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Effects of spinal manipulation on sensorimotor function in low back pain patients – a randomized controlled trial

Christine M. Goertz, DC, PhD^{a,*}, Ting Xia, PhD^a, Cynthia R. Long, PhD^a, Robert D. Vining, DC^a, Katherine A. Pohlman, DC, MS^b, James W. DeVocht, DC, PhD^a, M. Ram Gudavalli, PhD^a, Edward F. Owens Jr., MS, DC^c, William C. Meeker, DC, MPH^d, and David G. Wilder, PhD^e

^a Palmer Center for Chiropractic Research, Palmer College of Chiropractic, Davenport, IA

^b Department of Medicine & Dentistry, University of Alberta, Edmonton, AB, Canada

^c Dr. Sid E. Williams Center for Chiropractic Research, Life University, Marietta, GA

^d Palmer College of Chiropractic – West Campus, San Jose, CA

^e Department of Biomedical Engineering, University of Iowa, Iowa City, IA

Abstract

Background—Low back pain (LBP) is a major health problem in industrialized societies. Spinal manipulation (SM) is often used for treating LBP, though the therapeutic mechanisms remain elusive. Research suggests that sensorimotor changes may be involved in LBP. It is hypothesized that SM may generate its beneficial effects by affecting sensorimotor functions.

Objectives—To compare changes in sensorimotor function, as measured by postural sway and response to sudden load, in LBP patients following the delivery of high-velocity low amplitude (HVLA)-SM or low-velocity variable amplitude (LVVA)-SM versus a sham control intervention.

Design—A three-arm (1:1:1 ratio) randomized controlled trial.

Methods—A total of 221 participants who were between 21-65 years, having LBP intensity (numerical rating scale) 4 at either phone screen or the first baseline visit and 2 at phone screen and both baseline visits, and Quebec Task Force diagnostic classifications of 1, 2, 3 or 7 were enrolled to receive four SM treatments over two weeks. Study outcomes were measured at the first and fifth visits with the examiners blinded from participant group assignment.

Results—The LVVA-SM group demonstrated a significant increase in medial-to-lateral postural excursion on the soft surface at the first visit when compared to the control group. No other

* **Corresponding Author:** Christine M. Goertz, DC, PhD, Palmer Center for Chiropractic Research, Palmer College of Chiropractic, 741 Brady Street, Davenport, IA 52803, U.S.A., Tel: 563-884-5159, Fax: 563-884-5227, christine.goertz@palmer.edu.

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CONFLICT OF INTEREST

None.

significant between-group differences were found for the two sensorimotor tests, whether during the first visit or over two weeks.

Conclusions—It appears that short-term SM does not affect the sensorimotor functions as measured by postural sway and response to sudden load in this study.

Keywords

low back pain; clinical trial; spinal manipulation; sensorimotor function

INTRODUCTION

Low back pain (LBP) is one of the most common musculoskeletal disorders in modern society (Nachemson and Jonsson, 2000; Vos T. et al., 2012; Walker, 2000). A broad range of treatment approaches, including spinal manipulation (SM), are used to treat LBP. The majority of clinical studies conducted thus far have showed that SM conveys a mild to moderate therapeutic effect in treating LBP, comparable to other non-invasive treatment methods such as McKenzie therapy and structured exercise (Goertz et al., 2012; Lawrence et al., 2008; Rubinstein et al., 2011; Standaert et al., 2011). The underlying therapeutic mechanisms of SM are not known. It has been postulated that SM may interact with or influence somatosensory, neuromusculoskeletal, somatosympathetic, and/or neurohormonal pathways, thereby causing a reduction in LBP (Pickar and Wheeler, 2001; Sung et al., 2005; Uvnas-Moberg and Petersson, 2011). However, the actual mechanism(s) remains unclear.

To address this issue, we investigated the impact of SM on sensorimotor function, particularly balance control. Balance control is a complex process involving integration of multiple levels of sensory input and precise motor responses (Lephart et al., 1997; Mergner and Rosemeier, 1998). Laboratory-based studies have demonstrated that postural sway, a well-adopted assessment method for balance control, is greater in patients with LBP than their healthy counterparts (Parnianpour et al., 1988; Rougier, 2008; Ruhe et al., 2011). Patients with LBP also differ from healthy individuals by relying more on ankle movement but less on hip movement in maintaining upright standing posture (Mok et al., 2004). Further, patients with LBP demonstrate longer response times and less evoked contraction in their trunk muscles when perturbed by sudden load (Cholewicki et al., 2005; Hodges and Richardson, 1998; Magnusson et al., 1996; Radebold et al., 2001). Indications that muscle response in patients with LBP can approach those of healthy individuals after treatment suggests the possibility of a reversible compromise in balance control (Magnusson et al., 1996; Wilder et al., 1996).

The primary objectives of this study were to examine changes in sensorimotor function, as measured by postural sway and response to sudden load in patients with LBP following 2 weeks of 1) high-velocity, low-amplitude (HVLA)-SM, 2) low-velocity, variable-amplitude (LVVA)-SM, or 3) a control consisting of light effleurage and a mechanically-assisted sham. The two SM techniques were chosen because 1) the nature of the slow tissue loading rate seen in LVVA-SM might influence receptors differently, or even different groups of receptors, than seen in HVLA-SM, and 2) they both broadly represent SM techniques in common use by doctors of chiropractic and other SM practitioners including osteopathic

physicians and physical therapists (Christensen M.G. et al., 2010). HVLA-SM is characterized by very quick manual loading of spinal segments and typically produces joint distraction, often involving cavitation (Herzog et al., 1993). HVLA-SM has been shown to induce brief bursts of increased electromyography (EMG) activity in both humans and animals (Herzog, 2000; Pickar and Kang, 2006). There may also be an immediate decrease in EMG levels following HVLA-SM in patients with elevated muscle activity (Devocht et al., 2005). In contrast, LVVA-SM is characterized by a much slower application of force when distracting joints and stretching intersegmental and paraspinal tissues (Cox, 1999). By comparing the effects of these two SM techniques that locate at the opposite ends of the SM loading characteristics spectrum to a sham control, it allowed us an opportunity to investigate if SM, as a whole, influences sensorimotor function, as measured by postural sway and response to sudden load, in patients with LBP.

MATERIALS AND METHODS

Study population

Participants with acute (less than 4 weeks), sub-acute (4 to 12 weeks), or chronic (greater than 12 weeks) LBP were recruited primarily through direct mail advertisements distributed throughout the local communities. Inclusion criteria included: 1) ages 21 to 65; 2) LBP intensity ≥ 4 in numerical rating scale (NRS: 11 points, 0=no LBP, 10= worst LBP possible) at either phone screen or the first baseline visit and ≥ 2 at phone screen and both baseline visits; and 3) classification of 1, 2, 3, or 7 under the Quebec Task Force for Spinal Disorders. Exclusion criteria included: 1) safety concerns for receiving SM or biomechanical testing; 2) compliance; 3) ongoing treatment for LBP by other health care providers; 4) severe osteoporosis; 5) prior spinal surgery; 6) tumor; and 7) pain from a visceral source(s). A more detailed description of the recruitment process, screening procedures, inclusion/exclusion criteria, as well as the rationale for each criterion, can be found in the study protocol (Wilder et al., 2011). The study protocol and informed consent documents were approved by the institutional review board (IRB# 2007M093) and the study was monitored by an independent Data and Safety Monitoring Committee as well as a National Institutes of Health-appointed External Advisory Committee.

Study design

This was a prospective randomized controlled trial (RCT) with three groups: 1) HVLA-SM; 2) LVVA-SM; and 3) sham control. Participants were allocated in a 1:1:1 allocation ratio using a computer-generated algorithm minimizing on age, sex, and pain duration. All study personnel were blinded to upcoming treatment allocation. Sensorimotor function examiners remained blinded to group assignment throughout the study. All research activities were carried out at the Palmer Center for Chiropractic Research.

Demographic information was collected at baseline visit 1 (BL1). The sensorimotor function tests were performed immediately before and immediately after SM during treatment visits (TV) 1 and 5 (4 sets in total). Between-group comparisons were made at two time points: 1) immediately following the first intervention (pre to post change at TV1) and 2) from

baseline to 2 weeks (pre at TV1 to pre at TV5) between the two SM groups and the sham control group.

Spinal manipulation was applied only to the lumbar, sacral, and pelvic regions. HVLA-SM was performed with the participant in the lateral recumbent or side-lying position. The clinician applied a high-velocity low-amplitude manual thrust over specific areas of the participant's low back, typically resulting in cavitation, which was documented in the treatment record. HVLA-SM was used when physical findings such as pain, localized tenderness, muscle guarding, painful ranges of motion, and abnormal muscle tone were present. LVVA-SM was performed with the participant lying face down on a specially designed table that allows the clinician to apply a relatively focused distractive force on the participant. The sham control consisted of light effleurage and a de-activated mechanical adjusting device (Activator IV, Activator Methods®, Phoenix, AZ) that produced a clicking sound but applied no force. The light effleurage had a load limit of 30N to avoid stimulating deeper tissues that are targeted by HVLA-SM and LVVA-SM (Gandevia et al., 1992; Morelli et al., 1999; Sullivan et al., 1991). More detailed descriptions of the SM techniques and the sham control have been presented previously (Wilder et al., 2011). Two of the 5 treatment visits were video-recorded (TVs 1 and 5). These recordings were then reviewed by study personnel to assure fidelity with respect to group assignment.

Sensorimotor function tests

Postural Sway—Participants were asked to stand still both directly on a force plate (Model # 4060-NC, Bertec, Inc, Columbus OH) and on a 10 cm thick latex foam pad (soft surface) for a period of 35 seconds in their nature stance while blindfolded and without shoes. The movement of center of pressure (COP) was recorded at a sampling rate of 1000 Hz using a Motion Monitor data acquisition system (Innovative Sports Training, Inc., Chicago, IL). Three postural sway variables were extracted from the first 30 sec of COP data, including: 1) the mean excursion in the anterior-posterior (AP) direction; 2) the mean excursion in the medial-to-lateral (ML) direction; and 3) the mean planar sway speed (overall COP traveling distance divided by time). We chose to evaluate planar sway speed in addition to mean excursion because Brumagne et al (2000) suggested that muscle spindle information is processed differently between LBP and pain-free individuals. Raymakers et al (2005) concluded that “mean displacement velocity seems to be the most informative parameter in most situations”, and Ashton-Miller et al (2001) incorporated into their proprioception model both body segment and joint velocity feedback ‘provided mainly by the spindles. To keep the postural sway tests consistent, research assistants ensured that the participant's foot position was the same across all visits. To minimize force plate system drift due to temperature variation and other factors, the device was turned on at least 30 minutes before use and zeroed immediately before testing. The procedure was repeated twice for measurements on the force plate directly and on the soft surface. In both cases, the average of the two trials was used for data analysis. A custom-written data reduction program in MATLAB (MathWorks Inc., Natick, MA) was applied to smooth the COP data using a 10 Hz low-pass Butterworth filter and extract the postural sway variables.

Response to sudden load—The paraspinal muscle activity and COP were collected while the participant's balance was perturbed with a series of 6 sudden, unexpected loads generated by a falling weight of 1.6 kg (Fig. 1). The weight was attached via a rope to a chest mounted harness worn by the patient. The weight was then raised by the tester in order to eliminate the tension in the rope. Tension was returned suddenly when the weight was dropped by the tester, delivering a sudden unexpected load. The drop height was set between 25 and 35 cm, dependent on the participant's height and weight (Wilder et al., 2011). Participants were blindfolded and wore earphones with sufficient volume of white noise to prevent visual and auditory cues. Sudden loads were applied at randomly selected intervals of time to prevent expectation. Two EMG sensors (Delsys Inc., Boston, MA) were attached to the skin over the erector spinae musculature bilaterally, 3 cm from midline at the L3 spinal level. Data from surface EMG sensors and the force plate were sampled at 1000 Hz using the Motion Monitor data acquisition system (Wilder et al., 1996). Skin areas approximately 3 square inches were cleaned vigorously using alcohol wipes to remove oil and dirt before the EMG sensors were attached. Hair was shaved if necessary. Muscle response characteristics including response start time, peak response amplitude and time, and the maximum COP excursion in the anterior direction, were extracted for each of the 6 sudden loads using a wavelet-assisted visual inspection algorithm written in MATLAB (Xia et al., 2008). To minimize the effects of individual and EMG sensor contact variations, EMG data were normalized by dividing the sudden load muscle activity by the muscle extension activity acquired while participants held their unsupported upper body in a horizontal prone position with the lower extremities and pelvis stabilized on a table for 5-seconds.

Statistical analyses

A sample size of 73 per group was targeted based on the 3 postural sway variables, assuming 15% loss to follow-up (Wilder et al., 2011). This provided at least 80% power to detect a 4mm/sec difference of mean sway speed between-groups while standing on both a hard and a soft surface, and a 0.5mm difference of mean sway in the ML direction between-groups on the hard surface, and at least 69% power to detect a 1mm difference of mean sway in the AP direction between-groups on the hard surface.

We analyzed the immediate pre- to post-treatment changes at TV1 and the changes in the pre-treatment from TV1 to pre-treatment at TV5 for all variables as follows. For postural sway, we averaged over the 2 trials per assessment and fit analysis of covariance (ANCOVA) models adjusting for the 3 variables in the minimization algorithm (sex, age and pain duration). For the sudden load variables, we fit linear mixed models to account for the correlation among the 6 trials per assessment for each participant adjusting for sex, age, pain duration, BMI and the pulling point distance above L3.

We estimated the within-group changes and the differences between the control group vs. both the HVLA-SM and the LVVA-SM groups based on the models described above. Adjusted mean within group-changes and between-group differences are reported with their respective 95% confidence intervals. Statistical significance was set at 0.05. Data analyses were performed using SAS System for Windows (Release 9.2; SAS Institute Inc., Cary,

NC). We used an intention-to-treat approach in which participants were analyzed according to their original treatment group assignment.

RESULTS

From January 2009 to March 2011, a total of 1,688 potential participants were screened using a computer-assisted telephone interview (Fig. 2). Of the 736 participants screened in-person, 308 were excluded at BL1, and 201 either prior to or during BL2. A total of 221 participants were randomly allocated to three groups and 211 participants completed the 2-week assessment (Fig. 2). Table 1 summarizes participant demographic and baseline low back pain characteristics. While the study was intended to include LBP participants of all durations, only 4 (<5%) reported sub-acute LBP and none reported acute LBP. Approximately 90% of participants reported LBP duration for more than 1 year. A minimum level of pain (i.e. NRS 4 at either phone screen or the first baseline visit and 2 at phone screen and both baseline visits) was required in recruitment, resulting in a sample of participants with moderate pain (mean NRS 5.5, SD 1.7).

The adjusted within-group mean changes from baseline to the two follow-up time points for postural sway measurements are summarized in Table 2 and adjusted between-group mean differences are summarized in Table 3. The only statistically significant changes from baseline were mean ML excursion on the soft surface after 2 weeks for both SM groups. However, these changes were not significantly different from those found in the sham group. The LVVA-SM group also showed an immediate pre-post change at TV1 on the soft surface that was statistically significantly greater than that found in the sham control group.

The adjusted within-group mean changes from baseline to the two follow-up time points for the response to sudden load measurements are summarized in Table 4 and the adjusted between-group mean differences are summarized in Table 5. The mean changes in maximum anterior COP excursion during the sudden load from baseline to both time points were statistically significant for all 3 groups, but were very small. Many of the measurements had statistically significant mean changes from baseline in the HVLA-SM group, but only the percent normalized peak muscle response on the left side changed more than 25%. None of the mean changes were significantly different between the SM and sham control groups.

There were no serious or severe adverse events reported and quality control assessments revealed no treatment deviations with respect to group assignment. We were very proactive in engaging participants to report any symptoms they experienced and in documenting adverse events related and unrelated to study interventions. Adverse events were defined as “any untoward medical occurrence that may present itself during the conduct of the study and which may or may not have a causal relationship with the study procedures.” Over 1056 clinical evaluations of participants by study clinicians, 188 events were rated as mild and possibly, probably, or definitely related to treatment (63), biomechanical test procedures (115) or the combination of both (10). Mild events resolved within 48 hours and were characterized by joint/muscle stiffness or increased musculoskeletal pain. Moderate events (7) were characterized by joint /muscle stiffness or increased musculoskeletal pain that

resulted in some change in activity, necessitated self-care, or lasted longer than 48 hours. Of these, 3 were attributed as possibly, probably, or definitely related to biomechanical testing and 4 to treatment.

DISCUSSION

The majority of SM trials for LBP use patient-centered clinical variables such as pain and disability as primary outcome measures (Goertz et al., 2012). This study was an attempt to utilize sensorimotor function evaluation procedures (i.e. postural sway and response to sudden load) and gain insight regarding potential physiological mechanisms of SM. We applied HVLA-SM and LVVA-SM, which possess distinctly different loading characteristics, to stimulate the sensorimotor system. Overall, the findings from this study do not support the postulation that SM influences the sensorimotor function in terms of postural sway and response to sudden load, regardless of the SM loading characteristics.

Our study findings on postural sway are consistent with a recent study showing that postural sway may not change after short-term treatment. Maribo et al. (2012) evaluated 96 LBP patients referred from general practitioners. The authors reported that the reassessment of postural sway after 12 weeks showed little change. On the other hand, Ruhe et al. (2012) reported that patients with improvement in pain greater than an NRS level of 4 demonstrated a significant decrease in postural sway when compared to those who reported a change of less than 1 point.

Regarding response to sudden load, results from the current study differ from those found in previous studies. Magnusson et al. (1996) applied a 2-week specific rehabilitation program on chronic LBP patients that concentrated on postural training and found that LBP patients exhibit a shorter back muscle response time and smaller response amplitude following rehabilitation and that these values tend to approach those obtained from healthy controls. Wilder et al. (1996) applied a 2-week general rehabilitation program consisting of physical conditioning and cognitive-behavioral therapy on chronic LBP patients and found similar results in muscle response to sudden load. It is noteworthy that the control group in the current study consisted of LBP patients receiving sham treatment rather than healthy individuals. Additionally, sample size was far greater in the current study. Further, the rehabilitation programs used in these previous studies had more targeted components towards the neuromuscular system either in postural training or physical conditioning, while SM used in the current study was arguably less specific. Leinonen et al. (2003) also reported that impaired paraspinal muscle responses to sudden loading appeared to recover 3 months after discectomy. While the discectomy procedure may not affect the neuromuscular system, the study did not report if patients went through any additional treatment or rehabilitation during the 3-month post-surgical period. More importantly, the study involved no control. Methodological differences may in part explain the discrepancy in muscle response to sudden load between the current and previous studies. Besides paraspinal muscle activity, the maximum anterior movement of COP was obtained in response to sudden load. The lack of between-group difference in the maximum COP movement corroborates with the negative findings in EMG.

There are limitations in this study. First, it is possible that the methods applied to analyze postural sway, i.e. mean AP and ML excursions and mean sway speed, are not sensitive enough to detect important sensorimotor changes. Other methods utilizing more advanced time-domain and frequency domain analyses may need to be considered (Hur et al., 2012; Prieto et al., 1996). More rigorous methodological approaches such as including kinematic measures of joint movement at the ankle, knee, and hip may also help (Mok et al., 2004). Second, many participants were excluded due to concerns that their condition would be worsened by the testing procedures, potentially skewing the study population to those with less impaired balance control. Third, our sample reported pain severity levels comparable to other groups of patients with chronic LBP seeking care from primary care and chiropractic providers (Hass et al., 2003; Nyiendo et al., 2001; Scheele et al., 2014). However, our sample was also characterized with relatively low disability compared to the same patient groups, which could limit generalizability. Finally, it is also possible that a longer course of manipulative treatment is necessary to demonstrate changes in sensorimotor function within the population included in this study.

CONCLUSIONS

In this biomechanically-oriented study of male and female participants age 21-65 with moderate, primarily chronic LBP, no significant differences in changes of postural sway and response to sudden load parameters were observed following 2-week SM treatments when compared to the sham control. We conclude that short-term SM does not appear to affect the sensorimotor functions monitored in this study.

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Highlights

- Two distinct types of spinal manipulation were applied to treat low back pain.
- Sensorimotor function was studied using postural sway and response to sudden load.
- Two weeks of spinal manipulation did not affect these two sensorimotor functions.
- The neurophysiological effects of spinal manipulation remain unclear.

Fig. 1. Illustration of sudden load setup. The end stop describes the position of the weight when it is held by the participants. The drop height describes the position at which the weight is dropped.

Fig. 2.
Study flow CONSORT. HVLA-SM: high-velocity, low-amplitude spinal manipulation;
LVVA-SM: low-velocity, variable-amplitude spinal manipulation; NRS: numerical rating
scale; and QTF: Quebec Task Force on classification of spinal disorders.

Table 1

Participant demographic and baseline health characteristics.

		HVLA-SM (n = 74)		LVVA-SM (n = 74)		Sham (n = 73)	
	Values	n	%	n	%	n	%
Sex	Male	40	54	40	54	40	55
	Female	34	46	34	46	33	45
Race	African American	6	8	5	7	5	7
	White	67	91	63	85	67	92
Ethnicity	Hispanic or Latino	3	4	8	11	2	3
Age (years) *		44.1	(10.6)	44.5	(10.2)	44.4	(10.5)
BMI *		29.1	(5.7)	30.0	(7.1)	29.2	(5.1)
physical activity	Light	12	16	11	15	11	15
	Moderate	36	49	38	51	34	47
	Heavy/Very heavy	12	17	7	10	14	19
Currently smoke	Yes	17	23	14	19	16	22
QTF	1- Pain without radiation	56	75	50	67.6	51	69.9
	2- Pain with radiation to proximal extremity	14	18.9	21	28.4	16	21.9
	3- Pain with radiation to distal extremity	4	5.4	3	4.1	6	8.2
Duration of LBP	> 1 year	67	90.5	67	90.5	65	89
LBP NRS, past 24 hours. *		5.4	(1.6)	5.8	(1.6)	5.3	(1.8)
RMDQ *		4.7	(3.1)	6.6	(4.3)	5.6	(4.0)
FABQ-Work *		11.9	(10.0)	11.7	(8.3)	11.0	(9.5)
FABQ-Physical Function *		12.3	(6.2)	12.6	(4.9)	11.7	(5.7)
SF36 - Physical Component		42.8	(7.8)	42.2	(8.2)	43.3	(7.5)
Summary *							
SF36 - Mental Component		52.2	(8.1)	49.3	(9.6)	50.6	(11.3)
Summary *							
LBP Bothersomeness	Not at all bothersome	0	0	0	0	1	1.4
	Slightly bothersome	6	8.1	3	4.1	7	9.6
	Moderately bothersome	38	51.4	25	33.8	31	42.5
	Very bothersome	22	29.7	38	51.4	29	39.7
	Extremely bothersome	8	10.8	8	10.8	5	6.9

Any value not adding to 100% indicates missing data. HVLA-SM: high-velocity, low-amplitude spinal manipulation; LVVA-SM: low-velocity, variable-amplitude spinal manipulation; BMI – body mass index; QTF – Quebec Task Force on classification of spinal disorders; LBP – low back pain; NRS – numerical rating scale (0 - 10); RMDQ: Roland-Morris disability questionnaire (0 – 24); FABQ: fear-avoidance belief questionnaire

* in mean and (SD).

Table 2

Descriptive statistics of postural sway variables at baseline and adjusted mean within-group changes (95% confidence interval) immediately pre-to-post treatment in the first visit and over two weeks of treatment.

	Baseline		Immediate Pre-to-post *		BL-to-2 week *	
	Mean	SD	Adj. Mean	95% CI	Adj. Mean	95% CI
HVLA-SM						
AP excursion - Hard (mm)	3.65	1.67	0.46	(-0.14, 1.05)	-0.13	(-0.60, 0.35)
ML excursion - Hard (mm)	1.18	0.66	0.05	(-0.13, 0.23)	-0.06	(-0.25, 0.14)
AP excursion - Soft (mm)	5.18	1.49	0.48	(-0.13, 1.10)	-0.03	(-0.63, 0.56)
ML excursion - Soft (mm)	2.94	1.46	0.33	(-0.13, 0.79)	0.53	(0.09, 0.98)
Sway speed - Hard (mm/s)	10.77	4.10	0.32	(-0.53, 1.17)	0.02	(-1.14, 1.18)
Sway Speed - Soft (mm/s)	20.53	8.46	-0.65	(-2.26, 0.96)	-0.40	(-2.53, 1.74)
LVVA-SM						
AP excursion - Hard (mm)	4.06	1.25	0.46	(-0.15, 1.06)	-0.26	(-0.75, 0.22)
ML excursion - Hard (mm)	1.24	0.57	0.05	(-0.13, 0.23)	-0.06	(-0.26, 0.14)
AP excursion - Soft (mm)	5.35	1.31	0.28	(-0.36, 0.92)	0.02	(-0.58, 0.63)
ML excursion - Soft (mm)	2.86	1.42	0.41	(-0.07, 0.89)	0.51	(0.06, 0.96)
Sway speed - Hard (mm/s)	11.55	4.41	-0.14	(-1.01, 0.72)	-0.11	(-1.29, 1.07)
Sway Speed - Soft (mm/s)	21.03	8.94	-1.18	(-2.85, 0.49)	-1.71	(-3.87, 0.46)
Sham						
AP excursion - Hard (mm)	3.73	1.38	0.44	(-0.16, 1.04)	-0.18	(-0.66, 0.30)
ML excursion - Hard (mm)	1.25	0.70	-0.04	(-0.22, 0.14)	-0.11	(-0.31, 0.09)
AP excursion - Soft (mm)	5.44	1.43	0.09	(-0.53, 0.71)	-0.26	(-0.87, 0.34)
ML excursion - Soft (mm)	3.09	1.56	-0.02	(-0.49, 0.45)	0.2	(-0.25, 0.64)
Sway speed - Hard (mm/s)	11.53	5.04	-0.27	(-1.13, 0.58)	-0.23	(-1.40, 0.94)
Sway Speed - Soft (mm/s)	21.92	9.47	-1.48	(-3.11, 0.15)	-0.94	(-3.10, 1.21)

* Based on the ANCOVA model adjusted for sex, age and pain duration. HVLA-SM: high-velocity, low-amplitude spinal manipulation; LVVA-SM: low-velocity, variable-amplitude spinal manipulation; AP – anterior-posterior; ML – medial-lateral.

Table 3

Adjusted mean between-group postural sway changes (95% confidence interval) immediately following the first treatment and following 2 weeks of treatment.

	HVLA-SM vs. Sham		LVVA-SM vs. Sham	
	Adj. Mean	95% CI	Adj. Mean	95% CI
Immediate change in treatment visit 1				
AP excursion - Hard (mm)	0.02	(-0.47, 0.52)	0.02	(-0.48, 0.51)
ML excursion - Hard (mm)	0.09	(-0.06, 0.23)	0.09	(-0.06, 0.24)
AP excursion - Soft (mm)	0.39	(-0.12, 0.89)	0.20	(-0.31, 0.71)
ML excursion - Soft (mm)	0.35	(-0.03, 0.73)	0.44	(0.06, 0.82)
Sway speed - Hard (mm/s)	0.50	(-0.26, 1.27)	0.03	(-0.78, 0.74)
Sway Speed - Soft (mm/s)	0.74	(-0.66, 2.14)	0.29	(-1.12, 1.70)
Change over two weeks of treatment				
AP excursion - Hard (mm)	0.05	(-0.35, 0.46)	-0.07	(-0.47, 0.34)
ML excursion - Hard (mm)	0.06	(-0.11, 0.22)	0.07	(-0.10, 0.23)
AP excursion - Soft (mm)	0.23	(-0.27, 0.73)	0.28	(-0.22, 0.78)
ML excursion - Soft (mm)	0.33	(-0.03, 0.71)	0.34	(-0.03, 0.71)
Sway speed - Hard (mm/s)	0.03	(-0.73, 0.80)	-0.31	(-1.08, 0.45)
Sway Speed - Soft (mm/s)	0.52	(-1.25, 2.28)	-1.00	(-2.77, 0.76)

Based on the ANCOVA model adjusted for sex, age and pain duration. HVLA-SM: high-velocity, low-amplitude spinal manipulation; LVVA-SM: low-velocity, variable-amplitude spinal manipulation; AP – anterior-posterior; ML – medial-lateral; * – $p < 0.05$.

Table 4

Descriptive statistics of response to sudden load variables at baseline and adjusted mean within-group changes (95% confidence interval) of the immediate pre-to-post treatment changes in the first visit and the changes over two weeks of treatment.

	Baseline		Immediate Pre-to-post [*]		BL-to-2 week [*]	
	Mean	SD	Adj. Mean	95% CI	Adj. Mean	95% CI
HVLA-SM						
Max Ant. COP excursion in SL (mm)	67.4	14.6	-2.5	(-4.1, -0.9)	-4.7	(-7.9, -1.5)
Norm. Peak muscle response - L (%)	38.0	47.0	-10.3	(-17.8, -2.8)	-11.4	(-21.7, -1.2)
Norm. Peak muscle response - R (%)	21.4	22.2	-3.9	(-8.9, 1.0)	3.4	(-3.0, 9.8)
Response start time - L (ms)	119	95	-21.4	(-41.2, -1.7)	-18.3	(-54.2, 17.7)
Response start time - R (ms)	102	47	-17.4	(-34.0, -0.9)	-5.9	(-25.1, 13.2)
Peak response time - L (ms)	165	95	-20.7	(-37.8, -3.6)	-14.6	(-49.6, 20.3)
Peak response time - R (ms)	149	52	-14.1	(-26.0, -2.3)	-18.1	(-30.5, -5.8)
LVVA-SM						
Max Ant. COP excursion in SL (mm)	69.2	15.4	-3.4	(-5.1, 1.7)	-4.1	(-7.4, -0.7)
Norm. Peak muscle response - L (%)	27.5	29.9	-4.1	(-11.8, 3.6)	5.2	(-5.0, 15.4)
Norm. Peak muscle response - R (%)	23.9	20.4	-3.6	(-8.8, 1.6)	1.4	(-5.2, 8.0)
Response start time - L (ms)	108	86	-6.1	(-29.1, 16.8)	-42.8	(-82.4, -3.2)
Response start time - R (ms)	129	135	-13.4	(-34.0, 7.2)	-17.1	(-38.4, 4.3)
Peak response time - L (ms)	153	92	0.9	(-19.0, 20.9)	-25.2	(-63.7, 13.3)
Peak response time - R (ms)	163	66	-5.6	(-20.4, 9.0)	-2.2	(-15.9, 11.6)
Sham						
Max Ant. COP excursion in SL (mm)	74.9	17.7	-4.6	(-6.3, -2.9)	-5.8	(-9.2, -2.4)
Norm. Peak muscle response - L (%)	22.0	21.8	-0.8	(-9.0, 7.5)	0.1	(-10.0, 10.2)
Norm. Peak muscle response - R (%)	26.8	19.1	-1.5	(-6.8, 3.7)	-1.2	(-7.8, 5.3)
Response start time - L (ms)	115	63	4.8	(-17.5, 25.7)	-19.8	(-53.0, 13.3)
Response start time - R (ms)	114	129	-11.7	(-28.8, 5.3)	-20.8	(-38.9, -2.7)
Peak response time - L (ms)	164	70	0.4	(-18.3, 19.2)	-28.5	(-60.7, 3.7)
Peak response time - R (ms)	145	60	2.9	(-9.3, 15.0)	1.9	(-9.9, 13.8)

* Based on the mixed-model adjusted age, sex, pain duration, BMI, and the pulling point distance above L3. HVLA-SM: high-velocity, low-amplitude spinal manipulation; LVVA-SM: low-velocity, variable-amplitude spinal manipulation; Ant. COP: anterior movement in center of pressure; L – left side erector spinae; R – right side erector spinae.

Table 5

Adjusted mean between-group response to sudden load changes (95% confidence interval) immediately following the first treatment and following 2 weeks of treatment.

	HVLA-SM vs. Sham		LVVA-SM vs. Sham	
	Adj. Mean	95% CI	Adj. Mean	95% CI
Immediate change in treatment visit 1				
Max Ant. COP excursion in SL (mm)	2.1	(-0.2, 4.4)	1.2	(-1.1, 3.6)
Norm. Peak muscle response - L (%)	-9.6	(-20.6, 1.5)	-3.3	(-14.6, 7.9)
Norm. Peak muscle response - R (%)	-2.4	(-9.6, 4.9)	-2.0	(-9.4, 5.4)
Response start time - L (ms)	-25.5	(-55.0, 3.9)	-10.2	(-41.7, 21.3)
Response start time - R (ms)	-5.7	(-29.6, 18.2)	-1.7	(-28.4, 25.0)
Peak response time - L (ms)	-21.1	(-46.6, 4.4)	0.5	(-26.8, 27.9)
Peak response time - R (ms)	-17.0	(-34.1, 0.1)	-8.5	(-27.6, 10.5)
Change over two weeks of treatment				
Max Ant. COP excursion in SL (mm)	1.1	(-3.5, 5.7)	1.7	(-3.0, 6.5)
Norm. Peak muscle response - L (%)	-11.5	(-25.9, 2.9)	5.1	(-9.3, 19.6)
Norm. Peak muscle response - R (%)	4.6	(-4.6, 13.8)	2.6	(-6.6, 11.9)
Response start time - L (ms)	1.6	(-47.2, 50.4)	-23.0	(-74.8, 28.8)
Response start time - R (ms)	14.9	(-11.6, 41.3)	3.7	(-24.3, 31.7)
Peak response time - L (ms)	13.9	(-33.5, 61.3)	3.3	(-47.0, 53.6)
Peak response time - R (ms)	-20.1	(-37.4, 2.8)	-4.1	(-22.3, 4.1)

Based on the mixed-model adjusted age, sex, pain duration, BMI, and the pulling point distance above L3. HVLA-SM: high-velocity, low-amplitude spinal manipulation; LVVA-SM: low-velocity, variable-amplitude spinal manipulation; Ant. COP: anterior movement in center of pressure; L – left side erector spinae; R – right side erector spinae.