IMMEDIATE IMPACT OF SPINAL MANIPULATION ON STANDING CENTER OF PRESSURE OF CHIROPRACTIC COLLEGE STUDENTS WITH COMBINED NECK AND LOW BACK PAIN.

Author

Dr John Ward

Texas Chiropractic College - Faculty

Email: JWard@txchiro.edu

Abstract

Objective: Determine if spinal manipulation positively impacted standing center of pressure of college students with combined neck and low back pain.

Methods: At baseline 97 participants with combined neck (2.8 ± 1.3 Numeric Rating Scale/NRS, mean ± SD) and low back (3.1 ± 1.5 NRS) pain had their standing eyes-closed balance assessed for 30 seconds on a force plate. Participants then stepped off the force plate and received spinal manipulation to their cervical and lumbar spine areas of greatest pain. Afterwards, participants had their balance reassessed for 30 seconds. Anterior-to-posterior and medial-to-lateral center of pressure (COP) mean amplitude and range were the dependent variables compared pre to post utilizing a paired samples *t*-test.

Results: There was no statistically significant immediate change in center of pressure parameters assessed in response to spinal manipulation for individuals with combined neck (2.8 ± 1.3 NRS, 15.3 ± 4.9 months) and low back (3.1 ± 1.5 NRS, 20.4 ± 8.8 months) pain. However, sub-analysis of 32 individuals with moderate combined neck (4.1 ± 1.2 NRS, 32.1 ± 6.6 months) and low back (4.6 ± 1.3 NRS, 31.8 ± 12.5 months) pain demonstrated small positive improvements in medial-to-lateral COP mean amplitude and range.

Conclusion: Spinal manipulation did not impact immediate COP amplitude or range of chiropractic college students with low levels of combined neck and low back pain.

Key MeSH Indexing Terms: Spinal manipulation; neck pain; low back pain; kinesthesis; core stability; proprioception

INTRODUCTION

Balance is a fundamental attribute necessary to engage in activities of daily living. It involves the appropriate integration of vestibular, visual, and somatosensory proprioceptive information.[1] Balance is negatively affected by neck and low back pain,[2-5] in addition to other deleterious effects seen with spine pain on quality of life, work productivity, and increased medical expenditures.[6-8] When balance is impaired a person will be unable to maintain their body orientation in space[9] and this could lead to possible falls and greater risk of injury.[10-13]

Neck pain affects 22-70% of the population[14-15] and causes balance impairments. It is unclear if these impairments are due to abnormal cervical afferent proprioceptive input,[16-17] direct nociceptive input triggering guarding actions upon motion,[16-17] kinesiophobia,[18-19] poor postural control,[20-22] or reduced cervical range of motion.[23-24] Impaired cervical afferent input is believed to result in imprecise estimation of body position in space, leading to increased center of pressure shifts to maintain stability.[25-28] In particular, the upper cervical region muscles have been found to have a greater density of muscle spindles than the lower cervical spine associated musculature.[29-30] Nociceptive input to cervical facet joints and regional muscles, is believed to alter sensitivity of muscle spindles due to pain inducing protective localized muscle guarding which impairs correct body positioning in space.[31-32] This type of altered input can be caused by direct trauma, osteoarthritis, poor posture, joint strain, ligamentous sprain, and other associated conditions leading to the subsequent release of inflammatory mediators.[33]

Patients with low back pain have impaired motor control and that has been shown to negatively affect their balance.[3-5,34-35] When individuals suffer from low back pain, similar to neck pain, it can result in altered muscle activation patterns to avoid or prevent further localized pain.[36-37] Low back pain has additionally been seen to be associated with compromised sensory and motor factors affecting the neuromuscular junction which can make maintaining balance difficult.[38-39]

Spinal manipulation can decrease some forms of spine pain[40] and is recommended as a first-line treatment for many causes of neck and low back pain.[41-44] The impact of lowering spine pain on balance parameters should be studied further because there is a paucity of research on the immediate and multi-week relationship between spinal manipulation for spine pain and balance.[45-49] A recent pilot study involving 19 individuals with neck pain (2.4 $\pm$ 1.3 NRS) demonstrated that cervical spine manipulation improved lower limb relative reach distance in the short-term by 3.21% during a standing Y-balance test,[50] but it is unclear if that change was clinically relevant. Furthermore, Vining *et al* found small improvements (p = 0.01) in the number of seconds 53 low back pain patients could maintain single-leg balance with their eyes-closed in response to lumbar spine manipulation and additional forms of chiropractic care (education, self-management advice, and extremity adjustments when warranted).[51] Likewise, Goertz *et al* found small improvements in balance parameters in response to spinal manipulation involving 72 patients with low back pain.[52] However, not all studies have shown that spinal manipulation improves balance as was seen in the article by Smith *et al* on spinal stenosis low back pain patients[53] or the paper by Hawk *et al* on older adults.[54] One issue with these findings is that both of the aforementioned studies were underpowered with 12 and 14 participants, respectively. They also examined different patient populations, thus drawing conclusions should be done with this in mind. This is an ongoing issue on research on this topic, both for and against an association between spinal manipulation and balance. The reasons for the differing findings in these studies needs to be elucidated through further research with larger sample sizes to come to a conclusive consensus on if spinal manipulation for spine pain could positively impact.

balance attributes of patients. Additionally, an effort needs to be made to determine which region of the spine, cervical, lumbar, or both would be most impacted in terms of balance parameters by spinal manipulation. Further, the interrelationship between regional proprioception and the visual system on balance needs to be elucidated further to determine if a positive change in one system causes compensatory changes in the other.

Research suggests individuals with combined neck and low back pain may be more likely to have impairments in balance than having either condition in isolation alone.[55] Jorgensen *et al* found that individuals with both neck and low back pain demonstrated the greatest impairments in balance compared to individuals with just neck or low back pain alone.[55] Having both neck and low back pain at the same time is not uncommon. Sinnott *et al,* described how, "at any given time, 15% to 20% of adults will report having back pain and 10-20% will report neck pain symptoms".[56-58] Thus, the intent of this exploratory study was to engage in cervical and lumbar spinal manipulation for individuals with neck and low back pain in both regions to determine if it may offer a positive impact on short-term balance parameters. Determining this impact could aid in the development of clinical prediction rules to identify optimal characteristics of patients that would benefit from spinal manipulation.[59-60]

The study objective was: Determine if spinal manipulation to the cervical and lumbar spine of individuals with neck and low back pain improved their static standing balance. The hypothesis was: H1: Spinal manipulation to the cervical and lumbar spine of individuals with neck and low back pain would lower their pain level slightly and/or positively improve proprioception or supraspinal influences resulting in a positive small impact on short-term balance attributes.

METHODS

This within-subjects design was reviewed and approved by the Texas Chiropractic College's Institutional Review Board for human subjects in accordance with the Declaration of Helsinki (project#2023_06_29_V1). Chiropractic college students read and signed the informed consent and were then screened for study inclusion and exclusion criteria as shown in the study flow diagram (figure 1). Study inclusion criteria were: be a chiropractic college student with both neck and low back pain of at least 1 on a numeric rating scale (NRS) at each regional location. Study exclusion criteria were: pregnant, spine or lower limb surgery, sprained ankle, Meniere's disease, vestibular pathologies, any condition that would make standing still excessively difficult, fractures, dislocations, bone cancer, spinal cord tumor, joint infection, stroke, osteoporosis, ligamentous rupture, ankylosing spondylitis, rheumatoid arthritis, spine surgery, anticoagulant therapy, or any known contraindication to spinal manipulation. Next participants had their gender, height, weight, age, neck pain NRS, neck pain duration, low back pain NRS, and low back pain duration recorded (table 1). Following this, participants were instructed to remove their shoes and stand on a force plate with their feet shoulder-width apart eyes-closed as shown in figure 2 for their 30-second balance assessment. Then for the intervention phase of the study participants received both cervical and lumbar spine manipulation (figure 3) to the area of greatest pain in each of those 2 localized regions. After the intervention, participants performed a 30-second balance post-test identical to their baseline test. This study took place from May

2023 to May 2024 between 7-8 AM in a quiet biomechanics research lab room with the ambient room temperature set at 76°F. Data collection took approximately 20 minutes per participant and occurred during one session per participant. This study utilized a convenience sample and did not follow an *a priori* power analysis.

Figure 1. Study flow diagram. SMT= spinal manipulative therapy.

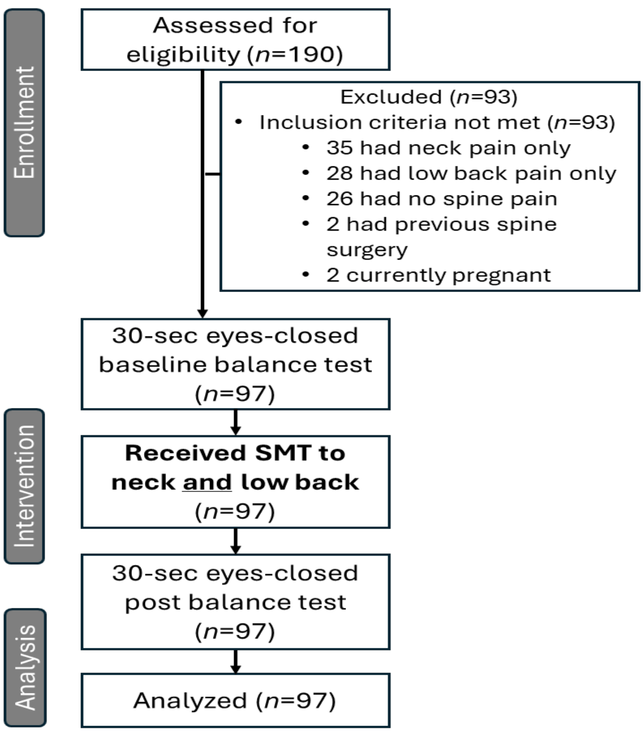
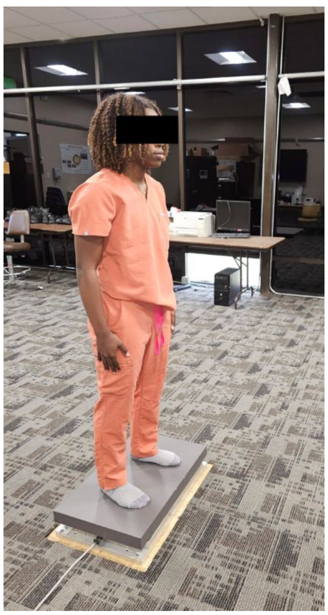


Table 1. Properties of the study participants. Based on BMI scales the average participant would be classified as being overweight. Moderate neck and low back pain was defined as having combined neck and low back pain between 8-14 on the NRS (e.g., neck pain 3 and low back pain 6, neck pain 5 and low back pain 3, etc.). The moderate neck and low back pain subgroup was a sub-analysis from the overall spine pain group of participants that fit the criteria of moderate combined neck and low back pain. Data listed as mean ± SD aside from sex and age range. NRS = numeric rating scale, n/a = not applicable.

	General neck and low back pain group	Moderate neck and low back pain subgroup
Sex (m/f)	43/54	10/22
Age (y)	27.5 ± 5.1	26.6 ± 2.8

Mass (kg)	81.6 ± 18.8	81.5 ± 20.7
Height (m)	1.71 ± 0.09	1.69 ± 0.08
Body Mass Index (kg/m^2)	27.8 ± 5.1	28.3 ± 6.1
Neck pain NRS	2.8 ± 1.3	4.1 ± 1.2
Months of neck pain	15.3 ± 4.9	32.1 ± 6.6
Low back pain NRS	3.1 ± 1.5	4.6 ± 1.3
Months of low back pain	20.4 ± 8.8	31.8 ± 12.5
Age range (yrs)	20-41	21-33

Figure 2. Image of a participant having their balance analyzed for 30 seconds eyes-closed on a force plate. Participants removed their shoes and stood with their feet shoulder-width apart and their arms at their side as still as possible.



Balance assessment

A 40 cm x 60 cm stable Bertec 4060-NC force plate (Bertec Corporation, Columbus, Ohio, USA) was used to measure balance parameters during the standing balance test. The gain was set to 1 and a data sampling rate at 100 Hz. Participant balance was measured approximately 1-minute post spinal manipulation. Participant data was recorded for 30-seconds with their eyes-closed. Having participants close their eyes in balance studies has been seen to help reduce compensatory ocular-based balance adaptations and stress the vestibular and proprioceptive systems more.[61] Participants were instructed to stand on the center of the force plate as still as possible until told to stop. To stress their cognitive balance systems further, as has been done in previous balance studies,[51] participants were asked to engage in a "dual-tasking" activity. This was performed by having participants count aloud backwards by 7s from 500 (e.g., 500, 493, 486, 479…). Displacement of center of pressure in the medial-to-lateral and anterior-to-posterior directions were recorded. Raw force plate data were recorded through the Vicon Nexus software system (Vicon, Yarnton, Oxford, UK) on a lab computer. The data was analyzed 10 seconds

after the start of signal acquisition, to account for any initial participant center of pressure stabilization as performed in other balance assessment studies.[35] The balance-related variables

measured in this study were center of pressure range and mean center of pressure amplitude as described in table 2.[62] A spotter was near participants during their balance test for safety reasons in case they were to fall.

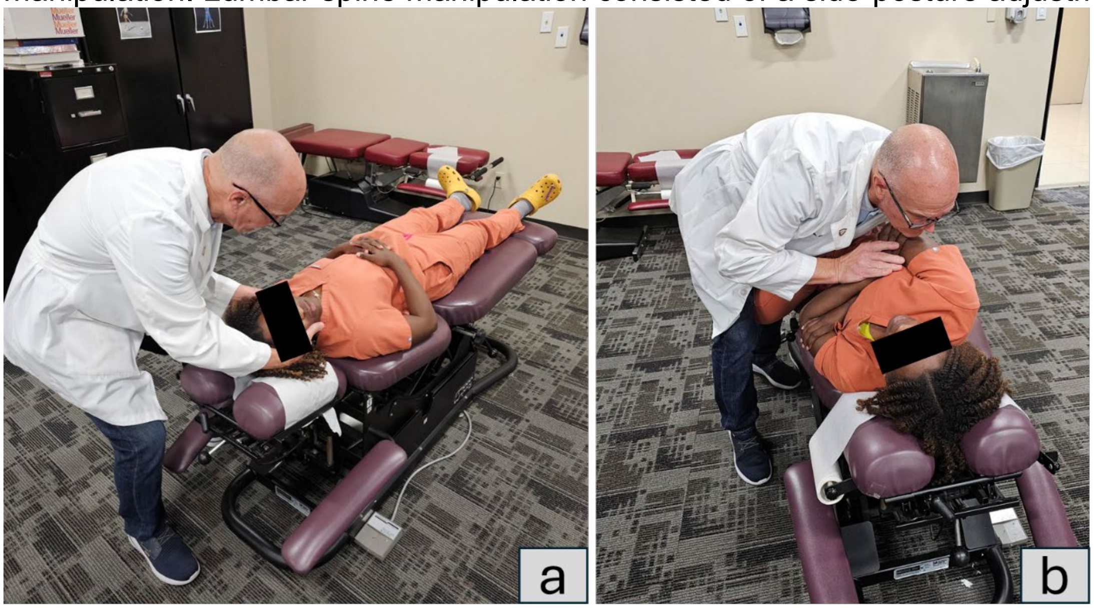
Table 2. Force plate balance properties analyzed.

Property	Description
Mean AP COP amplitude	Mean anterior-to-posterior center of pressure amplitude.
Mean ML COP amplitude	Mean medial-to-lateral center of pressure amplitude.
AP COP range	Anterior-to-posterior center of pressure maximal range.
ML COP range	Medial-to-lateral center of pressure maximal range.

Spinal manipulative therapy

Spinal manipulation was performed by a state-licensed chiropractic doctor with 31 years teaching experience at a chiropractic college on an Ergostyle 2000 adjusting table (Chattanooga Group Inc, Hixson, TX, USA). Prior to spinal manipulation participants would point to the area of greatest spine pain in their cervical and lumbar regions. This was followed by the chiropractic doctor palpating the affected areas. The location of spinal manipulation was the site of greatest spine pain upon palpation of regional vertebral segments. Cervical spine manipulation consisted of a diversified supine index pillar push manipulation as described by Bergman and Peterson while the patient was supine on the adjusting table as shown in figure 3a.[63] The spinal manipulative therapy used a high-velocity low-amplitude thrust in a posterior-to-anterior, medial-to-lateral, and superior-to-inferior direction. Lumbar spine manipulation consisted of a side-posture adjustment as described by Bergman and Peterson with the patient side-lying on the adjusting table as shown in figure 3b.[63] The spinal manipulative therapy used a high-velocity low-amplitude thrust in a posterior-to-anterior and inferior-to-superior direction. The chiropractic doctor performing the intervention underwent NIH Human subjects training prior to the beginning of the study and has experience performing spinal manipulation in previous published research articles. Researchers did not ask participants their spine pain NRS score after spinal manipulation because it was felt they would feel compelled to state a lower number no matter how they truly felt.

Figure 3. Image of a study participant receiving cervical (3a) and lumbar (3b) spinal manipulation. Cervical spine manipulation consisted of a diversified supine index pillar push manipulation. Lumbar spine manipulation consisted of a side-posture adjustment.



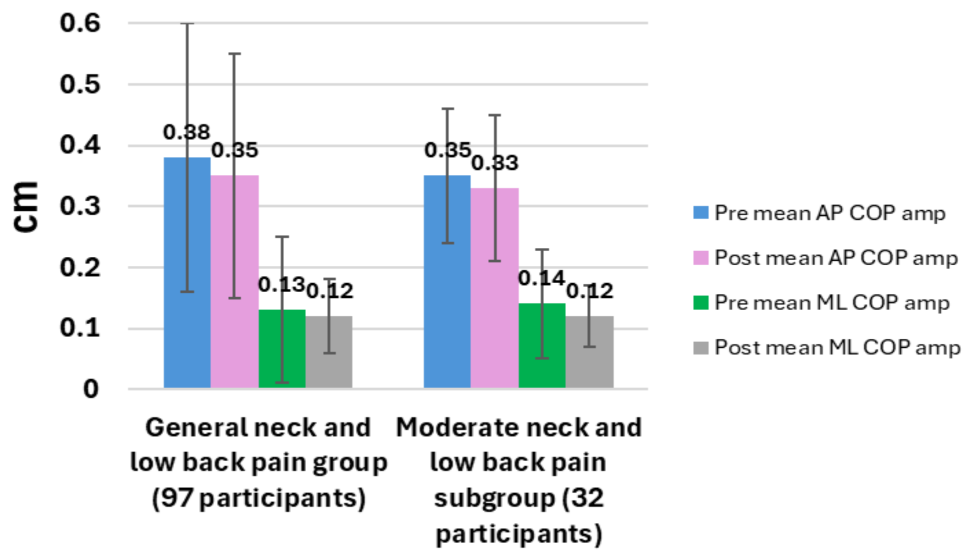
Statistical analysis

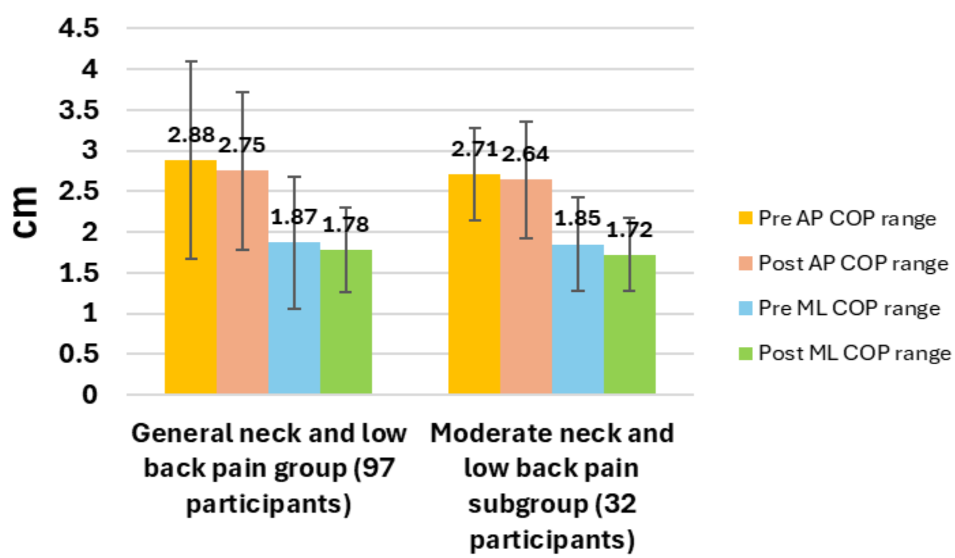
Force plate data was exported from the VICON system as .csv files and then x and y center of pressure attributes were transferred to an Excel worksheet (Microsoft Corporation, Redmond, WA, USA) for extrapolation of balance parameters that were analyzed in this study. Study data were analyzed with a paired samples *t*-test using SPSS version 20.0 (IBM, Armonk, NY, USA). Since 4 comparisons were made with *t*-tests a Bonferroni correction was used. Results were reported as mean $\pm$ standard deviation (SD) unless otherwise specified. The alpha level of $p \leq 0.0125$ was considered statistically significant for the 4 within-group measured center of pressure variables. Low and high 95% confidence intervals are reported for the *t*-test results.

RESULTS

Table 1 demonstrates baseline participant data in the 97-participant general analysis group and the 32-participant moderate neck and low back pain sub-analysis group. No adverse events were noted in the study in response to spinal manipulative therapy. The most commonly adjusted cervical segment was C2 (55.8% of the time) and in the lumbar spine L4 (68.3% of the time). Figure 4 demonstrates data trends. No statistically significant changes were observed in the balance parameters measured for the general 97 participant neck and low back pain group. Pre to post paired samples *t*-test *p*-values for the general neck and low back pain group were as follows: mean AP COP amplitude $p = 0.100$, mean ML COP amplitude $p = 0.220$, AP COP range $p = 0.160$, and ML COP range $p = 0.232$. For sub-analysis moderate combined neck and low back pain was defined as total pain between 8-14 on the NRS (e.g., neck pain = 5 NRS, low back pain = 6 NRS, combined = 11 NRS). Low combined neck and low back pain was defined as total pain between 2-7 on the NRS. Sub-analysis of 32 individuals with moderate neck (4.1 $\pm$ 1.2 NRS) and low back (4.6 $\pm$ 1.3 NRS) pain demonstrated positive improvements in medial-to-lateral COP mean amplitude (0.14 + 0.09 cm to 0.12 + 0.05 cm, p = 0.037, d = 0.39) and range (1.85 + 0.58 cm to 1.72 + 0.45 cm, p = 0.048, d = 0.36) and the p values were approaching statistical significance, but did not reach it. Both Cohen's d effect sizes were small. Pre to post paired samples t-test p-values for the moderate neck and low back pain subgroup were p = 0.181 for mean AP COP amplitude and p = 0.540 for AP COP range.

Figure 4. Force plate balance properties measured. Data listed as mean + SD. There was no statistically significant difference seen in response to spinal manipulation in the general neck and low back pain group. ML COP range and mean ML COP amplitude decreased by post-test in the sub-analysis of individuals with moderate combined neck and low back pain, but it did not reach statistical significance. ML = medial-to-lateral, AP = anterior-to-posterior, amp = amplitude, and COP = center of pressure.





For the general neck and low back pain group the difference between baseline to post-test mean AP COP amplitude was .03: 95% CI [-.005, .056]. The difference between baseline to post-test mean ML COP amplitude was .01: 95% CI [-.008, .033]. The difference between baseline to post-test AP COP range was .13: 95% CI [-.050, .299]. The difference between baseline to post-test mean ML COP amplitude was .09: 95% CI [-.057, .231]. For the moderate neck and low back pain 32-participant group the difference between baseline to post-test mean AP COP amplitude was .02: 95% CI [-.013, .064]. The difference between baseline to post-test mean ML COP amplitude was .02: 95% CI [.002, .047]. The difference between baseline to post-test AP COP range was .07: 95% CI [-.155, .291]. The difference between baseline to post-test mean ML COP amplitude was .13: 95% CI [.001, .251].

A post-hoc power analysis was conducted using G*Power version 3.1.9.7 for calculation of the study power of the sub-analysis of participants with moderate neck and low back pain that received spinal manipulation. Using a post-hoc power analysis, t-test: differences between two dependent means, one tail, effect size of = 0.36 (small effect), $\alpha = .048$, and sample size of 32 participants in the sub-analysis the total statistical power was 0.68 for medial-to-lateral COP range change. Thus, the sub-analysis was underpowered and researchers would need to have recruited 44 participants with moderate combined neck and low back pain for the analysis to be adequately powered, with a power of 0.80.

DISCUSSION

The result was that spinal manipulation for 97 individuals in the main analysis, which fit the criteria of low combined neck and low back pain, did not have a statistically significant positive impact on balance parameters. Sub-analysis of individuals with moderate neck and low back pain demonstrated a possible small benefit on medial-to-lateral COP amplitude and range, but it did not reach statistical significance. These sub-analysis findings are hindered by the number of participants being 32 and not reaching 44. Twelve more participants with combined pain between 8-14 would be needed to reach adequate statistical power. There was not a large difference in pain between the general neck and low back pain group (n=97) and the sub-analysis of individuals with moderate neck and low back pain (n=32). Recruiting participants with larger overall NRS pain across the neck and low back pain may have resulted in different study findings.

Existing research is mixed on there being a benefit to balance in response to spinal manipulation for individuals with neck or low back pain. Some researchers have found a small benefit,[50,51,52] while others have not.[53,54] Part of the problem may be that spinal manipulation cannot impact balance positively with some forms of spine pain, as was seen in the low back pain study by Smith *et al* on spinal stenosis. Additionally, the impact of afferentation on integration and possible modulation and compensation induced by spinal manipulation should be further explored in relation to its impact on balance.[64-68] For example, Haavik *et al* found that spinal manipulation for individuals with mild spine pain increased cortical excitability and descending cortical drive, resulting in an increase in strength.[69] Another significant problem with demonstrating an association between spinal manipulation for spine pain is to ensure studies have an adequate sample size. This study's sub-analysis on individuals with moderate neck and low back pain was underpowered. Having underpowered balance spinal manipulation studies is common in the limited literature in this field.[50,53,54]

One way that this study was different than many previous balance-related spinal manipulation studies is that it involved participants with spine pain in 2 different regions of their spine. Evidence suggests neck pain individually causes impairments in balance,[16-24] as does low back pain.[34-35] Patients with both neck and low back pain have been seen to have even larger impairments in balance, and an area of which is minimally studied in research.[55] The goal of this study was to determine if spinal manipulation to both the cervical and lumbar regions of individuals with spine pain resulted in short-term small significant improvements in balance.

A possible future direction of research to stem from this study would be to engage in a similar study design, but with a middle-age to older adult population, with more discrete ranges of pain for each group (e.g., 0-3 NRS group, 6-8 NRS group), and not chiropractic college students that receive spinal manipulation more often. Middle-aged adults experience neck pain more often than other age groups,[70] are more likely to experience dizziness[71-72] and are the most common chiropractic patient demographic.[73-74] Older adults, on the other hand, are more likely to be at an increased risk of falls,[75-76] and if spinal manipulation could improve balance that would be worthy of research. Factors increasing fall risk amongst older adults include impairments in proprioception, balance, and reduced trunk muscle strength.[75-76] Another research direction suggested by Goertz *et al* in addition to using a force plate to track balance changes in response to spinal manipulation would be to engage in kinematic analysis of motion at the ankle, knee, and hip.[52,77] Studies suggest individuals with low back pain tend to use corrective ankle motion strategies more than hip motion strategies to maintain their standing upright posture, which could be used as another variable to track improvements in functionality.[77-79] An additional possible direction of research that could stem from this study is determining the differential impact of neck pain on balance versus low back pain on balance, versus both combined. There is almost no research on the impact of combined neck and low back pain on balance parameters.

Strengths and Limitations

One strength of this study is that there is minimal published research using force plates to measure the impact of spinal manipulation on standing static balance for individuals with spine pain. More objective studies as opposed to subjective balance-related activities of daily living surveys are needed to quantify any possible improvements in balance performance in response to spinal manipulation.

One limitation of this study is that chiropractic college students were utilized which lowers the external validity of the findings of this experiment. It is reasonable to suggest that individuals that do not regularly receive spinal manipulation may have responded to a larger degree than students who receive spinal manipulation periodically in a chiropractic college program. This should be explored further by future research involving patients in the general public with neck and low back pain. However, this study data does help to establish baseline data that future patients can be compared against. Furthermore, the reason why researchers did not measure pain post-treatment is that they believed since the participants were chiropractic college students that they would feel compelled to state a lower NRS pain number no matter how they felt at post-test. Additionally, some study participants demonstrated low levels of pain (e.g., neck pain of 1 on the NRS and low back pain of 1 on the NRS). Raising the inclusion NRS cut-offs for participants in this experiment could have improved the study quality.

Another limitation of this study is that it measured the short-term change in balance parameters in response to spinal manipulation following a singular intervention period. It could be argued that balance should be assessed at baseline and after 4-6 weeks of chiropractic care as spine pain or other non-pain attributes impacting their activities of daily living resolve. Chiropractic care in a study like this should involve a combination of spinal manipulation, patient education, passive modalities, and active modalities. In the 2016 study by Goertz *et al* they performed high-velocity low-amplitude lumbar spinal manipulation on 72 patients with low back pain (44.1 age y, 5.4 low back pain NRS, with 93.1% having low back pain over 1-year) and found only small changes in balance parameters.[52] Although their study did measure immediate pre-to-post changes as this current study did, they only tracked patient balance response over 2 weeks of chiropractic care consisting of 5 total visits.[52] Longer duration balance-related spine pain chiropractic care studies over 4-6 weeks are warranted. Additionally, this study did not measure pain post-manipulation. As a result, a correlation cannot be made between improvements in pain and balance. Furthermore, no control or sham group was used and placebo effects cannot be ruled out as possible explanations for the study findings.

CONCLUSION

Spinal manipulation did not cause an immediate change in balance parameters of chiropractic college students with low or moderate levels of combined neck and low back pain to a statistically significant level. However, college students with moderate levels of combined neck and low back pain demonstrated short-term small improvements in their medial-to-lateral center of pressure mean amplitude and overall range. Future larger studies need to be performed with adequate statistical power on individuals with moderate neck and low back pain, preferably individuals that do not receive spinal manipulation as often to increase external validity for use as a benefit for the typical patient population.

REFERENCES

1.Peng B, Yang L, Li Y, Liu T, Liu Y. Cervical proprioception impairment in neck pain-pathophysiology, clinical evaluation, and management: a narrative review. *Pain Ther.* 2021;10(1):143-64. doi: 10.1007/s40122-020-00230-z.

2.Nies N, Sinnott P. Variations in balance and body sway in middle-aged adults. Subjects with healthy backs compared with subjects with low-back dysfunction. *Spine.* 1991;16(3):325-30. doi: 10.1097/00007632-199103000-00012.

3.Hodges P, Richardson C. Altered trunk muscle recruitment in people with low back pain with upper limb movement at different speeds. *Arch Phys Med Rehabil.* 1999;80(9):1005-12. doi: 10.1016/s0003-9993(99)90052-7.

4.Tsao H, Galea M, Hodges P. Reorganization of the motor cortex is associated with postural control deficits in recurrent low back pain. *Brain.* 2008;131(Pt 8):2161-71. doi: 10.1093/brain/awn154.

5.Tsao H, Druitt T, Schollum T, Hodges P. Motor training of the lumbar paraspinal muscles induces immediate changes in motor coordination in patients with recurrent low back pain. *J Pain.* 2010;11(11):1120-8. doi: 10.1016/j.jpain.2010.02.004.

6.GBD 2019 Diseases and Injuries Collaborators. Global burden of 369 diseases and injuries in 204 countries and territories, 1990-2019: a systemic analysis for the Global Burden of Disease Study 2019. *Lancet.* 2020;396(10258):1204-22. doi: 10.1016/S0140-6736(20)30925-9.

7.Cohen S, Hooten W. Advances in the diagnosis and management of neck pain. *BMJ.* 2017;358:j3221. doi: 10.1136/bmj.j3221.

8.Kazeminasab S, Nejadghaderi S, Amiri P, Pourfathi H, Araj-Khodaei M, Sullman M, Kolahi A, Safiri S. Neck pain: global epidemiology, trends and risk factors. *BMC Musculoskelet Disord.* 2022;23(1):26. doi: 10.1186/s12891-021-04957-4.

9.Borel L, Honoré J, Bachelard-Serra M, Lavieille J, Saj A. Representation of body orientation in vestibular-defective patients before and after unilateral vestibular loss. *Front Syst Neurosci.* 2021;15:733684. doi: 10.3389/fnsys.2021.733684.

10.Earhart G. Dynamic control of posture across locomotor tasks. *Mov Disord.* 2013;28(11):1501-8. doi: 10.1002/mds.25592.

11.Tokur D, Grimmer M, Seyfarth A. Review of balance recovery in response to external perturbations during daily activities. *Hum Mov Sci.* 2020;69:102546. doi: 10.1016/j.humov.2019.102546.

12.Granacher U, Bridenbaugh S, Muehlbauer T, Wehrle A, Kressig R. Age-related effects on postural control under multi-task conditions. *Gerontology.* 2011;57(3):247-55. doi: 10.1159/000322196.

13.Smith J, Stabbert H, Bagwell J, Teng H, Wade V, Lee S. Do people with low back pain walk differently? A systematic review and meta-analysis. *J Sport Health Sci.* 2022;11(4):450-65. doi: 10.1016/j.jshs.2022.02.001.

14.Childs J, Fritz J, Piva S, Whitman J. Proposal of a classification system for patients with neck pain. *J Orthop Sports Phys.* 2004;34(11):686-700. doi: 10.2519/jospt.2004.34.11.686.

15.Carroll L, Hogg-Johnson S, van der Velde G, Haldeman S, Holm L, Carragee E, Hurwitz E, Côté P, Nordin M, Peloso P, Guzman J, Cassidy J. Course and prognostic factors for neck pain in the general population: Results of the Bone and Joint Decade 2000-2010 Task Force on Neck Pain and Its Associated Disorders. *Eur Spine J.* 2008;17(Suppl 1):75-82. doi: 10.1007/s00586-008-0627-8.

16.Ruhe A, Fejer R, Walker B. Altered postural sway in patients suffering from non-specific neck pain and whiplash associated disorder – A systematic review of the literature. *Chiropr Man Ther.* 2011;19:13. doi: 10.1186/2045-709X-19-13.
17.Brandt T, Bronstein A. Cervical vertigo. *J Neurol Neurosurg Psychiatry.* 2001;71(1):8-12. doi: 10.1136/jnnp.71.1.8.
18.Luque-Suarez A, Martinez-Calderon J, Falla D. Role of kinesiophobia on pain, disability and quality of life in people suffering from chronic musculoskeletal pain: A systematic review. *Br J Sports Med.* 2019;53(9):554-9. doi: 10.1136/bjsports-2017-098673.
19.Ucurum S. The relationship between pain severity, kinesiophobia, and quality of life in patients with non-specific chronic neck pain. *J Back Musculoskeletal Rehabil.* 2019;32(5):677-83. doi: 10.3233/BMR-171095.
20.Grod J, Diakow P. Effect of neck pain on verticality perception: a cohort study. *Arch Phys Med Rehabil.* 2002;83(3):412-5. doi: 10.1053/apmr.2002.29660.
21.Vuillerme N, Pinsault N. Experimental neck muscle pain impairs standing balance in humans. *Exp Brain Res*. 2009;192(4):723-9. doi: 10.1007/s00221-008-1639-7.
22.Madeleine P, Nielsen M, Arendt-Nielsen L. Characterization of postural control deficit in whiplash patients by means of linear and nonlinear analyses- A pilot study. *J Electromyogr Kinesiol.* 2011;21(2):291-7. doi: 10.1016/j.jelekin.2010.05.006.
23.Burton W, Ma Y, Manor B, Hausdorff J, Kowalski M, Bain P, Wayne P. The impact of neck pain on gait health: a systematic review and meta-analysis. *BMC Musculoskelet Disord.* 2023;24:618. doi: 10.1186/s12891-023-06721-2.
24.Meisingset I, Stensdotter A, Woodhouse A, Vasseljen O. Neck motion, motor control, pain and disability: A longitudinal study of associations in neck pain patients in physiotherapy treatment. *Man Ther.* 2016;22:94-100. doi: 10.1016/j.math.2015.10.013.
25.Casadio M, Morasso P, Sanguineti V. Direct measurement of ankle stiffness during quiet standing: implications for control modelling and clinical application. *Gait Posture.* 2005;21(4):410-24. doi: 10.1016/j.gaitpost.2004.05.005.
26.Kristjansson E, Treleaven J. Sensorimotor function and dizziness in neck pain: implications for assessment and management. *J Orthop Sports Phys Ther.* 2009;39(5):364-77. doi: 10.2519/jospt.2009.2834.
27.Chaurangi R, Varghese A. Correlation of neck pain severity with balance in subjects with mechanical neck pain. *IJSR.* 2020;9(7):1434-8. doi: 10.21275/SR20718174653.
28.Mario D, Carla V, Paolo P, Antonio R. Structural and functional changes of cervical neuromuscular
system associated with insidious onset mechanical neck pain: a literature review. *Int J Phys Ther Rehab.* 2015;1:103-8. doi: 10.15344/2455-7498/2015/103.
29.Qu N, Tian H, De Martino E, Zhang B. Neck pain: do we know enough about the sensorimotor control system? *Front Comput Neurosci.* 2022;16:946514. doi: 10.3389/fncom.2022.946514.
30.Boyd-Clark L, Briggs C, Galea M. Muscle spindle distribution, morphology, and density in longus colli and multifidus muscles of the cervical spine. *Spine.* 2002;27(7):694-701. doi: 10.1097/00007632-200204010-00005.
31.Thunberg J, Hellström F, Sjölander P, Bergenheim M, Wenngren B, Johansson H. Influence on the fusimotor-muscle spindle system from chemosensitive nerve endings in cervical facet

joints in the cat: possible implications for whiplash induced disorders. *Pain* 2001;91(1-2):15-22. doi: 10.1016/s0304-3959(00)00415-2.
32.Sjölander P, Michaelson P, Jaric S, Djupsjöbacka M. Sensorimotor disturbances in chronic neck pain-range of motion, peak velocity, smoothness of movement, and repositioning acuity. *Man Ther.* 2008;13(2):122-31. doi: 10.1016/j.math.2006.10.002.
33.Treleaven J, Jull G, Sterling M. Dizziness and unsteadiness following whiplash injury: characteristic features and relationship with cervical joint position error. *J Rehabil Med.* 2023;35(1):36-43. doi: 10.1080/16501970306109.
34.Ge L, Wang C, Zhou H, Yu Q, Li X. Effects of low back pain on balance performance in elderly people: a systematic review and meta-analysis. *Eur Rev Aging Phys Act.* 2021;18(1):8. doi: 10.1186/s11556-021-00263-z.
35.Braga A, Rodrigues A, Lima G, Melo L, Carvalho A, Bertolini G. Comparison of static postural balance between healthy subjects and those with low back pain. *Acta Ortop Bras.* 2012;20(4):210-2. doi: 10.1590/S1413-78522012000400003.
36.van Dieën J, 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.
37.Lund J, Donga R, Widmer C, Stohler C. The pain-adaptation model: a discussion of the relationship between chronic musculoskeletal pain and motor activity. *Can J Physiol Pharmacol.* 1991;69(5):683-94.
doi: 10.1139/y91-102.
38.Ham Y, Kim D, Baek J, Lee D, Sung P. Kinematic analyses of trunk stability in one leg standing for individuals with recurrent low back pain. *J Electromyogr Kinesiol.* 2010;20(6):1134-40. doi: 10.1016/j.jelekin.2010.05.011.
39.Lee D, Ham Y, Sung P. Effect of visual input on normalized standing stability in subjects with recurrent low back pain. *Gait Posture.* 2012;36(3):580-5. doi: 10.1016/j.gaitpost.2012.05.020.
40.Schroeder J, Kaplan L, Fischer D, Skelly A. The outcomes of manipulation or mobilization therapy compared with physical therapy or exercise for neck pain: A systematic review. *Evid Based Spine Care J.* 2013;4(1):30-41. doi: 10.1055/s-0033-1341605.
41.Chou R, Deyo R, Friedly J, Skelly A, Hashimoto R, Weimer M, Fu R, Dana T, Kraegel P, Griffin J, Grusing S, Brodt E. Nonpharmacologic therapies for low back pain: A systematic review for an American College of Physicians Clinical Practice Guideline. *Ann Intern Med*. 2017;166(7):493-505. doi: 10.7326/M16-2459.
42.Qaseem A, Wilt T, McLean R, Forciea M. Noninvasive treatments for acute, subacute, and chronic low back pain: A Clinical Practice Guideline From the American College of Physicians. *Ann Intern Med.* 2017;166(7):514-30. doi: 10.7326/M16-2367.
43.National Guideline Centre. Low back pain and sciatica in over 16s: assessment and management. National Institute for Health and Care Excellence; 2016.
44.Murtagh S, Bryant E, Hebron C, Ridehalgh C, Horler C, Trosh C, Olivier G. Management of low back pain: treatment provision within private practice in the UK in the context of clinical guidelines. *Musculoskeletal Care.* 2021;19(4):540-9. doi: 10.1002/msc.1553.
45.Strunk R, Hawk C. Effects of chiropractic care on dizziness, neck pain, and balance: a single-group, preexperimental, feasibility study. *J Chiropr Med.* 2009;8(4):156-64. doi: 10.1016/j.jcm.2009.08.002.

46.Reid S, Rivett D, Katekar M, Callister R. Sustained natural apophyseal glides (SNAGs) are an effective treatment for cervicogenic dizziness. *Man Ther.* 2008;13(4):357-66. doi: 10.1016/j.math.2007.03.006.
47.Karlberg M, Magnusson M, Malmström E, Melander A, Moritz U. Postural and symptomatic improvement after physiotherapy in patients with dizziness of suspected cervical origin. *Arch Phys Med Rehabil.* 1996;77(9):874-82. doi: 10.1016/s0003-9993(96)90273-7.
48.Hawk C, Khorsan R, Lisi A, Ferrance R, Evans M. Chiropractic care for nonmusculoskeletal conditions: a systematic review with implications for whole systems research. *J Altern Complement Med.* 2007;13(5):491-512. doi: 10.1089/acm.2007.7088.
49.Vindigni D, Zark L, Sundberg T, Leach M, Adams J, Azari M. Chiropractic treatment of older adults with neck pain with or without headache or dizziness: analysis of 288 Australian chiropractors' self-reported views. *Chirop Man Therap.* 2019;27:65. doi: 10.1186/s12998-019-0288-1.
50.Ward J, Lawrence L, Coats J. Pilot study of cervical spine manipulation impact on Y-balance test results of chiropractic college students with and without neck pain. Under review by *J Chiropr Med.* 2023.
51.Vining R, Long C, Minkalis A, Gudavalli M, Xia T, Walter J, Coulter I, Goertz C. Effect of chiropractic care on strength, balance, and endurance in active-duty U.S. military personnel with low back pain: A randomized controlled trial. *J Altern Complement Med.* 2020;26(7):592-601. doi: 10.1089/acm.2020.0107.
52.Goertz C, Xia T, Long C, Vining R, Pohlman K, DeVocht J, Gudavalli R, Owens Jr E, Meeker W, Wilder D. Effects of spinal manipulation on sensorimotor function in low back pain patients – a randomized controlled trial. *Man Ther.* 2016;21:183-90. doi: 10.1016/j.math.2015.08.001.
53.Smith D, Olding K, Malaya C, McCarty M, Haworth J, Pohlman K. The influence of flexion distraction spinal manipulation on patients with lumbar spinal stenosis: A prospective, open-label, single-arm, pilot study. *J Bodyw Mov Ther.* 2022;32:60-7. doi: 10.1016/j.jbmt.2022.05.012.
54.Hawk C, Cambron J. Chiropractic care for older adults: effects on balance, dizziness, and chronic pain. *J Manipulative Physiol Ther.* 2009;32(6):431-7. doi: 10.1016/j.jmpt.2009.06.009.
55.Jørgensen M, Skotte J, Holtermann A, Sjøgaard G, Petersen N, Søgaard K. Neck pain and postural balance among workers with high postural demands – a cross-sectional study. *BMC Musculoskelet Disord.* 2011;12:176. doi: 10.1186/1471-2474-12-176.
56.Sinnott P, Dally S, Trafton J, Goulet J, Wagner T. Trends in diagnosis of painful neck and back conditions, 2002 to 2011. *Medicine.* 2017;96(20):e6691. doi: 10.1097/MD.0000000000006691.
57.Bovim G, Schrader H, Sand T. Neck pain in the general population. *Spine*. 1994;19(12):1307–9. doi: 10.1097/00007632-199406000-00001.
58.Côté P, Cassidy J, Carroll L, Kristman V. The annual incidence and course of neck pain in the general population: a population-based cohort study. *Pain.* 2004;112(3):267–73. doi: 10.1016/j.pain.2004.09.004.
59.Gevers-Montoro C, Provencher B, Descarreaux M, de Mues A, Piché M. Clinical effectiveness and efficacy of chiropractic spinal manipulation for spine pain. *Front Pain Res.* 2021;2:765921. doi: 10.3389/fpain.2021.765921.

60.Hancock M, Maher C, Latimer J, Herbert R, McAuley J. Independent evaluation of a clinical prediction rule for spinal manipulative therapy: a randomised controlled trial. *Eur Spine J.* 2008;17(7):936–43. doi: 10.1007/s00586-008-0679-9.
61.Khasnis A, Gokula R. Romberg's test. *J Postgrad Med.* 2003;49(2):169-72.
62.Palmieri-Smith R, Ingersoll C, Stone M, Krause B. Center-of-pressure parameters used in the assessment of postural control. *J Sport Rehabil.* 2002;11(1):51-66. doi: 10.1123/jsr.11.1.51.
63.Bergmann T, Peterson D. Chiropractic technique: Principles and procedures. 3rd ed. Elsevier-Mosby, 2011,180-181, 254-255.
64.Haavik H, Murphy B. The role of spinal manipulation in addressing disordered sensorimotor integration and altered motor control. *J Electromyogr Kinesiol.* 2012;22:768-76. doi: 10.1016/j.jelekin.2012.02.012.
65.Marshall P, Murphy B. The effect of sacroiliac joint manipulation on feed-forward activation times of the deep abdominal musculature. *J Manip Physiol Ther.* 2006;29:196-202. doi: 10.1016/j.jmpt.2006.01.010.
66.Haavik-Taylor H, Murphy B. Cervical spine manipulation alters sensorimotor integration: a somatosensory evoked potential study. *Clin Neurophysiol.* 2007;118:391-402. doi: 10.1016/j.clinph.2006.09.014.
67.Haavik-Taylor H. Murphy B. Transient modulation of intracortical inhibition following spinal manipulation. *Chiropr J Aust.* 2007;37:106-16.
68.Taylor H, Murphy B. Altered sensorimotor integration with cervical spine manipulation. *J Manip Physiol Ther.* 2008;31:115-26. doi: 10.1016/j.jmpt.2007.12.011.
69.Haavik H, Niazi I, Jochumsen M, Sherwin D, Flavel S, Türker K. Impact of spinal manipulation on cortical drive to upper and lower limb muscles. *Brain Sci.* 2017;7(1):2. doi: 10.3390/brainsci7010002.
70.Skillgate E, Magnusson C, Lundberg M, Hallqvist J. The age- and sex-specific occurrence of bothersome neck pain in the general population- results from the Stockholm public health cohort. *BMC Musculolskelet Disord.* 2012;13:185. doi: 10.1186/1471-2474-13-185.
71.Yardley L, Owen N, Nazareth I, Luxon L. Prevalence and presentation of dizziness in a general practice community sample of working age people. *Br J Gen Pract.* 1998;48(429):1131-5.
72.Hoepel S, Jouvencel A, van Linge A, Goedegebure A, Altena E, Luik A. Sleep and dizziness in middle-aged and elderly persons: A cross-sectional population-based study. *Sleep Epidemiology.* 2023;3:100066. doi: 10.1016/j.sleepe.2023.100066.
73.Stevens G, Campeanu M, Sorrento A, Ryu J, Burke J. Retrospective demographic analysis of patients seeking care at a free university chiropractic clinic. *J Chiropr Med.* 2016;15(1):19-26. doi: 10.1016/j.jcm.2016.02.001.
74.Beliveau P, Wong J, Sutton D, Simon N, Bussières A, Mior S, French S. The chiropractic profession: a scoping review of utilization rates, reasons for seeking care, patient profiles, and care provided. *Chiropr Man Therap.* 2017;25:35. doi: 10.1186/s12998-017-0165-8.
75.Rosano C, Newman A, Katz R, Hirsch C, Kuller L. Association between lower digit symbol substitution test score and slower gait and greater risk of mortality and of developing incident disability in well-functioning older adults. *J Am Geriatr Soc.* 2008;56(9):1618-25. doi: 10.1111/j.1532-5415.2008.01856.x.

76.Kyrdalen I, Thingstad P, Sandvik L, Ormstad H. Associations between gait speed and well-known fall risk factors among community-dwelling older adults. *Physiother Res Int.* 2019;24(1):e1743. doi: 10.1002/pri.1743.
77.Mok N, Brauer S, Hodges P. Hip strategy for balance control in quiet standing is reduced in people with low back pain. *Spine.* 2004;29(6):E107-12. doi: 10.1097/01.brs.0000115134.97854.c9.
78.Radebold A, Cholewicki J, Polzhofer G, Greene H. Impaired postural control of the lumbar spine is associated with delayed muscle response times in patients with chronic idiopathic low back pain. *Spine (Phila Pa 1976).* 2001;26(7):724-30. doi: 10.1097/00007632-200104010-00004.
79.Hodges P, Richardson C. Inefficient muscular stabilization of the lumbar spine associated with low back pain. A motor control evaluation of transversus abdominis. *Spine (Phila Pa 1976).* 1996;21(22):2640-50. doi: 10.1097/00007632-199611150-00014.