RESEARCH ARTICLE

Comparison of Postural Balance between Subgroups of Nonspecific Low-back Pain Patients Based on O'Sullivan Classification System and Normal Subjects during Lifting

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Abstract

Background: Balance disorder is one of the most-studied fields in low-back pain patients (LBP). However, there is insufficient information regarding the effect of LBP subgrouping on postural control. The purpose of the present study was to compare postural control between subgroups of chronic nonspecific LBP and healthy subjects during lifting.

Methods: A total of 35 men with chronic LBP (19 active extension pattern [AEP] and 16 flexion pattern [FP]) and 15 healthy controls were enrolled in this cross-sectional study. Pooled LBP was subdivided based on the O'Sullivan's classification system (OCS). The participants were asked to lift a box from the ground to the waist level and hold it for 20 seconds. The load was 10% of the subject's weight. Force plate system was used to record balance parameters, including standard deviations (SDs) of center of pressure (COP) amplitude and COP velocity in anterior-posterior and medial-lateral directions and mean total velocity. The test was divided into two static and dynamic phases. Data were analyzed using one-way analysis of variance and independent t-test.

Results: There were no significant differences between pooled LBP and control groups in any of the variables, except for the SD of the anterior-posterior direction velocity in the X-plane in the static phase (*P=0.017*). After classifying LBP, the results showed that the healthy and AEP groups were significantly different in SD of COP velocity in the frontal plane (*P=0.021*), mean total velocity (*P=0.010*), and SD of COP velocity in the sagittal plane (*P=0.039*).

Conclusion: The present study showed that postural control was not different between the pooled LBP and normal groups. After classifying pooled LBP based on OCS, we found that the AEP showed different postural control as compared to healthy controls in the dynamic phase. The FP and AEP exhibited different postural control relative to the healthy controls in the static phase, and COP velocity was lower in those groups compared to the control group. The results of this study support the concept of LBP classification.

Level of evidence: IV

Keywords: Classification, Lifting, Low back pain, Postural balance

Introduction

Nowadays, more than 80% of the population experience back pain in their lifetime (1). Many of these patients suffer from chronic mechanical non-specific low back pain (LBP), while 85% of them have no evidence of radiological abnormalities (1, 2). Despite extensive efforts, the causes of LBP still remain

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inconspicuous and the effect of treatment is elusive (3). Balance impairment is one of the LBP problems. There is a little information regarding the extent of changes in balance and postural responses in LBP patients (4).

Proper postural control is essential to performing daily activities (5). From biomechanical and psychophysiological perspectives, a significant number of fall-related injuries is due to loss of balance, and lifting can affect balance control (6, 7). Therefore, further understanding of balance may help prevent fall-related injuries (6).

Postural control in LBP may be affected by various factors such as reduction in somatosensory input when visual and vestibular senses are intact. Age, external loads, localized muscle fatigue, neurological deficits, and musculoskeletal disorders like back pain may also affect postural control and reduce the quality of afferents (5, 6).

A systematic study revealed contradictory results about the oscillation of the center of pressure (COP) in LBP patients (8). Several factors have been cited for this inconsistency, but they did not consider the effect of subgrouping of LBP (4). The source of this inconsistency may be the “wash out effect” caused by studying LBP in heterogeneous groups. In other words, if different groups of LBP are investigated as a heterogeneous group, differences between subgroups, which are in the form of patterns, cancel out each other showing no difference between LBP and healthy controls (9, 10).

There are limited data regarding postural control responses in subgroups of LBP (4). Given these inconsistencies, before motor control disorder can be effectively treated, its nature should be clearly recognized (4). Hence, LBP should be examined in homogeneous groups (11). Various classification systems have been proposed for LBP (2). In this study, O’Sullivan’s classification system (OCS) was used for classifying LBP. The majority of studies related to the classification of LBP have only focused on one aspect of this disorder (1). OCS is a novel multi-dimensional and mechanism-based classification model. It describes the loss of motor control and excessive movement, that aggravate symptoms in patients with LBP; however, a multi-step process is required to validate this multi-dimensional classification system (12, 13). Detailed analysis of spinal movements and postures aggravating the symptoms as reported by patients is a central component of the classification system presented by O’Sullivan (1).

Therefore, the aim of this study was to investigate the indicators of postural control during stoop lifting in subgroups of LBP based on OCS. Lifting, which is the extension of spine from flexion position, seems to have a challenging effect on postural control. Another purpose was to conduct a laboratory-based test to examine the ability of OCS to differentiate postural control in LBP patients in lifting task. Lifting is an extension activity and is aggravating factors in active extension pattern (AEP) in this classification system (14). Therefore, we hypothesized that postural control during lifting would be different in AEP patients.

Materials and Methods

Patient Demographics

This study was carried out among patients with nonspecific chronic LBP referred to the Physical Therapy Clinic of School of Rehabilitation, Iran Universality of Medical Sciences, Tehran, Iran. Forty male LBP patients with the mean age of 32.73±8.69 years were selected. Furthermore, 20 healthy subjects were assigned to the control group. The two groups were matched based on age, height, and weight. Before initiating the study, we obtained the approval of the Ethics Committee of Iran University of Medical Sciences, and the subjects provided written informed consent.

Inclusion and exclusion criteria

The inclusion criteria comprised of local pain in the lumbar spine (between the first lumbar vertebra and gluteal fold), chronic or repeated pain for more than three months, pain intensity of less than 5 to at least 1 based on the visual analogue scale, and reduced symptoms by decreasing the mechanical strain on the involved segment.

The exclusion criteria were neurological, orthopedic, and vestibular disorders affecting the balance system, flexion and extension restriction of the lumbar region, previous surgery, discrepancy between physiotherapists’ opinions (familiar with this method of classification) in the diagnosis process, clear yellow flag, and other conditions that affected the normal functioning of the central and peripheral nervous system such as alcohol abuse, addiction, dementia, and cognitive disorders.

Study design

In this study, FP and AEP were studied because of their high prevalence (1, 15). To classify the patients, the following diagnostic process was applied: 1) subjective examination of medical history, symptoms and activities aggravating or reducing the symptoms, 2) examination of physiological and accessory movements (with the thumb press directly on the spinous process of lumbar spine to determine the level of involvement) as well as 3) examination of functional movements including forward, backward, and side bending, and single-leg standing (16). Posture and functional movement of lumbopelvic rhythm were also controlled. Finally, FP and AEP cases were selected from among patients referred to the clinic. The articles by O’Sullivan and Dankaerts are introduced for more information about this classification system. The participants were barefoot on the force plate system (Kistler 9260AA6; Winterthur, Switzerland) with their feet parallel and hip-width apart (17, 18). They were asked to take their clothes off and wear shorts. The testing method was described to the patients prior to the test. For each test, the patients should step off the force plate system in order to re-set it. Feet position on the force plate was determined, and the speed of movement during the test was arbitrary. For normalization, the subjects lifted boxes that weighed 10% of their body weight. The box dimensions were 34 (width) ×34 (length) ×27 (height) cm. While lifting the box from the ground, the upper limb position was vertical, and the box was placed under the participant's hands [Figure 1]. The subjects stooped and lifted the box by both hands from the ground to the waist level and held it for 20 seconds (19, 20). The examiner emphasized holding the elbows and knees straight during the test. According to this method, the lifting test was divided into two phases of static and dynamic. A motion analysis system (a 6-camera motion capture system, Qualisys AB, Sweden) was used to divide the static and dynamic phases of the test. The system recorded vertical displacement of the marker placed on the anterior of the box. The dynamic phase ended when vertical displacement of the marker was finished. The motion analysis system was synchronized with the force plate system. If the symptoms of patients increased acutely during the test, they were excluded from the study (9).

Figure 1. Waist level of box (Used with permission).

Methods of measurement

A force plate system (model 9260AA6, Kistler, Switzerland) along with its related software was used to record postural control parameters and measuring the standard deviation of COP amplitude in the frontal (SD.Apx) and sagittal (SD.Apy) planes; standard deviation of COP velocity in the frontal (SD.APvx) and sagittal (SD.APvy) planes; and mean total velocity (MTV). These parameters are used as indicators of postural balance. The reliability of COP measures had already been established by Salavati et al. They had shown that the mean total velocity in all conditions of postural difficulty had high to very high reliability, with intraclass correlation coefficient (ICC) range of 0.74–0.91, standard error of measurement (SEM) range of 0.09–0.40 cm/s, coefficient of variation (CV) range of 5.31–8.29%, and minimal metrically detectable change (MMDC) range of 0.19–0.79 cm/s. Phase plane portrait in anteroposterior–mediolateral (AP–ML) and mediolateral (ML) directions was another good parameter with respect to the level of reliability (21). Motion analysis system and force plate system signals were collected at sampling frequency of 100 Hz (force plate data were filtered using a Butterworth 4th order low-pass filter with a cutoff frequency of 2 Hz) (22). The reliability of the motion analysis system for tracking the three-dimensional marker positions was studied by Kejonen et al., who reported the range of variation in ICC values as 0.44-0.70 in lateral direction, 0.33-0.86 in AP direction, and 0.27-0.79 in vertical direction (23).

Statistical analysis

Descriptive statistics were utilized for all data. The Kolmogorov–Smirnov test was performed to assess the normality of the quantitative variables. Considering the normal distribution of the variables, independent t-test was run to investigate the relationship between the quantitative variables in LBP and healthy controls. Additionally, one-way analysis of variances (ANOVA) was performed for examining the association of these variables in the three groups (FP, AEP, and normal group). Post-hoc test was used when there were significant differences between the three groups. Multiple COP parameters like MTV were applied to examine the different aspects of postural behavior in this study. MTV showed more dynamic aspects of postural control (24). Data were analyzed with SPSS version 20 (SPSS Inc., Chicago, IL, USA). P-values less than 0.05 were considered statistically significant.

Results

Demographic characteristics of the participants are presented in Table 1. There were no significant

Table 1. Clinical characteristics of the healthy, flexion pattern and active extension pattern groups

Variables	Healthy group (n =20)	flexion pattern (n =20)	active extension pattern (n =20)	*P value*
Age (years)	31.06 ± 8	32.42 ± 8.36	33.05 ± 9.01	.764
Weight (kg)	70.46 ± 9.47	76.75 ± 12.14	79.63 ± 18.70	.826
Height (cm)	175.73 ± 5.36	175 ± 8.45	173.21 ± 6.75	.555
BMI (kg/m2)	25.09 ± 2.89	24.99 ± 3.14	26.47 ± 5.72	.520

Data are mean ± SD. SD: Standard deviation

Table 2. Comparison of variables in healthy and pooled low-back pain groups during lifting

Phase	Variables	Normal	Low back Patients	*p-value*
Dynamic	SD.APx (mm)	6.65 ± 1.62	7.35 ± 2.61	.103
	SD.APy (mm)	25.41 ± 5.42	6.54 ± 23.05	.292
	SD.APvx (mm/s)	22.55 ± 70.73	26.20 ± 50.97	.711
	SD.APvy(mm/s)	27.12 ± 113.37	29.94 ± 94.66	.870
	MTV (mm/s)	27. ± 1.17	.33 ±.89	.881
Static	SD.APx (mm)	3.92 ± 1.08	4.19 ± 1.45	.153
	SD.APy (mm)	12.89 ± 1.98	12.45 ± 3.37	.056
	SD.APvx (mm/s)	58.40 ± 31.21	29.06 ± 21.99	.017*
	SD.APvy(mm/s)	70.74 ± 23.96	45.58 ± 22.84	.121
	MTV (mm/s)	.74 ± .31	.41 ± .27	.102

SD.APx: Standard deviation of center of pressure amplitude in frontal plane; SD.APy: Standard deviation of center of pressure amplitude in sagittal plane SD.APvx: Standard deviation of center of pressure velocity in frontal plane; SD.APvy: Standard deviation of center of pressure velocity in sagittal plane; MTV: Mean total velocity of COP; Data are mean ± SD. SD: Standard deviation; * A significance difference between two groups

differences in age, weight, height, and body mass index among the healthy subjects, AEP, and FP.

No significant differences were found between the pooled LBP and healthy subjects in any of the variables in dynamic and static phases, except for SD.APvx (*P=0.017*) in the static phase [Table 2]. Figure 2 illustrates MTV in the pooled LBP, control, and AEP groups, as well as FP in the dynamic phase. Figure 3 shows MTV of the above groups in the static phase.

During dynamic phase, the SD.APvx (*P=0.028*), SD.APvy (*P=0.048*), and MTV (*P=0.014*) were significantly different between the subgroups and healthy subjects. The post hoc analysis demonstrated that the healthy subjects and the AEP group were significantly different in the variables of SD.APvx (*P=0.021*), SD.APvy *(P=0.039*), and MTV (*P=0.010*).

In the static phase, the healthy subjects, AEP group, and FP group differed significantly with respect to SD.APvx (*P=0.002*), SD.APvy (*P=0.003*), and MTV (*P=0.002*). The post hoc test revealed that the SD.APvx (*P=0.002*), SD.APvy (*P=0.002*), and MTV (*P=0.002*) were significantly different between the control and AEP groups, and SD.APvx (*P=0.017*), SD.APvy (*P=0.041*), and

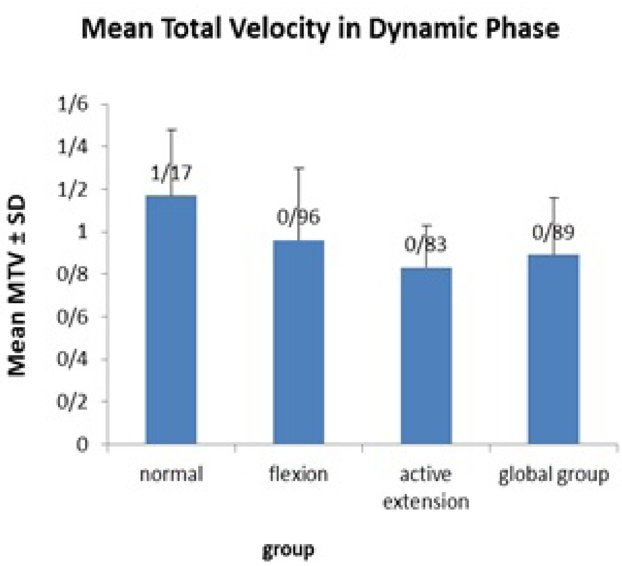

Figure 2. Mean total velocity in four groups for dynamic phase.

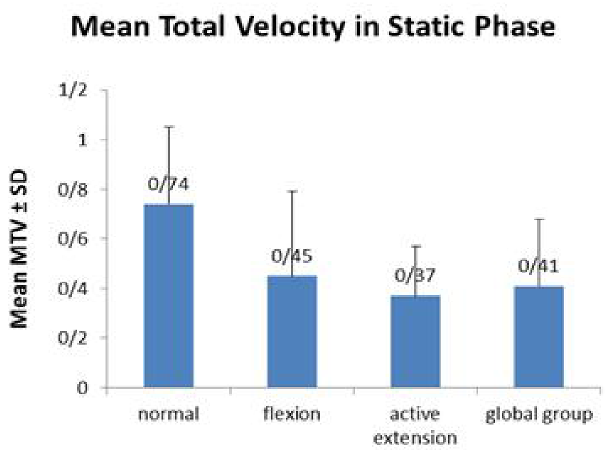

Figure 3. Mean total velocity in four groups for static phase.

MTV (*P=0.021*) were significantly different between the healthy subjects and the FP group [Table 3].

Discussion

Our findings showed no significant difference between the pooled LBP patients and healthy subjects in neither of the dynamic and static phases of lifting. After subgrouping of LBP patients into AEP and FP, the results exhibited a difference in postural control between AEP and healthy subjects in the dynamic phase and among the AEP, FP, and normal subjects in the static phase. Our results confirmed the wash out effect. In this phenomenon, findings in one subgroup of patients were counteracted by outcomes of another subgroup of patients when the patients were studied heterogeneously (25). Our outcomes also reflected that postural sway in the subgroups of LBP was less than the normal group.

To the best of our knowledge, there are no studies comparing postural control in the subgroups of LBP during lifting. However, there are some articles on other problems of LBP based on the subgrouping of patients. Dankaerts et al. showed that muscle activation patterns and flexion-relaxation phenomenon were different in subgroups during forward bending. Their analysis also revealed that LBP subgroups had different lumbar postures than the healthy group (1). Dankaerts et al. studied lumbar posture in LBP (pooled and subgroups) and control subjects in normal sitting position. Their findings presented no differences between the controls and pooled LBP. In contrast, analyses based on the subgrouping presented that the subgroups of LBP had different lumbar postures during normal sitting (25).

Table 3. Comparison of variables in healthy, flexion and active extension pattern groups during lifting

phase	Variables	Normal	Patients		*p-value*
			Flexion pattern	Active extension pattern	
Dynamic	SD.APx (mm)	6.65 ± 1.62	7.75 ± 3.21	7.02 ± 2.01	.428
	SD.APy (mm)	25.41±5.42	22.17±7.43	23.79±5.79	.364
	SD.APvx (mm/s)	70.73±22.55	56.11±34.28	46.65±16.55 ◊	.028
	SD.APvy (mm/s)	113.37±27.12	102.28±33.82	88.24±25.39 ◊	.048
	MTV (mm/s)	1.17±.27	.96±.40	.83±.25 ◊	.014
Static	SD.APx (mm)	3.92±1.08	4.29±1.51	4.12±1.43	.764
	SD.APy (mm)	12.89±1.98	12.04±3.33	12.80±3.45	.692
	SD.APvx (mm/s)	58.40±31.21	32.61±29.40 ◊	26.07±13.15 ◊	.002
	SD.APvy (mm/s)	70.74±23.96	49.90±27.95 ◊	41.94±17.43 ◊	.003
	MTV (mm/s)	.74±.31	.45±.34 ◊	.37±.20 ◊	.002

◊ A significance difference Between control and other groups

Sheeran et al. found that spinal position sense in LBP group was similar to that in healthy subjects. However, once LBP patients were classified into FP and AEP, the results showed a different joint position sense as compared with healthy controls (16). These findings are in agreement with our original hypothesis, which demonstrated wash out effect in LBP. In some studies, motor control defects were not detected despite the sub-classification of patients. The studies by Sheeran et al. and Astfalck et al. could not detect different muscle activities in AEP and FP patients (16, 26). Nonetheless, some aspects of LBP movement patterns are unclear and further studies are needed.

In the current study, no significant differences were observed between pooled LBP and the control groups, except in frontal plane in static phase. A possible explanation is that stability in the ML plane depends largely on the strength and coordination of the hip abductors (27). Dysfunction in the hip abductor muscles in LBP patients was reported; thus, it seems that this difference in balance may be affected by dysfunction in hip abductors and adductors (28). It is worth mentioning that the aggravating factors and postural deformity of AEP and FP patients were in the sagittal plane and in opposite direction, and because of wash out effect, we did not observe any differences in balance between the pooled LBP and control groups in the sagittal plane (25). This result confirms the accuracy of our classification of patients. Mazaheri et al. showed that postural sway was decreased, which could arise from increased stiffness due to cocontraction (29).

AEP patients had different postural sway compared to the normal subjects in dynamic phase. As described in the definition of this subgroup, lifting from the ground to the waist level is considered a dynamic test and an aggravating factor in AEP. The central nervous system may be dependent on proprioceptive input of lumbopelvic muscles for postural control (30). It was suggested that postural control disorder in LBP patients may arise from change in lumbopelvic proprioception (31). It has been argued that altered postural sway in AEP patients during the test may be due to changed proprioceptive inputs of the paravertebral muscles. In fact, several studies have shown that pain can affect proprioceptive input of muscles (32, 33).

The dynamic phase of lifting test involves extension of the lumbar spine categorized as an aggravating factor in AEP (34). During the dynamic phase of lifting, the neuromotor system can reduce movement artifacts by cocontraction mechanism leading to smooth movements with decreased sway (35). It has been suggested that this stiffness strategy decreases postural sway (36). Another possible explanation is that this movement induces pain or fear of pain in AEP patients, and based on the pain adaptation model, the body responds through stiffening the trunk with increasing activity of the large muscles. During the movement with pain or fear of pain, antagonist muscle activity increases, that may enhance vertebral control. Relative stiffening of the spine can also occur in the presence of pain or fear of pain (32). Our results showed no significant difference between the normal and flexion pattern groups. A possible explanation may be the nature of the movement. The extension movement of this phase of lifting was an easing factor for the FP group (34).

FP and AEP groups had different postural sways in comparison with the normal subjects in the static phase of lifting in both AP and ML directions. While holding external loads, to prevent the spine from collapsing, large and superficial trunk muscles are suggested to play a dominant role in providing stability (32). Cocontraction of muscles on both sides of the joint is needed to maintain static balance, which can increase total spinal load (37).

It seems that increased abdominal muscles activity can enhance load on anterior elements of the spine in FP, which can be an aggravating factor in FP. Accordingly, muscle coactivation may occur in the FP to protect tissues from damage. Hyperactivity of paraspinal muscles in AEP group can increase load on the posterior spinal structures (25). This increased muscle activity may be a result of poor osseoligamentous integrity to prevent further pain or injury and seems to be an effective short-term strategy (38). This coactivation can result in the stiffness of spine and reduced postural sway (36).

In the present study, lower COP velocity was observed in the patient groups (pooled and homogeneous groups) in comparison with the normal subjects. Our findings are in agreement with those of Salavati et al. and Lafond et al. (24, 39). Cocontraction of trunk muscles can increase trunk stiffness (40). This decreased postural sway can be due to cocontraction, and in turn, increased stiffness (29, 41). There are different possible mechanisms for the explanation of these results, one of which is the task condition. This test was dynamic and associated with lifting. More cognitive effort is required with increased task demand that may affect postural control and gait variability with freezing postural sway and gait kinematics in patients with musculoskeletal disorders including LBP patients, patelofemoral pain syndrome and ACL deficient patients (42-44). Another possible mechanism may be that LBP patients have defects in proprioceptive input, thereby, they may select the cocontraction strategy to provide more proprioceptive input (45-47). Cocontraction can also increase reflexes, which might be caused by presynaptic stimulation of Ia afferents (41). Fear of reinjury or pain or anticipation of pain can be another possible mechanism for decreased postural sway. Patients may attempt to prevent tissue damage by cocontraction of trunk muscles, which decreases postural sway (48). Another possible mechanism could be related to the effect of load. Co-contraction occurs in load lifting to enhance spinal stability, which is associated with decreased damping (49). Analysis of the body sway based on the nonlinear dynamical pattern may also lead to different results (8). However, more studies are needed to confirm these findings.

Study limitations and suggestions for future studies

There are some limitations in this study that need to be recounted when the results are discussed. First, only one lifting technique was investigated in this study; thus, further studies examining other lifting techniques are required. Second, the subjects of this study were men and limited in number, thus, further studies are required with more and female subjects. Finally, in this study electromyography was not used, but it can help to better interpret the results.

Comparison of heterogonous non-specific chronic LBP patients with normal subjects showed no differences in postural sway during lifting. In contrast, when these patients were classified into FP and AEP groups, some postural sway differences were detected compared to the normal group. The results were influenced by wash out effect. It should be considered for sub-classification in both clinical and research settings.

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References

1. Dankaerts W, O'Sullivan P, Burnett A, Straker L, Davey P, Gupta R. Discriminating healthy controls and two clinical subgroups of nonspecific chronic low back pain patients using trunk muscle activation and lumbosacral kinematics of postures and movements: a statistical classification model. Spine. 2009; 34(15):1610-8.
2. Luomajoki H, Kool J, de Bruin ED, Airaksinen O. Reliability of movement control tests in the lumbar spine. BMC Musculoskelet Disord. 2007; 8(1):90.
3. van Dieën JH, Selen LP, Cholewicki J. Trunk muscle activation in low-back pain patients, an analysis of the literature. J Electromyogr Kinesiol. 2003; 13(4):333-51.
4. Henry SM, Hitt JR, Jones SL, Bunn JY. Decreased limits of stability in response to postural perturbations in subjects with low back pain. Clin Biomech. 2006; 21(9):881-92.
5. Maribo T, Schiøttz-Christensen B, Jensen LD, Andersen NT, Stengaard-Pedersen K. Postural balance in low back pain patients: criterion-related validity of centre of pressure assessed on a portable force platform. Eur Spine J. 2012; 21(3):425-31.
6. Qu X. Development and evaluation of postural control models for lifting motions and balance control. Virginia: Virginia Polytechnic Institute and State University; 2008.
7. Commissaris DA, Toussaint HM. Load knowledge affects low-back loading and control of balance in lifting tasks. Ergonomics. 1997; 40(5):559-75.
8. Mazaheri M, Coenen P, Parnianpour M, Kiers H, van Dieen JH. Low back pain and postural sway during quiet standing with and without sensory manipulation: a systematic review. Gait Posture. 2013; 37(1):12-22.
9. Hoffman SL, Johnson MB, Zou D, Van Dillen LR. Differences in end-range lumbar flexion during slumped sitting and forward bending between low back pain subgroups and genders. Man Ther. 2012; 17(2):157-63.
10. Shahbazi Moheb Seraj M, Maroufi N, Ebrahimi Takamjani I, Ahmadi A, Negahban H. The ratio of lumbar to hip motion during the trunk flexion in patients with mechanical chronic low back pain according to o'sullivan classification system: a cross-sectional study. Arch Bone Joint Surg. 2018; 6(6):560-9.
11. O'Sullivan P. Diagnosis and classification of chronic low back pain disorders: maladaptive movement and motor control impairments as underlying mechanism. Man Ther. 2005; 10(4):242-55.
12. Dankaerts W, O'Sullivan PB, Straker LM, Burnett AF, Skouen JS. The inter-examiner reliability of a classification method for non-specific chronic low back pain patients with motor control impairment. Man Ther. 2006; 11(1):28-39.
13. Luomajoki H, Kool J, de Bruin ED, Airaksinen O. Movement control tests of the low back; evaluation of the difference between patients with low back pain and healthy controls. BMC Musculoskelet Disord. 2008; 9(1):170.
14. O'sullivan PB. Lumbar segmental 'instability': clinical presentation and specific stabilizing exercise management. Man Ther. 2000; 5(1):2-12.
15. O'Sullivan P. Classification of lumbopelvic pain disorders--why is it essential for management? Man Ther. 2006; 11(3):169-70.
16. Sheeran L, Sparkes V, Caterson B, Busse-Morris M, van Deursen R. Spinal position sense and trunk muscle activity during sitting and standing in nonspecific chronic low back pain: classification analysis. Spine. 2012; 37(8):E486-95.
17. Sadler E. Principal component analyses of joint angle curves to examine lifting technique. [Doctoral Dissertation]. Ontario, Canada: Queen"s University; 2010.
18. Kollmitzer J, Oddsson L, Ebenbichler GR, Giphart JE, DeLuca CJ. Postural control during lifting. J Biomech. 2002; 35(5):585-94.
19. Faber GS, Kingma I, Bakker AJ, van Dieën JH. Low-back

loading in lifting two loads beside the body compared to lifting one load in front of the body. J Biomech. 2009; 42(1):35-41.
20. Dickin DC, McClain MA, Hubble RP, Doan JB, Sessford D. Changes in postural sway frequency and complexity in altered sensory environments following whole body vibrations. Hum Mov Sci. 2012; 31(5):1238-46.
21. Salavati M, Hadian MR, Mazaheri M, Negahban H, Ebrahimi I, Talebian S, et al. Test-retest reliabty of center of pressure measures of postural stability during quiet standing in a group with musculoskeletal disorders consisting of low back pain, anterior cruciate ligament injury and functional ankle instability. Gait Posture. 2009; 29(3):460-4.
22. Meng H, O'Connor DP, Lee BC, Layne CS, Gorniak SL. Effects of adiposity on postural control and cognition. Gait Posture. 2016; 43(1):31-7.
23. Kejonen P, Kauranen K. Reliability and validity of standing balance measurements with a motion analysis system. Physiotherapy. 2002; 88(1):25-32.
24. Salavati M, Mazaheri M, Negahban H, Ebrahimi I, Jafari AH, Kazemnejad A, et al. Effect of dual-tasking on postural control in subjects with nonspecific low back pain. Spine. 2009; 34(13):1415-21.
25. Dankaerts W, O'Sullivan P, Burnett A, Straker L. Differences in sitting postures are associated with nonspecific chronic low back pain disorders when patients are subclassified. Spine. 2006; 31(6):698-704.
26. Astfalck RG, O'Sullivan PB, Straker LM, Smith AJ, Burnett A, Caneiro JP, et al. Sitting postures and trunk muscle activity in adolescents with and without nonspecific chronic low back pain: an analysis based on subclassification. Spine. 2010; 35(14):1387-95.
27. Shumway-Cook A, Williams MW. Motor control: theory and practical applications. Philadelphia: Lippincqtt Williams & Wilkins; 2001.
28. Nadler SF, Malanga GA, Bartoli LA, Feinberg JH, Prybicien M, Deprince M. Hip muscle imbalance and low back pain in athletes: influence of core strengthening. Med Sci Sports Exerc. 2002; 34(1):9-16.
29. Mazaheri M, Heidari E, Mostamand J, Negahban H, van Dieen JH. Competing effects of pain and fear of pain on postural control in low back pain? Spine. 2014; 39(25):E1518-23.
30. Mann L, Kleinpaul JF, Pereira Moro AR, Mota CB, Carpes FP. Effect of low back pain on postural stability in younger women: Influence of visual deprivation. J Bodyw Mov Ther. 2010; 14(4):361-6.
31. della Volpe R, Popa T, Ginanneschi F, Spidalieri R, Mazzocchio R, Rossi A. Changes in coordination of postural control during dynamic stance in chronic low back pain patients. Gait Posture. 2006; 24(3):349-55.
32. Hodges PW, Moseley GL. Pain and motor control of the lumbopelvic region: effect and possible mechanisms. J Electromyogr Kinesiol. 2003; 13(4):361-70.
33. Van Hoof W, Volkaerts K, O'Sullivan K, Verschueren S, Dankaerts W. Comparing lower lumbar kinematics in cyclists with low back pain (flexion pattern) versus asymptomatic controls--field study using a wireless posture monitoring system. Man Ther. 2012; 17(4):312-7.
34. Astfalck RG, O'Sullivan PB, Smith AJ, Straker LM, Burnett AF. Lumbar spine repositioning sense in adolescents with and without non-specific chronic low back pain--an analysis based on sub-classification and spinal regions. Man Ther. 2013; 18(5):410-7.
35. van Dieën JH, Kingma I, Van der Bug J. Evidence for a role of antagonistic cocontraction in controlling trunk stiffness during lifting. J Biomech. 2003; 36(12):1829-36.
36. 36. Schelldorfer S, Ernst MJ, Rast FM, Bauer CM, Meichtry A, Kool J. Low back pain and postural control, effects of task difficulty on centre of pressure and spinal kinematics. Gait Posture. 2015; 41(1):112-8.
37. van Dieën JH, Cholewicki J, Radebold A. Trunk muscle recruitment patterns in patients with low back pain enhance the stability of the lumbar spine. Spine. 2003; 28(8):834-41.
38. Hodges P, van den Hoorn W, Dawson A, Cholewicki J. Changes in the mechanical properties of the trunk in low back pain may be associated with recurrence. J Biomech. 2009; 42(1):61-6.
39. Lafond D, Champagne A, Descarreaux M, Dubois JD, Prado JM, Duarte M. Postural control during prolonged standing in persons with chronic low back pain. Gait Posture. 2009; 29(3):421-7.
40. Lee PJ, Rogers EL, Granata KP. Active trunk stiffness increases with co-contraction. J Electromyogr Kinesiol. 2006; 16(1):51-7.
41. Nielsen J, Sinkjær T, Toft E, Kagamihara Y. Segmental reflexes and ankle joint stiffness during co-contraction of antagonistic ankle muscles in man. Exp Brain Res. 1994; 102(2):350-8.
42. Salavati M, Mazaheri M, Negahban H, Ebrahimi I, Jafari AH, Kazemnejad A, et al. Effect of dual-tasking on postural control in subjects with nonspecific low back pain. Spine. 2009; 34(13):1415-21.
43. Zeinalzadeh A, Talebian S, Naghdi S, Salavati M, Nazary-Moghadam S, Zeynalzadeh Ghoochani B. Effects of vision and cognitive load on static postural control in subjects with and without patellofemoral pain syndrome. Physiother Theory Pract. 2018; 34(4):276-85.
44. Nazary-Moghadam S, Salavati M, Esteki A, Akhbari B, Keyhani S, Zeinalzadeh A. Gait speed is more challenging than cognitive load on the stride-to-stride variability in individuals with anterior cruciate ligament deficiency. Knee. 2018; 160(8):30921-9.
45. Brumagne S, Cordo P, Lysens R, Verschueren S, Swinnen S. The role of paraspinal muscle spindles in lumbosacral position sense in individuals with and without low back pain. Spine. 2000; 25(8):989-94.
46. Gill KP, Callaghan MJ. The measurement of lumbar proprioception in individuals with and without low back pain. Spine. 1998; 23(3):371-7.
47. Craig CE, Goble DJ, Doumas M. Proprioceptive acuity predicts muscle co-contraction of the tibialis anterior and gastrocnemius medialis in older adults' dynamic postural control. Neuroscience. 2016; 322(1):251-61.

48. Van Daele U, Hagman F, Truijen S, Vorlat P, Van Gheluwe B, Vaes P. Decrease in postural sway and trunk stiffness during cognitive dual-task in nonspecific chronic low back pain patients, performance compared to healthy control subjects. Spine. 2010; 35(5):583-9.
49. Hodges PW. Pain and motor control: from the laboratory to rehabilitation. J Electromyogr Kinesiol. 2011; 21(2):220-8.