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Original Article

The effect of height of lifting on dynamic postural control in low back pain patients and healthy subjects

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ABSTRACT

Objectives: The study investigated the influence of starting load position during lifting on postural control in nonspecific chronic low back pain (LBP) and healthy volunteers.

Patients and methods: The cross-sectional study included 20 healthy males (mean age: 31.8±7.4 years; range, 18 to 55 years) and 52 male patients (mean age: 33.4±9.2 years; range, 18 to 55 years) with chronic LBP between February 2016 and April 2018. Postural control characteristics were assessed by a force plate system. Center of pressure signals were obtained at a frequency of 100 Hz, and the mean of three trials was calculated. The participants were told to place their feet hip-width apart on the force plate while standing barefoot. They were then asked to lift a box weighing 10% of their body weight from the ground to waist height and then from waist height to overhead with straight elbows. They moved the box at their selected speed. The examinations began upon the examiner's command.

Results: Results indicated a significant difference ($p<0.001$) in all postural control variables in chronic LBP patients who lifted a load at different heights. In addition, there was a significant difference between all of the postural control measures of this study in healthy participants during load lifting at different heights ($p<0.05$), with the exception of the mediolateral standard deviation of velocity ($p=0.067$).

Conclusion: Different lifting heights impact LBP patients' and healthy people's postural control differently. Postural control was more challenging during waist-to-overhead lifting in the patient group. This may be due to a stiffening strategy. The central nervous system reduces postural sway at higher centers of mass.

Keywords: Low back pain, postural balance, postural control, weight liftings.

The performance of manual weight lifting is necessary for every profession, as well as daily tasks. There is no industry immune to the known health risks of manual weight lifting. According to prior studies, low back pain (LBP) is the most prevalent and well-developed occupational health risk connected to lifting weights.[1-3]

The prevalence of LBP is about 9.4%, making it a prominent ailment among musculoskeletal disorders. Low back pain and injury are believed to be caused by compressive stresses on the spine, particularly at the L5/S1 intervertebral disc.[4] Tasks that require many bending, twisting, and abrupt movements and require much lifting, lowering, pushing, pulling, carrying, and holding tend to have a high risk of causing LBP.[5] Additionally, it was discovered that one of the key variables impacting the workload when lifting was the lifting height.[6] However, surprisingly little scientific investigation has focused on determining the quantitative connection between lifting height and low backloading.[6] The external force pressing on the spine is the primary risk factor for back injuries, and from this standpoint, it is imperative to minimize the external force as much as possible. It is widely known

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that lifting from a higher height and lifting less weight would result in a minor external moment acting on the lumbar spine.[7] The height of the load position is claimed to be more significant than the lifted weight.[7] The effects of lifting height on the spine's biomechanics have been the subject of numerous studies. When lifting height increases, it results in considerably increased low back load, according to an electromyography (EMG)-assisted model.[8] Low lifting heights are shown to place high pressure on the lumbar spine, and higher lifting heights are observed to reduce the load on the lumbar spine.[6,9] A greater peak compression load and anteroposterior (AP) shear stress have been observed when boxes are lifted nearer the ground.[10] When lifting from lower lifting heights, a study indicated that the peak net sagittal plane moment on L5/S1 considerably increased, and lifting tasks that require considerable bending may increase spinal loads and cause LBP.[1,11] Additionally, it has been demonstrated that the starting height affected the peak vertical ground response forces on the spine and the variance of the sagittal plane kinematic variables.[12] It was found that postural control can be altered by an external load, which is essential for daily life.[13] Poor balance performance and reduced postural control have frequently been reported in patients with LBP. This population's lack of hip strategy utilization, low postural strategy variety, and poor balance recovery after perturbation have all been well documented. Given that poor postural control may significantly contribute to the chronicity of LBP symptoms and predict the future occurrence of LBP, monitoring improvements in postural control as an indicator of whole-body performance appears to be prioritized during therapy.[14] To our knowledge, there are only a few studies about the effect of lifting height on LBP postural control. Thus, the purpose of the current study was to investigate how patients with chronic LBP (CLBP) and healthy individuals' postural control were affected by their starting load positions during lifting. It was hypothesized that the participants, both patients and healthy individuals, have different posture control when lifting loads at different heights. It was further hypothesized that the lower lifting height would challenge postural control more in both groups.

PATIENTS AND METHODS

The cross-sectional study included 52 males (mean age: 33.4±9.2 years; range, 18 to 55 years) with LBP and 20 healthy males (mean age: 31.8±7.4 years; range, 18 to 55 years) as controls. Participants in our physical therapy clinic at the School of Rehabilitation were selected as LBP patients for this study. People from outside the university, students, and university staff were selected for the control group. In addition to word-of-mouth marketing on campus and in the physical therapy clinic, the study was promoted through email broadcasts, posters, pamphlets, and posters. Participants had local back pain between the L1 and gluteal folds and had persistent or recurrent pain that lasted for at least three months. The Motion Analysis Laboratory of the Department of Physical Therapy was the site of all experimental procedures from February 2016 to April 2018. The most typically used criteria for chronic pain was continuous pain for at least three months.[15] The level of pain experienced by the patients did not interfere with their usual daily activities. The patients in this study did not experience acute discomfort and could maintain everyday lifestyles. Consequently, only pain levels below 6.5 on the Visual Analog Scale (VAS) were considered in the study.[16] Patients whose level of pain was almost at the severe pain threshold were not included in the trial since the subjects' spines would be subjected to an external load, and there was a potential that the patient's symptoms would worsen. Modifying the mechanical load on the affected tissues changed the patients' symptoms. A VAS score of at least 1 point while moving would support the patient's clinical diagnosis. To be considered for inclusion, healthy volunteers needed to fulfill the following criteria: *(i)* not experiencing back pain that would have kept them from working in the past two years; *(ii)* no prior experience with posture control exercises; *(iii)* similar age and body mass index to participants with back pain; and *(iv)* the spine's natural alignment.[16-18] A fracture, cancer, a history of back surgery, a leg injury within the previous two years, vestibular abnormalities, balance disorders, radiating pain with painful legs, abnormalities in the arms, patients who had engaged in physical therapy strength training, or an increase in the intensity of symptoms throughout examinations disqualified all groups.

This study involved load-lifting tests from the ground to the waist (GW) and from the waist to the overhead (WO) position. To train the participants and rectify their motion faults, the examiner presented the testing procedure and conducted the test once (before the actual rest). The exams were conducted randomly. Each test was carried out three times, the mean of the three trials was calculated, and participants were given a 1-min rest to prevent tiredness. The individuals were told to stand barefoot on the force plate (hip-width apart) and raise a box from GW and from WO. To assess balance performance, the center of pressure (COP) motions were measured using a force plate device (Kistler 9260AA6; Kistler Instrumente AG, Winterthur, Switzerland). Every participant saw an object suspended from the ceiling at the anterior superior iliac spine level, and they were all assessed in the same way to solve problems related to defining the height of the box at the lumbar level. For every person, the object's height was altered. The participant next maintained or lifted the load to the designated height while keeping their elbows straight. The participants kept the box at the anterior superior iliac spine level while raising it, keeping their elbows straight. Afterward, the box was lifted to a position around 20° above the participant's line of gravity, placing their arms roughly between the corners of their mouth and ears.

To verify the angle, a goniometer was also used. Participants maintained their elbows straight throughout the testing and moved the box at their selected speed. Two A4 papers were put on the force plate during each experiment, and they were used to record the position of the feet. To reset the system, individuals exited the force plate after every trial. About 10% of each person's total weight was made up of the box and its contents combined. The examinations began upon the examiner's command. During the testing, only the participant's hands were in contact with the box (Figure 1).

Using customized MATLAB software version 2018a (MathWorks Inc., Natick, MA, USA), all data analysis was performed offline. For each stability test, a wide array of eight variables was calculated. The COP signal was acquired at a frequency of 100 Hz. Excursion and velocity variables were used to define the COP pattern (and their combinations). Center of pressure parameters consisted of the standard deviation (SD) of COP velocity in the frontal and sagittal planes, the mean total velocity (MTV), the amplitude of sway in the AP and mediolateral (ML) directions, the phase

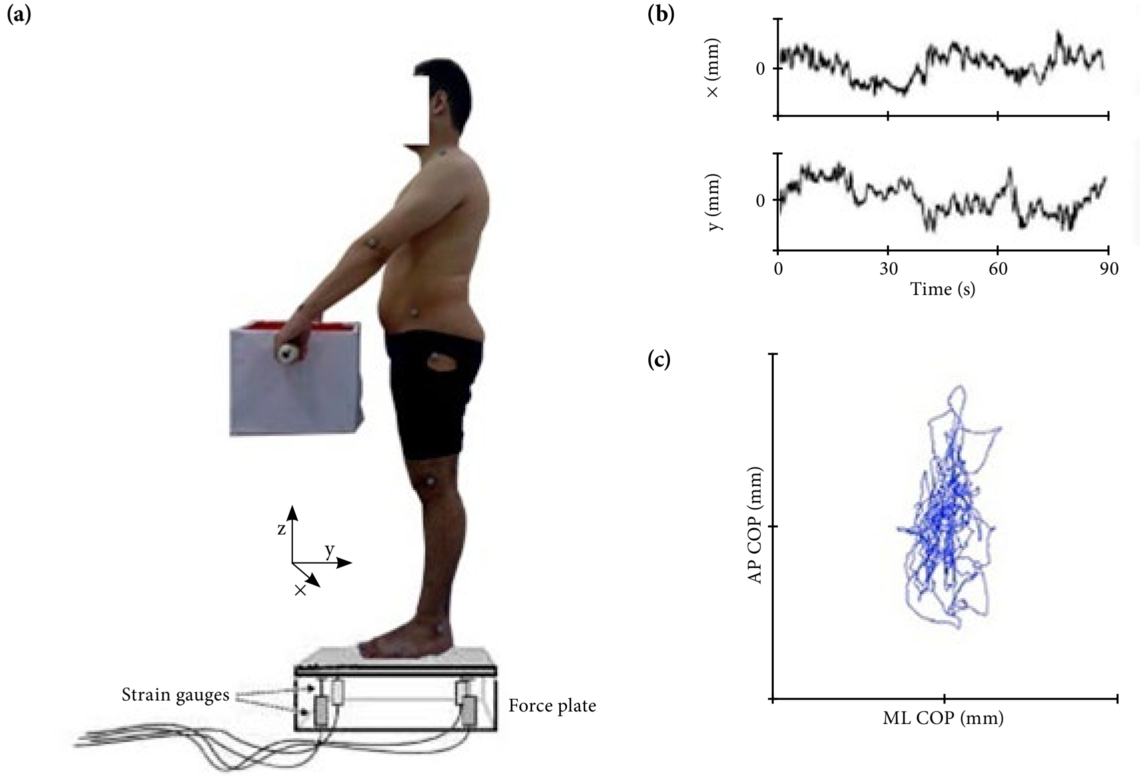

Figure 1. The image displays the variation in the COP determined using a force plate. **(a)** In this setup, the participants stand on the force plate and lift the box to assess their postural sway. The dashed line in the human-shaped outline represents the natural sway that occurs. Typically, the force plate is equipped with strain gauges positioned at the four corners beneath the supporting surface, enabling the calculation of ground reaction force and the path of COP. **(b)** The time-series data of COP in both the ML and AP directions. **(c)** The trajectory followed by COP.

COP: Center of pressure; AP: Anterior-posterior; ML: Medial-lateral

TABLE 1
Participants' demographic data

	LBP	Normal	
Variables	Mean±SD	Mean±SD	*p*
Age (year)	33.37±9.23	31.75±7.43	0.478
Weight (kg)	91.6±91.88	78.05±8.72	0.514
Height (cm)	174.49±7.03	175.52±5.1	0.552
Body mass index (kg/m^2)	29.81±28.45	25.34±2.63	0.467

LBP: Low back pain; SD: Standard deviation; P-value: Probability value.

plane portrait in the AP and ML directions, and combinations of them.[19]

Statistical analysis

The sample size needed to identify changes in postural control parameters between individuals with and without CLBP was calculated using data from an earlier study with the PASS software version 11.0.4 (NCSS, LLC, Kaysville, Utah, USA).[8] According to the mean COP sway velocity values of normal subjects with and without CLBP (6.12 and 5.21 mm/sec, respectively), 50 subjects would be required for the LBP group and 19 for the control group to perform an unpaired t-test with a 95% confidence interval and a power of 0.80.

Data were analyzed using IBM SPSS version 20.0 software (IBM Corp., Armonk, NY, USA). Routine analysis was used to make descriptive statistics about the subjects. To examine the normality of the COP variables, the Kolmogorov-Smirnov test was employed. Moreover, for within-group and between-group comparisons, respectively, the paired t-test and its nonparametric equivalent, the Wilcoxon test, and the independent t-test and its nonparametric counterpart, the Mann-Whitney U test, were used. The level of significance for all statistical tests was set at $p<0.05$.

RESULTS

The descriptive statistics for the participants' demographic information are presented in Table 1. The participants' demographic differences were not statistically significant.

The results of the paired t-test in LBP patients indicated significant differences ($p<0.001$) in the variables of SD of amplitude in the AP direction and the phase plane in both the ML and AP-ML directions between the two test conditions, GW and WO. Additionally, the Wilcoxon test revealed significant differences ($p<0.001$) in the variables of SD of velocity and phase plane in the AP direction, as well as SD of amplitude and SD of velocity in the ML direction, along with the variable MTV.

In healthy individuals, the results of the paired t-test demonstrated significant differences in the variables of SD of amplitude in the ML direction, SD of amplitude, SD of velocity, and phase plane in the AP direction, as well as phase plane in the AP-ML direction, under the two testing conditions, GW and WO ($p=0.001$, $p<0.001$, $p=0.001$, $p<0.001$, and $p<0.001$, respectively). Furthermore, the Wilcoxon test revealed significant results for the variables of

TABLE 2
Comparison of postural control of healthy subjects during different lifting heights

	Ground to waist			Waist to overhead			
Variables	Mean±SD	Median	Min-Max	Mean±SD	Median	Min-Max	*p*
Anterior/posterior							
SD of amplitude (mm)	21.7±4.1			16.3±3.7			<0.001*
SD of velocity (mm/s)	105.4±28.2			86.6±21.3			0.001*
Phase plane (arbitrary unit)	10.5±1.5			8.9±1.6			<0.001*
Medial/lateral							
SD of amplitude (mm)	6.8±1.5			3.6±1.4			0.001*
SD of velocity (mm/s)	61.2±15.5			50.2±25.7			0.067
Phase plane (arbitrary unit)		25.3	22.2-26.1		18.7	16.8-21.4	<0.001†
Total							
Phase plane (AP-ML) (arbitrary unit)	28.9±5.1			21±3.4			<0.001*
Mean total velocity (mm/s)		1	0.9-1.1		0.7	0.6-1.1	0.002†

SD: Standard deviation; AP: Anterior-posterior; ML: Medial/lateral; * Paired t-test; † Wilcoxon test.

TABLE 3
Comparison of postural control of LBP during different lifting heights

	Ground to waist			Waist to overhead			
Variables	Mean±SD	Median	Min-Max	Mean±SD	Median	Min-Max	*p*
Anterior/posterior							
SD. of amplitude (mm)	21.6±4.8			14.6±4.5			<0.001*
SD. of velocity (mm/s)		89.1	77.5-103		63.8	51.4-90.1	<0.001†
Phase plane (arbitrary unit)		9.82	9.11-11.9		8.2	6.8-9.1	<0.001†
Medial/lateral							
SD. of amplitude (mm)		6.9	5.9-9.3		5.6	4.4-6.4	<0.001†
SD. of velocity (mm/s)		49.5	36.9-56.3		30.6	25.6-40.8	<0.001†
Phase plane (arbitrary unit)	22.7±4.2			16.7±4.3			<0.001*
Total							
Phase plane (AP-ML) (arbitrary unit)	28.6±7.1			19.1±4.7			<0.001*
Mean total velocity (mm/s)		0.8	0.6-0.9		0.6	0.5-0.8	<0.001†

LBP: Low back pain; SD: Standard deviation; AP: Anterior-posterior; ML: Medial-lateral; * Paired t-test; † Wilcoxon test.

SD of amplitude and phase plane in the ML direction, as well as the variable MTV (p<0.001 and p=0.002, respectively).

As shown in Tables 2 and 3, a higher height had a substantial impact on physical load handling in the magnitude and velocity of postural control measures in both groups (p<0.05). In LBP, all indicators increased significantly (p<0.001, Table 3).

During the process of lifting a load in conditions of GW, the comparison between the two groups using an independent t-test revealed significant differences in the variables SD of velocity in the ML direction and MTV (p=0.002 and p=0.007, respectively). Furthermore, while lifting a load in WO conditions, the independent t-test between the two groups showed significant differences in the variables SD of velocity in the AP direction and phase plane in the ML

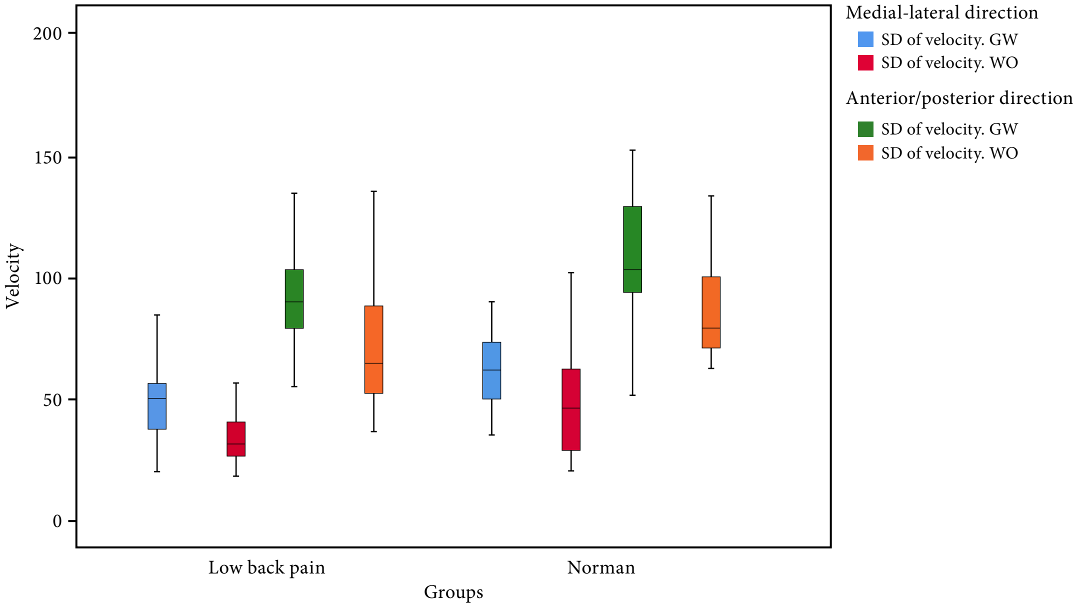

Figure 2. The velocity of the center of pressure during GW and WO lifting.

GW: Ground to waist; WO: Waist to overhead.

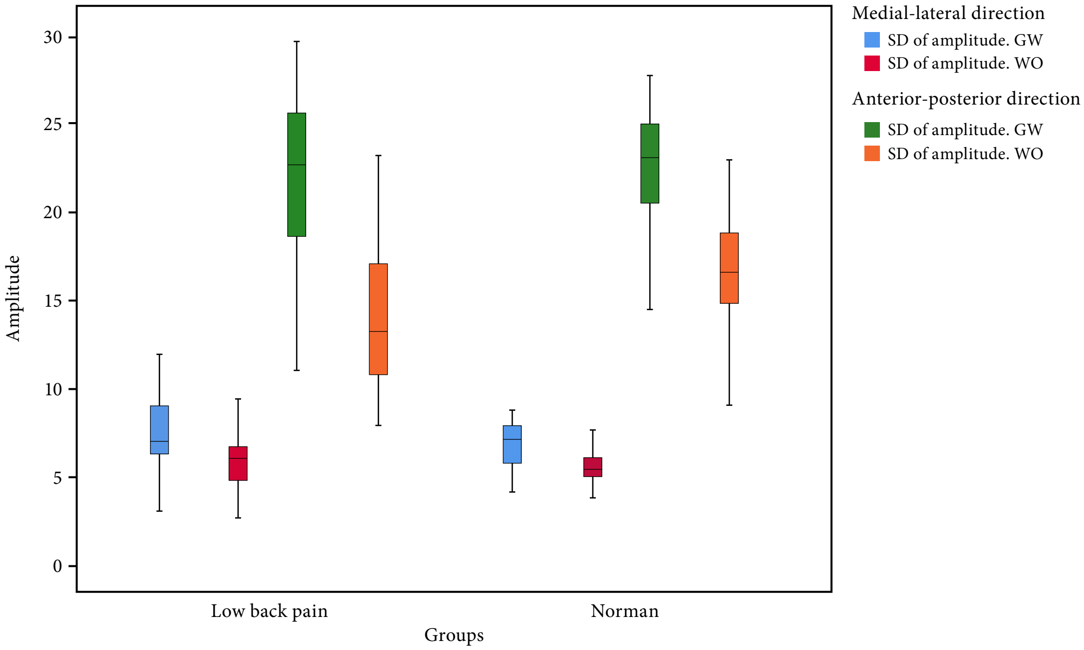

Figure 3. The amplitude of the center of pressure during GW and WO lifting.

GW: Ground to waist; WO: Waist to overhead.

direction (p=0.027 and p=0.028, respectively). The Mann-Whitney U test indicated that the variables SD of velocity in the ML direction and MTV also had significant results (p=0.015 and p=0.003, respectively).

Figures 2 and 3 depict the COP movement (amplitude and velocity) during the two tasks performed by the control and patient groups.

DISCUSSION

The purpose of this study was to find out if patients with LBP and healthy volunteers experienced any changes in dynamic postural control when lifting heights were varied. The results support our initial hypothesis that patients with a history of nonspecific LBP and normal subjects would exhibit varied postural control at the various lifting heights. These variations were shown mainly in the patient group. Our findings, however, did not support the second hypothesis. During lifting from a higher height, both groups displayed decreased postural sway.

The impact of lifting height on the postural control of LBP has not been studied, as far as we are aware. Other biomechanical effects of lifting height on the spine include EMG of back muscles, maximum compression force, maximum AP shear force, and the horizontal distance between the load and L5/S1, among others.[6,7,20] They support our findings that varied lifting heights can impact the biomechanics of postural control, particularly in our patient population. Our findings showed that postural control during lifting from WO was more challenging than lifting from GW. These findings conflict with earlier research regarding additional biomechanical impacts caused by lifting height.[6,7,20] There are several possible explanations for these results. The height of the center of mass (COM) could be a possible explanation for these observations. Numerous factors influence the postural control of humans. External loading and mass redistribution are two examples of these variables.[21] The inverted pendulum hypothesis specifically states that the height of the COM above the support base is inversely proportional to the rigid body's stability.[22,23] Postural sway may also be influenced by the COM position.[17] Consequently, while lifting from WO, the COM was positioned at a greater height than when lifting from GW. Another potential explanation for this inconsistency is muscular activation. When external stresses were held at higher heights, it was observed that muscle activation increased.[20] Our results demonstrated that the postural sway decreased during lifting from WO. These decreases are consistent with the stiffness strategy.[24] During the stiffening strategy, there is a rise in the cocontraction of trunk muscles.[25,26] Those alterations are consistent with a postural strategy that enhances trunk rigidity, prevents lumbar spine buckling, and restricts trunk mobility, presumably to avoid nociceptive excitement, pain, or damage or in anticipation of such dangers.[24,25] In addition, a greater force would be needed to deviate the spine from its position or trajectory in the presence of a stiffer trunk. Reducing the need to precisely manage the sequences of muscle activation to match the task's demands would be advantageous.[25] The central nervous system (CNS) is believed to establish effective stiffnesses for separate functions based on task conditions.[27] Following this function of the CNS, it has been proven that higher antagonistic activity occurs with heavier loads, particularly at the highest altitudes.[20] Another probable explanation was the amount of applied load in this investigation. The external load represented 10% of the participant's weight. Light loads may give a sensory cue to reduce trunk repositioning error, improve proprioceptive expressions of the trunk, and finally reduce postural sway in both groups.[28]

This study had some limitations. The first limitation pertained to participants. In this study, all subjects were male, which can impair the generalizability of the results. The second limitation was related to external load. The results may have differed at loads exceeding 10% of the subject's weight. Since we lacked EMG for collecting data on synchronized muscle activity with a force plate device, the discussion of the results was restricted.

In conclusion, lifting height is a risk factor that remarkably contributes to low back problems in healthy individuals and those with LBP. Our findings indicate that patients and healthy individuals have impaired postural control during lifting at greater heights to maintain balance. They display altered postural control as evidenced by decreased postural sway. The findings indicate that the CNS tightened its posture control in conditions of heightened postural threat. A change in COM height or external load could cause this problem. This information enhances comprehension of postural control during lifting at various heights. Without an active pain event in healthy individuals and patients with LBP, these data may aid in developing therapeutic approaches.

Ethics Committee Approval: The study protocol was approved by the Iran University of Medical Sciences Ethics Committee (date: 2015, no: IR.IUMS.REC.1394.9211342215). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Patient Consent for Publication: A written informed consent was obtained from each patient.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions: Concept development (provided idea for the research): M.S., J.S.; Design (planned the methods to generate the results): J.S., H.N.; Supervision (provided oversight, responsible for organization and implementation, writing of the manuscript): I.E.T., H.N.; Data collection/ processing (responsible for experiments, patient management, organization, or reporting data): M.S.; Writing (responsible for writing a substantive part of the manuscript): M.S.; Critical review (revised manuscript for intellectual content, this does not relate to spelling and grammar checking): M.S., J.S.

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