Immediate Effects of Cervical Spine Manipulation Compared With Muscle Energy Technique on Neck Muscle Activity and Range of Motion in Asymptomatic Participants: A Randomized Study

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Abstract

Objective: The purpose of this study was to investigate the immediate effects of cervical spine manipulation (SM) compared with muscle energy technique (MET) on neck muscle activity and range of motion in asymptomatic people.
Methods: A randomized parallel-group study was conducted at a chiropractic teaching clinic in Durban, South Africa. Fifty asymptomatic participants between 18 and 35 years of age were randomly assigned into group 1 or group 2. Group 1 received cervical SM, and group 2 received MET. Participants were blinded to group allocation only. Baseline and post-test measurements consisted of resting upper trapezius and posterior cervical muscle activity and cervical spine range of motion (ROM) in lateral flexion and extension.
Results: A significant difference was found in cervical ROM within groups ($P < .001$), with no significant difference observed between the 2 groups. The right posterior cervical muscles showed a significant difference in group 1 only ($P = .012$). No significant muscle activity changes occurred in group 2. Resting muscle activity measures showed no statistically significant changes between groups.
Conclusion: A single application of SM and MET to the cervical spine immediately increased cervical ROM. Neither cervical SM nor MET changed resting posterior cervical and upper trapezius muscle activity. (J Chiropr Med 2022;21;241-248)
Key Indexing Terms: *Chiropractic; Electromyography; Isometric Contraction; Manipulation, Spinal; Range of Motion, Articular*

Introduction

Spinal manipulation (SM) is a common manual therapeutic technique used to decrease neck pain (NP) and increase cervical spine range of motion (ROM).[1,2,3] Muscle energy technique (MET) is a form of mobilization used by manual therapists for the upper cervical spine.[4] During MET, the restricted joint is positioned at the end of its limited ROM, and the patient's own voluntary muscle contraction is used in a precisely controlled direction against a practitioner's applied counterforce. After relaxation, the restrictive barrier is often felt to yield, and the procedure is repeated several times.[4,5,6] The successful application of MET relies on patient-practitioner cooperation, as the patient plays an active role in its application.[5] During SM, a high-velocity, low-amplitude thrust is directed beyond the passive ROM of the joint.[7,8] The practitioner controls the velocity, magnitude, and direction of the impulse.[9] Both SM and MET may induce physiological responses, including pain reduction, improved joint mobility, and changes in muscle activity.[3,6,10] Though their applications may differ, these interventions are hypothesized to stimulate sensory receptors of the joint, which may alter muscle activity and improve ROM by affecting the central nervous system at the spinal segmental level and cortical level.[10,11,12] The neurophysiological effect may be dependent on the type of force applied to the spine during the manual intervention.[13]

Neck pain is sometimes associated with reduced ROM and abnormal activity of superficial spinal muscles. Decreased cervical ROM is a common finding in people with neck pain compared to healthy individuals.[14,15,16] In addition, people with neck pain sometimes are unable to

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completely relax the cervical extensor muscles and have increased muscle activity during full forward cervical flexion.[17] It is hypothesized that this is to protect the spine from further injury. Furthermore, some individuals with neck pain have increased electromyographic activity of the upper trapezius (UT) in most movements of the cervical spine,[18] which may result in greater loading, mostly compressive, of the cervical spine.[18,19] Thus, improving ROM and normalizing spinal muscle activity may be important for pain reduction and optimal function.

As far as we are aware, there is no evidence of literature comparing the effect of SM and MET on neck muscle activity and cervical ROM in people with NP, although a study of patients with mechanical neck pain showed a significant decrease in pain in manipulated patients when compared with MET patients.[20] However, both interventions increased neck ROM. These findings suggest that MET may be comparable to SM in increasing neck ROM. However, it is unclear if these reported changes are dependent on the hypoalgesic effect or the neurophysiological effect of the manual interventions. Therefore, comparing the potential effects of these 2 modalities on asymptomatic individuals may provide a way to compare the effects of SM and MET in the absence of pain.

The effect of either SM and MET on spinal muscle activity in healthy individuals has been investigated separately. A single session of both interventions has shown to decrease surface electromyographic activity, alpha motoneuron activity, or overall motor excitability.[6,13,21,22,23] The effects of SM and MET on cervical ROM have also been investigated separately in patients with and without mechanical neck pain. A single session of cervical SM increased cervical ROM in patients with mechanical NP.[24] Likewise, a sham-controlled study demonstrated significant improvements in cervical ROM in asymptomatic participants following MET.[25] Since the effects of SM and MET on neck muscle activity and cervical ROM in healthy individuals have yet to be compared, it is unclear whether MET would have a similar effect to SM. Therefore, the purpose of this study was to investigate the effect of cervical SM and MET on neck muscle activity and ROM in asymptomatic participants. The study hypothesized that differences in muscle activity and ROM outcomes exist between patients receiving SM or MET for the cervical spine.

Methods

Participant screening, outcome measures, and interventions were carried out by a final-year master's in technology chiropractic student under supervision of a chiropractic clinician.

Participants

We chose asymptomatic individuals to allow for the effects to be compared without the presence of current pain, which could alter sensory processing and motor control. The sample size of required, using repeated measures analysis of variance (ANOVA) (alpha .05, power .8, and effect size .25), is 50. The study took place at the Durban University of Technology Chiropractic Day Clinic, situated in eThekwini Municipality. Participants in this area responded to recruitment methods, which included word of mouth as well as the use of advertisements. Participant screening, outcome measures, and interventions were carried out by a final-year master's in technology chiropractic student under supervision of a chiropractic clinician. Inclusion criteria were participants of either sex, between the ages of 18 and 35 years, asymptomatic with respect to neck and upper quadrant pain, with the presence of 1 or more cervical spine restrictions. Asymmetry in hard or soft tissue landmarks, abnormal ROM, tissue texture abnormality, and tenderness to palpation of the relevant joints comprised the clinical evidence of a joint restriction.[26,27] Any participant with NP, taking any pain medication or muscle relaxants or receiving any other form of treatment to the neck, exhibiting contra-indications to SM (such as atherosclerosis of major blood vessels, vertebrobasilar insufficiency, aneurysm, tumors, fractures, late-stage osteoarthritis, uncarthrosis, clotting disorders, osteopenia, space-occupying lesions, diabetic neuropathy),[28] or contra-indications to MET (included but not limited to tissue fragility, hypermobility, myositis, tumors),[29,30] were excluded from the study. A case history along with physical and cervical spine regional examinations were performed to screen for exclusionary criteria. Participants were not excluded if they had previously seen or received either SM or MET.

Trial Design

This was a randomized parallel-group study. Assessment, measurements, and interventions were conducted in the same room at the Durban University of Technology Chiropractic Day Clinic. Ethical clearance was obtained from the Durban University of Technology Institutional Research Ethics Committee (Ethical Clearance No. IREC 012/19). The trial was registered with the Pan African Clinical Trial Registry (PACTR201906557214661). All participants read and signed a letter of information and informed consent.

Once accepted into the study, participants were randomly assigned following simple randomization procedures ("hat" method)[31] to 1 of 2 parallel groups, with a 1:1 ratio. Group 1 received SM, and Group 2 received MET. Participants were blinded to group allocation only.

Interventions

Participants in both groups underwent a single session of either SM or MET, following the recording of demographic and baseline measurements.

Group 1. Cervical SM was applied supine to restrictions found on motion palpation, according to the technique described by Bergmann and Peterson[28] The participant's head and neck were simultaneously rotated and laterally flexed over the contact point—specifically, the posterior supramastoid groove or zygomatic arch (C0-C1), the posterior aspect of the transverse process (C1-C2), or the posterior articular pillar of superior vertebrae (C2-C7) —to the end of passive ROM. Thereafter, a high-velocity, low-amplitude thrust was delivered in the direction of restricted movement. Participants with more ROM restriction in the lateral plane were given more lateral-to-medial directed thrusts; participants with more restriction in rotation were given thrusts in the direction of restricted axial rotation; and participants with more restriction in extension were given more anteriorly directed thrusts.

Group 2. Muscle energy technique was applied to the joint restrictions found on motion palpation, using the method outlined by DeStefano.[27] The researcher used 1 hand to move the participant's cervical spine into the desired direction, whilst either the web of the thumb and the index finger (C0-C1) or the index and middle finger of the other hand (C2-C7) stabilized the vertebra inferior to the fixated segment. The participant exerted a small isometric effort against the researcher's resisting hand. After a 3- to 5-second muscle effort, the participant relaxed, and the researcher relocalized against the resisted barrier after each effort. The process was repeated 3 times.

Fig 1. *Cervical range of motion goniometer.*

Outcome Measures

Surface electromyography and cervical ROM were used as primary outcome measures. Measurements were recorded before and immediately after the application of SM or MET, according to group allocation.

Cervical Spine Range of Motion. The cervical ROM was measured using a CROM goniometer (Performance Attainment Associates, Lindstrom Minnesota), which is said to have good reliability and validity.[32] For the purpose of this study, only lateral flexion and extension were measured, as the posterior cervical (PC) and UT muscles control the movements of lateral flexion and the extension of the neck, respectively.

The CROM goniometer was attached to the participant's head and was secured with a strap (Fig 1). The participant was then instructed to sit in an upright position, with both feet placed firmly on the ground. The goniometer was read and recorded on a data sheet at the starting and end position for extension and lateral flexion before and after the intervention. For extension, the participant was instructed to look up to the ceiling and place his or her neck as far back as possible until limited by tightness. For lateral flexion, the participant was instructed to look forward and try and bring his or her ear down to the shoulder on either side until limited by tightness or discomfort.[33]

Surface Electromyography. The resting PC and UT muscle activity were measured using sEMG (BioNomadix complete wireless research system, BIOPAC Systems Inc, Goleta, California), which is said to be a repeatable and reliable tool for measuring muscle activity.[34] The root mean square value, a measure of the power of the signal, is said to be the preferred method[35] and for this reason was collected in this study.

Skin Preparation and Electrode Placement. Vitatrode midi-ACF 35-mm round, pregelled Ag/AgCl, disposable, electrocardiogram electrodes were used.

The participant's skin was prepared for electrode placement by the removal of hair with a razor, if necessary, to improve adhesion of the electrode.[35] The skin was then cleaned will alcohol pads to remove any oils and dead skin so that the biological potentials could reach the recording electrodes easily.[36]

The resting activity of the PC and UT were measured as they are general muscles that extend throughout the cervical spine. Electrodes were placed according to the positioning described by Criswell[36]:

- UT: Two electrodes (2 cm apart) running parallel to the muscle fibers of the UT, along the ridge of the shoulder, slightly lateral to and halfway between the cervical spine at C7 and the acromion (Fig 2).

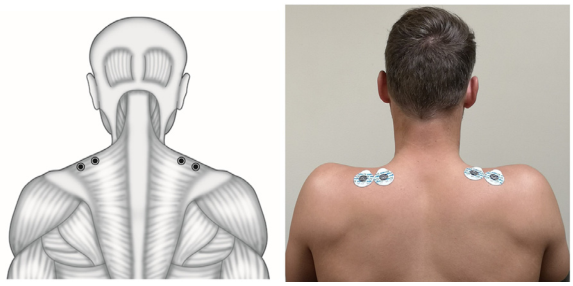

Fig 2. *Electrode placement of the upper trapezius muscles.*[36]

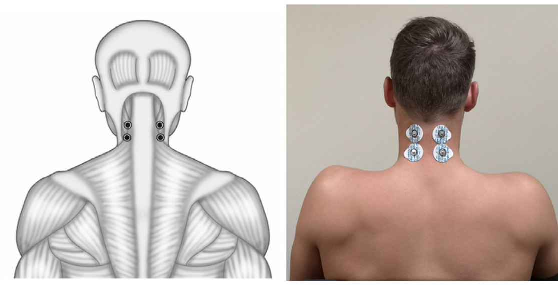

Fig 3. *Electrode placement of the posterior cervical muscles.*[36]

- PC: Two active electrodes (2 cm apart) running parallel to the spine, 2 cm from the midline, over the muscle belly at C4 (Fig 3). The hairline was to be avoided.

Resting Muscle Activity Assessment. Resting PC and UT muscle activity were measured similarly to protocols used in other studies.[22,37] Prior to any collection of data, patients were seated with their head and neck in a neutral position. The participant's arms were rested with the elbows bent at 90 degrees and fingers interlocked over the abdomen to limit movement of their upper limbs. The participant was then instructed not to move any part of his or her body and to "relax as fully as possible." Baseline resting sEMG activity levels were then recorded for 30 seconds before the intervention. The readings were taken for another 30 seconds after the intervention. Measurements were recorded on the datasheet. To avoid any changes to the results due to differences in electrode placement between readings, the electrodes remained in the same place throughout the study,[36] but for the application of the intervention, the electrode leads were unclipped from the electrodes to increase the participant's comfort.

Statistical Analysis

Data were captured and sent to a biostatistician with 18 years of experience for analysis of the statistical outputs. SPSS version 24 (IBM Corporation, Armonk, NY) was used to analyze the data. A P value <.05 was considered statistically significant. Categorical variables were compared between the groups using Pearson's χ^2 test or the Fisher exact test as appropriate. All outcome variables were nonnormally distributed and, thus, were summarized using median and interquartile ranges by group. Intragroup changes were compared pre- and postintervention using paired Wilcoxon signed ranks tests. Median changes between pre- and postintervention were compared between the 2 treatment groups using Mann-Whitney U tests. Plots of the distributions of the values by group were graphed using box and whisker plots.

Results

Fifty participants were initially admitted into the study. All participants completed the session that comprised the protocol as shown in Figure 4. Twenty-five participants were allocated to each group. Average age and sex were comparable as follows: group 1 age: 23.56 years; group 2 age: 23.60 years; group 1 sex: 11 men and 14 women; group 2 sex: 12 men and 13 women (Table 1).

Group 1 demonstrated a significant difference in muscle activity for the right posterior cervical muscles ($P = .012$), whereas there was no significant difference for the other muscles. No significant muscle activity changes occurred in group 2 (Table 2). When comparing both groups for postintervention changes in muscle activity, no significant difference was present (Table 3). As for cervical ROM, both groups showed statistically significant improvement in extension and right and left lateral flexion ($P < .001$) (Table 2). Both groups revealed the same statistical outputs, thereby indicating both had similar outcomes, showing SM and MET to have an effect on cervical ROM (Table 3).

Discussion

No significant difference in muscle activity was found within and between groups. Our results differ from previous studies reporting changes in muscle activity following either cervical, thoracic and lumbar, lumbar or lumbosacral SM, or lumbosacral MET.[6,10,13,21,23] The mean age values in the present study were significantly younger than those of previous studies, as most participants were students. While age does not appear to influence sEMG levels at rest,[36] there is paucity in the literature concerning the effect of age on the resting sEMG activity generated by the muscles of young, healthy individuals. Ahamed et al.[38] demonstrated that adolescents (17.3 ± 1.4 years) and vicenarians (24.6 ± 2.1 years) exhibit greater muscle activity during maximum voluntary contractions of the biceps brachii than tricenarians (33.2 ± 1.1 years). Therefore, the discrepancy in findings may be explained by the differences in the protocols and the joints tested. Most of the previous

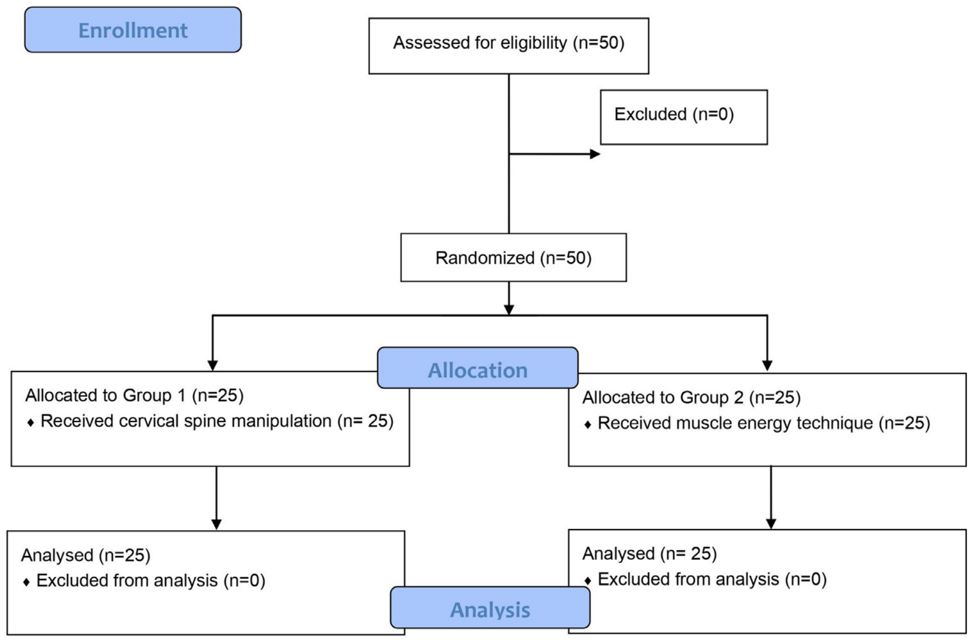

Fig 4. *Participant flow.*

Table 1. *Demographic Characteristics*

	Group 1 (n = 25)	Group 2 (n = 25)	*P* Value
Age (y)	23.56 (2.888)	23.60 (3.109)	.963
Male sex; female sex	11 (44%); 14 (56%)	12 (48%); 13 (52%)	.777

Data are presented as mean (standard deviation) or n (%).

studies tested either corticospinal and spinal reflex excitability,[6] muscle reflex responses,[21] alpha motoneuron pool excitability,[13] or sEMG during active movements.[23] This study tested resting muscle activity. Unlike people with NP, healthy patients do not have abnormally high muscle activity from pain. Thus, a single session of SM or MET may not be enough to elicit changes in the activity of neck muscles in a healthy population. Therefore, no changes

Table 2. *Intragroup Analysis of Changes in Values Between Pre- and Post-treatment*

		Test Statistics[a]						
		Surface Electromyographic Muscle Activity				Cervical Range of Motion		
Group		RPC (pre) to RPC (post)	LPC (pre) to LPC (post)	RUT (pre) to RUT (post)	LUT (pre) to LUT (post)	EXT (pre) to EXT (post)	RLF (pre) to RLF (post)	LLF (pre) to LLF (post)
1	Z	−2.518[b]	−1.413[b]	−1.143[b]	−.552[b]	−3.752[c]	−3.861[c]	−3.877[c]
	Asymp. Sig. (2-tailed)	.012	.158	.253	.581	<.001	<.001	<.001
2	Z	−1.415[b]	−.094[b]	−.624[c]	−1.359[b]	−3.736[c]	−3.550[c]	−3.475[c]
	Asymp. Sig. (2-tailed)	.157	.925	.533	.174	<.001	<.001	<.001

EXT, extension; *LLF*, left lateral flexion; *LPC*, left posterior cervical muscles; *post*, after treatment; *pre*, before treatment; *RLF*, right lateral flexion; *RPC*, right posterior cervical muscles; *RUT*, right upper trapezius muscles.
[a] Wilcoxon signed rank test.
[b] Based on positive ranks.
[c] Based on negative ranks.

Table 3. *Intergroup Analysis*

Hypothesis Test Summary

Null Hypothesis	Test	Sig.	Decision
The distribution of rpc/change is the same across categories of group.	Independent Samples Mann-Whitney U Test	.371	Retain the null hypothesis.
The distribution of lpc/change is the same across categories of group.	Independent Samples Mann-Whitney U Test	.383	Retain the null hypothesis.
The distribution of rut/change is the same across categories of group.	Independent Samples Mann-Whitney U Test	.101	Retain the null hypothesis.
The distribution of lut/change is the same across categories of group.	Independent Samples Mann-Whitney U Test	.290	Retain the null hypothesis.
The distribution of ext/change is the same across categories of group.	Independent Samples Mann-Whitney U Test	.744	Retain the null hypothesis.
The distribution of rlf/change is the same across categories of group.	Independent Samples Mann-Whitney U Test	.936	Retain the null hypothesis.
The distribution of llf/change is the same across categories of group.	Independent Samples Mann-Whitney U Test	.102	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.
ext, Extension; *llf*, left lateral flexion; *lpc*, left posterior cervical muscles; *lut*, left upper trapezius muscles; *rlf*, right lateral flexion; *rpc*, right posterior cervical muscles; *rut*, right upper trapezius muscles.

were observed after SM or MET. One previous study detected significant changes in resting muscle activity after manual and instrument applied lumbar SM.[22] This discrepancy in findings between the previous study and our study might come from the lack of normalization of EMG data. It is generally accepted that raw EMG signals can be used for comparisons between short-term interventions under the same experimental conditions without changes to the electrode setup.[39] However, normalization of data presents pre-post changes as percentages, allowing for more accurate and fair comparisons of data between participants, where significant changes may have been detected.

A statistically significant difference in cervical ROM was found in both groups, consistent with the findings of previous studies.[24,25] These studies demonstrated an immediate increase in cervical ROM following a single session of either cervical SM or MET. In addition, in the current study, both groups acted with equal effectiveness. This is consistent with the findings of Cassidy[20] where a single session of cervical SM and MET in participants with neck pain increased cervical ROM to a similar degree. These results would appear to suggest that SM and MET act with equal effectiveness in producing an immediate increase in cervical ROM. This would strengthen the use of SM in the chiropractic treatment of neck pain and, when SM is contraindicated, provide chiropractors with an alternative, comparatively effective treatment option. However, owing to the many limitations in the present study, the results should be considered with caution. Additionally, in a clinical setting, most interventions are applied more than once; thus, studies with follow-up sessions are required to confirm these results. Furthermore, post-treatment cervical ROM findings might be quite different in a sample more representative of patients in a clinical setting who, on average, may be older with diverse health conditions and degeneration and varying levels of acute and chronic pain. Owing to the development of degenerative changes, age influences the majority of primary and coupled movements, producing a decline in cervical ROM in all primary planes. Thus, cervical ROM decreases with increasing age.[40-43]

Limitations and Future Studies

There are many potential ways that bias could have been introduced into this study, namely that a single individual recruited and screened participants, recorded outcome measures, and performed interventions. Moreover, the individual was a final-year chiropractic student with limited experience in sEMG and the use of the CROM goniometer. However, there were no specific indications that data collection was compromised by the investigator. Future studies should eliminate this bias and consider utilizing practitioners with sufficient experience in using sEMG and the CROM goniometer. Another limitation of the study was a lack of a control group. Thus, it is not possible to solely attribute the changes to a response to the interventions. Additionally, the sample population consisted of young, healthy, asymptomatic participants, which is not representative of participants in a clinical setting, limiting the ability of generalization. Future blinded, controlled studies, consisting of a sample representative of patients in a clinical setting, with EMG data normalization and follow-up sessions, should be conducted to confirm these findings.

Conclusion

This preliminary study showed that a single session of cervical SM or MET on young, healthy, asymptomatic participants did not show statistically significant changes in resting PC and UT muscle activity. However, a single session of SM and MET resulted in significant improvements in cervical ROM that were of equal effectiveness.

Funding Sources and Conflicts of Interest

Funding for this study was provided by Durban University of Technology National Research Fund. No conflicts of interest were reported for this study.

Contributorship Information

Concept development (provided idea for the research): A.A-R.
Design (planned the methods to generate the results): S.L.K.
Supervision (provided oversight, responsible for organization and implementation, writing of the manuscript): A.D., A.A-R.
Data collection/processing (responsible for experiments, patient management, organization, or reporting data): S.L.K.
Analysis/interpretation (responsible for statistical analysis, evaluation, and presentation of the results): S.L.K.
Literature search (performed the literature search): S.L.K.
Writing (responsible for writing a substantive part of the manuscript): S.L.K.
Critical review (revised manuscript for intellectual content, this does not relate to spelling and grammar checking): A. D., A.A-R.

Practical Applications

- We investigated the immediate effects of cervical spine manipulation (SM) compared with muscle energy technique (MET) on neck muscle activity and range of motion (ROM) in asymptomatic people.
- A significant difference was found in cervical ROM within groups ($P < .001$), with no significant difference observed between the 2 groups.
- A single application of SM and MET to the cervical spine immediately increased cervical ROM.
- Neither cervical SM nor MET changed resting posterior cervical and upper trapezius muscle activity.

References

1. Hurwitz EL, Morgenstern H, Harber P, Kominski GF, Yu F, Adams H. A randomized trial of chiropractic manipulation and mobilization for patients with neck Pain: clinical outcomes from the UCLA neck-pain study. *Am J Public Health*. 2002;92(10):1634-1641.
2. Gemmell H, Miller P. Comparative effectiveness of manipulation, mobilisation and the Activator instrument in treatment of non-specific neck pain: a systematic review. *Chiropr Osteopat*. 2006;14:7.
3. Gross A, Miller J, D'Sylva J, et al. Manipulation or mobilisation for neck pain: a cochrane review. *Man Ther*. 2010;15(4):315-333.
4. Hamilton L, Boswell C, Fryer G. The effects of high-velocity, low-amplitude manipulation and muscle energy technique on suboccipital tenderness. *Int J Osteopath Med*. 2007;10(2-3):42-49.
5. Lenehan KL, Fryer G, McLaughlin P. The effect of muscle energy technique on gross trunk range of motion. *J Osteopath Med*. 2003;6(1):13-18.
6. Fryer G, Pearce AJ. The effect of muscle energy technique on corticospinal and spinal reflex excitability in asymptomatic participants. *J Bodyw Mov Ther*. 2013;17(4):440-447.
7. Cardinale M, Boccia G, Greenway T, Evans O, Rainoldi A. The acute effects of spinal manipulation on neuromuscular function in asymptomatic individuals: a preliminary study. *Phys Ther Sport*. 2015;16(2):121-126.
8. Fryer G, Bird M, Robbins B, Johnson JC. Acute electromyographic responses of deep thoracic paraspinal muscles to spinal manual therapy interventions. An experimental, randomized cross-over study. *J Bodyw Mov Ther*. 2017;21(3):495-502.
9. Pickar JG, Kang YM. Paraspinal muscle spindle responses to the duration of a spinal manipulation under force control. *J Manipulative Physiol Ther*. 2006;29(1):22-31.
10. Fryer G, Pearce AJ. The effect of lumbosacral manipulation on corticospinal and spinal reflex excitability on asymptomatic participants. *J Manipulative Physiol Ther*. 2012;35:86-93.
11. Fryer G. Muscle energy technique: an evidence-informed approach. *Int J Osteopath Med*. 2011;14:3-9.
12. Potter L, McCarthy C, Oldham J. Physiological effects of spinal manipulation: a review of proposed theories. *Phys Ther Rev*. 2005;10:163-170.
13. Dishman JD, Bulbulian R. Spinal reflex attenuation associated with spinal manipulation. *Spine*. 2000;25(19):2519-2525.
14. Rudolfsson T, Björklund M, Djupsjöbacka M. Range of motion in the upper and lower cervical spine in people with chronic neck pain. *Man Ther*. 2012;17:53-59.
15. Guo LY, Lee SY, Lin CF, et al. Three-dimensional characteristics of neck movements in subjects with mechanical neck disorder. *J Back Musculoskelet Rehabil*. 2012;25(1):47-53.
16. Bahat HS, Weiss PL, Sprecher E, Krasovsky A, Laufer Y. Do neck kinematics correlate with pain intensity, neck disability or with fear of motion? *Man Ther*. 2014;19(3):252-258.
17. Maroufi N, Ahmadi A, Khatir SRM. A comparative investigation of flexion relaxation phenomenon in healthy and chronic neck pain subjects. *Eur Spine J*. 2013;22(1):162-168.
18. Lascurain-Aguirrebeñ I, Newham DJ, Galarraga-Gallastegui B, Critchley DJ. Differences in neck surface electromyography, kinematics and pain occurrence during physiological neck movements between neck pain and

asymptomatic participants: a cross-sectional study. *Clin Biomech*. 2018;57:1-9.

19. Castelein B, Cools A, Bostyn E, Delemarre J, Lemahieu T, Cagnie B. Analysis of scapular muscle EMG activity in patients with idiopathic neck pain: a systematic review. *J Electromyogr Kinesiol*. 2015;25(2):371-386.
20. Cassidy JD, Lopes AA, Yong-Hing K. The immediate effect on manipulation versus mobilization on pain and range of motion in the cervical spine: a randomized controlled trial. *J Manipulative Physiol Ther*. 1992;15(9):570-575.
21. Herzog W, Scheele D, Conway PJ. Electromyographic responses of back and limb muscles associated with spinal manipulative therapy. *Spine*. 1999;24(2):146-152.
22. DeVocht JW, Pickar JG, Wilder DG. Spinal manipulation alters electromyographic activity of paraspinal muscles: a descriptive study. *J Manipulative Physiol Ther*. 2005;28(7):465-471.
23. Bicalho E, Setti JAP, Macagnan J, Cano JLR, Manffra EF. Immediate effects of a high-velocity spine manipulation in paraspinal muscles activity of nonspecific chronic low-back pain subjects. *Man Ther*. 2010;15(5):469-475.
24. Martínez-Segura R, Fernández-de-las-Peñas C, Ruiz-Sáez M, López-Jiménez C, Rodríguez-Blanco C. Immediate effects on neck pain and active range of motion after a single cervical high-velocity low-amplitude manipulation in subjects presenting with mechanical neck pain: a randomized controlled trial. *J Manipulative Physiol Ther*. 2006;29(7):511-517.
25. Burns DK, Wells MR. Gross range of motion in the cervical spine: The effects of osteopathic muscle energy technique in asymptomatic subjects. *J Am Osteopath Assoc*. 2006;106(3):137-142.
26. Henderson CNR. The basis for spinal manipulation: chiropractic perspective of indications and theory. *J Electromyogr and Kinesiol*. 2012;22(5):632-642.
27. DeStefano LA. *Greenman's Principles of Manual Medicine*. 5th ed. Philadelphia, PA: Wolters Kluwer; 2017.
28. Bergmann TF, Peterson DH. *Chiropractic Technique: Principles and Procedures*. 3rd ed. St. Louis, MO: Mosby; 2011:175-182.
29. Chaitow L. *Muscle Energy Techniques*. 4th ed. Toronto, ON, Canada: Elsevier; 2013.
30. Fernández de las Peñas C, Cleland J, Huijbregts P. *Neck and Arm Pain Syndrome: Evidence-Informed Screening, Diagnosis and Management*. St. Louis, MO: Elsevier; 2011.
31. Thompson SK. *Sampling*. 3rd ed. Hoboken, NJ: Wiley and Sons; 2012.
32. Williams MA, McCarthy CJ, Chorti A, Cooke MW, Gates S. A systematic review of reliability and validity studies of methods for measuring active and passive cervical range of motion. *J Manipulative Physiol Ther*. 2010;33(2):138-155.
33. Fletcher JP, Brandy WD. Intrarater reliability of CROM measurement of cervical spine active range of motion in persons with and without neck pain. *J Orthop Sports Phys Ther*. 2008;38(10):640-645.
34. Mathur S, Eng JJ, MacIntyre DL. Reliability of surface EMG during sustained contractions of the quadriceps. *J Electromyogr and Kinesiol*. 2005;15(1):102-110.
35. De Luca CJ. *Surface Electromyography: Detection and Recording*. Natick, MA: DelSys; 2002.
36. Criswell E. *Cram's Introduction to Surface Electromyography*. 2nd ed. Burlington, MA: Jones and Bartlett Publishers; 2011.
37. Dunning J, Rushton A. The effects of cervical high-velocity low-amplitude thrust manipulation on resting electromyographic activity on the biceps brachii muscle. *Man Ther*. 2009;14(5):508-513.
38. Ahamed NU, Taha Z, Alqahtani M, Altwijri O, Rahman M, Deboucha A. Age related differences in the surface EMG signals on adolescent's muscle during contraction. *IOP Conf Ser: Mater Sci Eng*. 2016;114: 012131.
39. Halaki M, Ginn K. Normalization of EMG signals: to normalize or not to normalize and what to normalize to? In: Naik GR, ed. *Computational Intelligence in Electromyography Analysis: A Perspective on Current Applications and Future Challenges*. Rijeka, Croatia: InTech; 2012:175-194.
40. Malmström EM, Karlberg M, Fransson PA, Melander A, Magnusson M. Primary and coupled cervical movements: the effect of age, gender, and body mass index. A 3-dimensional movement analysis of a population without symptoms of neck disorders. *Spine*. 2006;31(2):E44-E50.
41. Simpson AK, Biswas D, Emerson JW, Lawrence BD, Grauer JN. Quantifying the effects of age, gender, degeneration, and adjacent level degeneration on cervical spine range of motion using multivariate analyses. *Spine*. 2008;33(2):183-186.
42. Lansade C, Laporte S, Thoreux P, Rousseau M, Skalli W, Lavaste F. Three-dimensional analysis of the cervical spine kinematics: effect of age and gender in healthy subjects. *Spine*. 2009;34(26):2900-2906.
43. Park MS, Moon S, Lee H, et al. Age-related changes in cervical sagittal range of motion and alignment. *Global Spine J*. 2014;4(3):151-156.