dysfunctional [30], with prolonged latency caused by reduced spindles feedback. These functional changes could also lead to reduced muscular control and increased postural oscillation. This latter hypothesis is controversial, since Popa et al. [13] failed to demonstrate pain influence on postural control using force plate.

Some variables, such as severity and intensity of pain, and functional capacity were captured only in those with LBP, using the methods suggested by Liddle et al. [31]. The demographic and clinical characteristics of individuals in the cLBP group are in alignment with other studies [32,

33], with the exception of duration of chronic pain, (54 ± 31 vs 85 ± 17 months) [32].

A limitation of our study regards the time of assessment by CTSBm (10 s, pre-programmed time). Tests were performed in a predetermined sequence, starting from the simplest to the more complex. Thus, the more complex tests would not influence in the simplest. Studies with specific methodology in order to test the influence of the visual system in postural control in individuals with cLBP should be conducted to better understand the mechanisms related to increased sway in these individuals.

Conclusion

Our findings suggest that the postural control is impaired in individuals with cLBP, relative to controls. This is evidenced by increased oscillation of COP measurements. Differences are amplified by visual deprivation on unstable surfaces by the results of this preliminary case–control study.

Clinical relevance

Further studies are needed to confirm the hypothesis that individuals with LBP have changes in postural control. The clinical relevance needs to be evaluated before any changes or treatment recommendations can be offered. Clinical trials that have postural control as a study variable should be encouraged.

COP measurements may also be useful as outcome measures of efficacy of treatment in LBP populations.

Acknowledgments This study had Public Financial Support of: State of São Paulo Research Foundation (FAPESP), state of São Paulo, Brazil.

Conflict of interest Financial disclosure statements have been obtained, and no conflicts of interest have been reported by the authors or by any individuals in control of the content of this article. This study had Public Financial Support of: Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) and there are no conflicts of interests to the work.

References

1. Rozenberg S (2008) Chronic low back pain: definition and treatment. *Rev Prat* 58(3):265–272
2. Costa Lda C, Maher CG, McAuley JH, Hancock MJ, Herbert RD, Refshauge KM, Henschke N (2009) Prognosis for patients with chronic low back pain: inception cohort study. *BMJ* 339:b3829. doi:10.1136/bmj.b3829
3. Hemmila HM (2002) Quality of life and cost of care of back pain patients in Finnish general practice. *Spine (Phila Pa 1976)* 27(6):647–653
4. Hodges PW (2001) Changes in motor planning of feed forward postural responses of the trunk muscles in low back pain. *Exp Brain Res* 141(2):261–266. doi:10.1007/s002210100873
5. Hodges PW, Richardson CA (1996) Inefficient muscular stabilization of the lumbar spine associated with low back pain. A motor control evaluation of transversus abdominis. *Spine (Phila Pa 1976)* 21(22):2640–2650
6. Brumagne S, Cordo P, Lysens R, Verschueren S, Swinnen S (2000) The role of paraspinal muscle spindles in lumbosacral position sense in individuals with and without low back pain. *Spine (Phila Pa 1976)* 25(8):989–994
7. Henry SM, Hitt JR, Jones SL, Bunn JY (2006) Decreased limits of stability in response to postural perturbations in subjects with low back pain. *Clin Biomech (Bristol, Avon)* 21(9):881–892. doi:10.1016/j.clinbiomech.2006.04.016
8. della Volpe R, Popa T, Ginanneschi F, Spidalieri R, Mazzocchio R, Rossi A (2006) Changes in coordination of postural control during dynamic stance in chronic low back pain patients. *Gait Posture* 24(3):349–355. doi:10.1016/j.gaitpost.2005.10.009
9. Nies N, Sinnott PL (1991) Variations in balance and body sway in middle-aged adults. Subjects with healthy backs compared with subjects with low-back dysfunction. *Spine (Phila Pa 1976)* 16(3):325–330
10. Hamaoui A, Do MC, Bouisset S (2004) Postural sway increase in low back pain subjects is not related to reduced spine range of motion. *Neurosci Lett* 357(2):135–138. doi:10.1016/j.neulet.2003.12.047
11. Mientges MI, Frank JS (1999) Balance in chronic low back pain patients compared to healthy people under various conditions in upright standing. *Clin Biomech (Bristol, Avon)* 14(10):710–716
12. Luoto S, Aalto H, Taimela S, Hurri H, Pyykko I, Alaranta H (1998) One-footed and externally disturbed two-footed postural control in patients with chronic low back pain and healthy control subjects. A controlled study with follow-up. *Spine (Phila Pa 1976)* 23(19):2081–2089 (discussion 2089–2090)
13. Popa T, Bonifazi M, Della Volpe R, Rossi A, Mazzocchio R (2007) Adaptive changes in postural strategy selection in chronic low back pain. *Exp Brain Res* 177(3):411–418. doi:10.1007/s00221-006-0683-4
14. Kuukkanen TM, Malkia EA (2000) An experimental controlled study on postural sway and therapeutic exercise in subjects with low back pain. *Clin Rehabil* 14(2):192–202
15. Paalanen N, Korpelainen R, Taimela S, Remes J, Mutanen P, Karppinen J (2008) Isometric trunk muscle strength and body sway in relation to low back pain in young adults. *Spine (Phila Pa 1976)* 33(13):E435–E441. doi:10.1097/BRS.0b013e318175c2c7
16. Ruhe A, Fejer R, Walker B (2011) Center of pressure excursion as a measure of balance performance in patients with non-specific low back pain compared to healthy controls: a systematic review of the literature. *Eur Spine J* 20(3):358–368. doi:10.1007/s00586-010-1543-2
17. Raymakers JA, Samson MM, Verhaar HJ (2005) The assessment of body sway and the choice of the stability parameter(s). *Gait Posture* 21(1):48–58. doi:10.1016/j.gaitpost.2003.11.006
18. Boulgarides LK, McGinty SM, Willett JA, Barnes CW (2003) Use of clinical and impairment-based tests to predict falls by community-dwelling older adults. *Phys Ther* 83(4):328–339
19. Hageman PA, Leibowitz JM, Blanke D (1995) Age and gender effects on postural control measures. *Arch Phys Med Rehabil* 76(10):961–965
20. Gill KP, Callaghan MJ (1998) The measurement of lumbar proprioception in individuals with and without low back pain. *Spine (Phila Pa 1976)* 23(3):371–377
21. Sung PS, Yoon B, Lee DC (2010) Lumbar spine stability for subjects with and without low back pain during one-leg standing

- test. *Spine (Phila Pa 1976)* 35(16):E753–E760. doi:[10.1097/BRS.0b013e3181d53b9c](https://doi.org/10.1097/BRS.0b013e3181d53b9c)
22. Ham YW, Kim DM, Baek JY, Lee DC, Sung PS (2010) Kinematic analyses of trunk stability in one leg standing for individuals with recurrent low back pain. *J Electromyogr Kinesiol* 20(6):1134–1140. doi:[10.1016/j.jelekin.2010.05.011](https://doi.org/10.1016/j.jelekin.2010.05.011)
 23. Brumagne S, Cordo P, Verschueren S (2004) Proprioceptive weighting changes in persons with low back pain and elderly persons during upright standing. *Neurosci Lett* 366(1):63–66. doi:[10.1016/j.neulet.2004.05.013](https://doi.org/10.1016/j.neulet.2004.05.013)
 24. Brumagne S, Janssens L, Knapen S, Claeys K, Suuden-Johanson E (2008) Persons with recurrent low back pain exhibit a rigid postural control strategy. *Eur Spine J* 17(9):1177–1184. doi:[10.1007/s00586-008-0709-7](https://doi.org/10.1007/s00586-008-0709-7)
 25. Ruhe A, Fejer R, Walker B (2011) Is there a relationship between pain intensity and postural sway in patients with non-specific low back pain? *BMC Musculoskelet Disord* 12:162. doi:[10.1186/1471-2474-12-162](https://doi.org/10.1186/1471-2474-12-162)
 26. Ruhe A, Fejer R, Walker B (2013) On the relationship between pain intensity and postural sway in patients with non-specific neck pain. *J Back Musculoskelet Rehabil* 26(4):401–409. doi:[10.3233/BMR-130399](https://doi.org/10.3233/BMR-130399)
 27. Anne SC, Marjorie HW (2003) *Controle Motor teoria e aplicações práticas*, 2^a edn
 28. Wand BM, Tulloch VM, George PJ, Smith AJ, Goucke R, O'Connell NE, Moseley GL (2012) Seeing it helps: movement-related back pain is reduced by visualization of the back during movement. *Clin J Pain* 28(7):602–608. doi:[10.1097/AJP.0b013e31823d480c](https://doi.org/10.1097/AJP.0b013e31823d480c)
 29. Rossi A, Decchi B, Groccia V, Della Volpe R, Spidalieri R (1998) Interactions between nociceptive and non-nociceptive afferent projections to cerebral cortex in humans. *Neurosci Lett* 248(3):155–158
 30. Capra NF, Ro JY (2000) Experimental muscle pain produces central modulation of proprioceptive signals arising from jaw muscle spindles. *Pain* 86(1–2):151–162
 31. Liddle SD, Baxter GD, Gracey JH (2004) Exercise and chronic low back pain: what works? *Pain* 107(1–2):176–190
 32. Tsao H, Hodges PW (2007) Immediate changes in feed forward postural adjustments following voluntary motor training. *Exp Brain Res* 181(4):537–546. doi:[10.1007/s00221-007-0950-z](https://doi.org/10.1007/s00221-007-0950-z)
 33. Ferreira ML, Ferreira PH, Latimer J, Herbert RD, Hodges PW, Jennings MD, Maher CG, Refshauge KM (2007) Comparison of general exercise, motor control exercise and spinal manipulative therapy for chronic low back pain: a randomized trial. *Pain* 131(1–2):31–37. doi:[10.1016/j.pain.2006.12.008](https://doi.org/10.1016/j.pain.2006.12.008)