Title: Localised manual therapy treatment has a preferential effect on the kinematics of the targeted motion segment

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ABSTRACT:

**Aim:** An observational cohort study to determine whether localised manual therapy results in a preferential increase in mobility of the targeted motion segment.

**Method:** Eighteen participants with mechanical neck pain had three MRIs of their cervical spine. The first two were taken prior to treatment in neutral and at the end of active rotation in their more limited rotation. Participants received localised manual therapy targeting a motion segment deemed to be relevant to their presentation until either their range increased by >10 degrees or eight minutes, whichever came first. A third MRI was performed immediately after treatment with their head in the same rotated position as pre-treatment. In the images, each vertebra was segmented using a semi-automated process. Movement between neutral and rotated positions was calculated as Euler angles and distance of facet translations for each motion segment.

**Results:** Rotation and lateral flexion at the targeted location increased by 40% (mean 0.86º (CI: 0.24-1.48)) and 15% (mean 0.52º (CI: -0.17-1.21)) respectively with only the CIs for rotation not containing zero. The mean changes for the non-targeted locations were less than 0.1º for each axis and all CIs contained zero. Facet translations at the targeted location increased by 25% (0.419mm) and decreased by >4% (>0.01mm) at the untreated locations but the wide CIs both contained zero.

**Conclusion:** Localised manual therapy seems to have a preferential effect on mobility of the targeted motion segment. The findings support considering segmental dysfunction in clinical reasoning and the use of specifically targeted manual therapy interventions.
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KEYWORDS:
Tropism
Musculoskeletal System
Range of Motion, Articular
Palpation

KEY PRACTICE POINTS:

- This study provides qualified support for specifically targeted manual therapy treatment.
- Localised spinal manual therapy treatment appears to preferentially increase segmental movement at the targeted motion segment during active movement.
- These kinematic changes in active movement following treatment are consistent with previously reported localised changes in passive stiffness and provides qualified support for targeted manual therapy treatment and a decision process based on identifying and treating movement dysfunctions at an intervertebral level.

INTRODUCTION

Neck pain is one of the most common musculoskeletal disorders worldwide (Jahre, Grotle, Smedbråten, Dunn, & Øiestad, 2020) leading to considerable pain, disability and economic cost (Safiri et al., 2020). So-called mechanical or non-specific neck pain (NSNP) is the most common type of neck pain and people with NSNP often experience a loss of active range of movement (AROM). Spinal manual therapy (SMT) is frequently used by physiotherapiststo treat this condition (Carlesso, MacDermid, Gross, Walton, & Santaguida, 2014) and has been found to be effective for improving neck pain and the associated loss of AROM (Coulter et al., 2019).

How AROM becomes limited in people with NSNP and conversely how AROM improves following SMT however remains a puzzle. There is a lack of consensus on the mechanisms underlying limitations of AROM including whether the effects of SMT are localised and therefore whether the application of SMT should be specifically targeted (Bialosky, Simon, Bishop, & George, 2012). The purpose of this study was to clarify one small piece of this puzzle - is there a preferential effect on
the targeted level when comparing segmental movement pre- and post-SMT? In other words, is it reasonable for SMT to be targeted to a specific level?

One of the challenges in addressing this question is how to measure segmental movement in vivo. Measuring the segmental movement from neutral to the limit of AROM pre-treatment and comparing that with the segmental movement at the increased AROM post-treatment would seem reasonable. However, there are several difficulties with this deceptively simple approach. First, comparing the contributions of individual motion segments at different parts of AROM is problematic because their relative contributions alter through the range of movement to the extent that many motion segments exhibit anti-directional movement during some part of AROM (Qu, Lindstrøm, Hirata, & Graven-Nielsen, 2019).

A second difficulty is illustrated by conditions such as cervical radiculopathy where dysfunction of a single motion segment produces a much greater reduction in AROM than could be accounted for by that motion segment. An example was reported in a case study where the individual developed a C6 cervical radiculopathy with a reduction in AROM of approximately 40° (Tuttle & Evans, 2015). Serendipitously their segmental mobility had been measured prior to their symptom onset and even though radiculopathies would be expected to result from pathology at a single segment, the individual’s segmental mobility was limited proportionately across all levels to the extent that the pathological level could not be identified from the segmental kinematics. If one motion segment can produce a limitation of segmental movement across the entire region, then improvement of that motion segment would also be expected to result in a comparable increase in AROM.

The simple approach of assessing segmental kinematics in different AROM positions pre- and post-treatment would therefore be unlikely to adequately address the question of the presence of a localised effect of SMT. The authors considered that remeasuring segmental mobility in the same AROM position pre- and post-treatment would minimise the noise and be more likely able to detect a preferential change in the targeted motion segment. For example, if movement of the target
location lagged slightly behind its normal contribution pre-treatment, and that lag decreased post-treatment, then this difference would be more likely to be detectable with re-imaging in the same position. It is worth noting that where segmental movement is limited by structure rather than pain, such as following a surgical fusion, a regional loss of mobility may not occur (Anderst, Lee, Donaldson, & Kang, 2013).

The aims of this study were: 1) to determine if there is a preferential effect of treatment with localised non-thrust SMT on the segmental movement at a targeted level in participants with neck pain. It was hypothesised that there would be an increase in segmental mobility post-treatment at the targeted location but not at other locations; and 2) to determine if there was a different response for participants with higher and lower pain levels. It was thought that the movement in participants with higher level of pain may behave like the example of someone with a cervical radiculopathy whereas a local effect might be more obvious in those with lower pain levels.

Methods

Eighteen participants from the university community with ≥3-month history of NSNP volunteered to participate in the study. The inclusion criteria were: 1) AROM in cervical rotation on one side limited by > 15° compared to their other side; 2) the ability to tolerate their head in the position of onset of pain for at least four minutes while measurements were performed; and 3) a localised, hypomobile, symptomatic segment could be identified clinically by one of the researchers. Participants were excluded if they had any contraindications to SMT. Participants were asked to rate their maximum pain intensity over the past week with zero being no pain and 10 being worst pain imaginable. Level of pain was dichotomised based on their maximum pain over the past week with low being 4/10 or less and high being 5/10 or greater.

A sports mouthguard was moulded for each participant to standardise their rotated position. Each participant had three magnetic resonance imaging (MRI) scans in supine. The first in a neutral position and the second with their head rotated to the onset of pain in the limited direction. The
rotated head position was controlled by having the participant’s head in a custom-made acrylic frame. A cable tie between the frame and their mouthguard was adjusted so the position could be repeated for the post-treatment scan (Figure 1).

Figure 1 Frame for ensuring repeatable positioning. A) shows the acrylic frame with an individually moulded sports mouthguard attached with a cable tie. B) shows the frame in use. The participant turned to the onset of pain and the cable tie adjusted to that length. The yellow arrow shows where the cable tie attaches to the frame.

The range of active movement was assessed with a bubble inclinometer (Baseline, Fabrication Enterprises, White Plains, New York, USA) in supine.

The location that was deemed to be hypomobile and contributing to the participant’s symptoms was determined using a tiered approach (Tuttle & Hazle, 2018). Briefly a ‘first pass’ using either posterior-anterior (PA) or anterior-posterior (AP) movements was used to select the motion segments which were potentially symptomatic. This first pass was performed with low force (typically less than about 10N which was not provocative of symptoms) and without questioning the patient on symptom reproduction. The levels selected as potentially symptomatic were then explored further using accessory and physiological movements and the patient was questioned on
symptom reproduction to determine which level was most relevant to their symptoms. The location was marked by a small vitamin E capsule taped to the skin so that it would be visible on MRI.

Localised manual therapy was performed with the intention of increasing the mobility of the selected location. Non-thrust techniques using accessory and/or physiological movements were selected by the therapist and applied according to an empirical reflection-in-interaction approach (Tuttle & Hazle, 2019). Briefly the mobility of the symptomatic location was assessed in both accessory and physiological movements. The most limited type (accessory or physiological) and direction of movement was selected. Direction of limitation was considered in three dimensions (e.g. a combination of rotation, lateral flexion and flexion/extension for physiological movements or a combination of AP/PA, medial/lateral, cephalad/caudad for accessory (translational) movements). Parameters of the technique including the force, amplitude, speed, and rhythm were adjusted in real-time to maximise the moment-to-moment change in the limitation (considering stiffness and/or pain response).

The range of active movement was reassessed every one or two minutes and treatment was continued until either AROM was increased by 10° or eight minutes had elapsed. A third MRI was taken using the frame, mouthguard and cable tie to ensure the participant’s head was in the same position as pre-treatment. Repeatability of the positioning was evaluated prior to data collection and repeated positions were found to be within +/- 2.0°.

Imaging and processing were performed according to our previous study on the reliability of the methodology (Tuttle & Evans, 2015). Specifically, A 3-T MRI scanner (Ingenia, Philips Medical Systems, Best, The Netherlands) with a neck coil having a field of view of 25 cm, an acquisition matrix of 256 x 256 giving a voxel size of 1mm isotropic, and a reconstructed matrix of 512 x 512 to display a voxel size of 0.5mm isotropic. A 3D magnetization prepared T1 gradient echo sequence was used with a 1 mm slice thickness and no interslice gap.
Mimics V17.9 and 3Matic V9 (Materialise NV) were used to process the images. Each vertebra was segmented with a semi-automatic procedure. The centre of facet (COF) for the inferior facets on each side of each vertebrae from C2 to C7 were determined by manually drawing an outline of the facet and using an automated software function to calculate the centre. An automated voxel-based registration using 3Matic was used to align contours and determine 1) the Euler angular movement calculated using the order Flexion/extension (X), Lateral Flexion (Y), Rotation (Z), and 2) the facet movements calculated as a single value for the translation of the COF of each side (contralateral and ipsilateral). ICCs for angles and facet translations using this method were reported previously to be from 0.80 to 0.99 (Tuttle, Rocha, Sheehan, Kennedy, & Evans, 2019). The Limits of agreement indicating the range within which 95% of repeated measures of rotation and translation would lie was 2.73°. It is useful to note that approximately 1/4 of this variance was due to error in repeated measures of vertebral position and the remainder likely due to the fact that the segmental contribution of individual motion segments varies with repeated movements (Bogduk & Mercer, 2000).

The likely effect size for this study was unknown prior to commencement so a power calculation was not possible at that time. A post-hoc power analysis was therefore performed using GPower (Faul, Erdfelder, Buchner, & Lang, 2009). The sample size of n=18, an alpha of 0.05, a mean change in rotation of the targeted locations of 0.91 and a standard deviation (from (Tuttle et al., 2019)) of 1.36 resulted in an effect size of 0.67 and a power of 0.85.

**Statistical Analysis**

Descriptive statistics were calculated for angles by level, axes, time point and marker location. Initially, a repeated measures ANOVA was used to investigate the effect of target location on pre-post angular movement and facet translation. Pain (and axis for angular movement) were included as factors. The x axis (flexion/extension) angles and the facet translations were not normally distributed, as assessed by Shapiro-Wilk's test nor did they meet the assumption of sphericity as
assessed by Mauchly's test. When neither assumption is met, it has been proposed that the appropriate method of analysis is to compare confidence intervals (CIs) of change values calculated using a bootstrapping approach (Berkovits, Hancock, & Nevitt, 2000). Bootstrapping the original data with 1000 resamples with replacements was therefore used to determine the means and CIs.

Ethics approval was obtained from the university’s Human Research Ethics Committee (PES/34/11/HREC). The study was registered with the Australia New Zealand Clinical Trials Register (ANZCTR) ACTRN12612000262808 prior to data collection.

RESULTS

Out of the 18 participants there were 11 females and 7 males with a median age of 37 years (range 18 – 67) who had symptoms for a median duration of 48 months (range 3 – 240). Participants rated their pain on an 11-point Likert scale (0–10) over the preceding week as 2.3 (SD 1.9) and 3.2/10 (SD 2.7) for their average and maximum respectively. Ten participants had maximum pain in past week < 4/10 so were classified as low pain and the remaining eight were high pain. The frequency of locations deemed to be symptomatic for C2/3, C3/4, C4/5, C5/6, C6/7 were 4, 2, 6, 4, 2 respectively.

Angles

Several outliers were found on inspection of boxplots of pre-treatment angles. Rechecking the original MRI scans indicated that these were genuine unusual values so they were retained in the data for analysis. Pre-treatment, the movement in the flexion/extension axis was small (about 0.1 degree) for both the control and targeted locations but the movements are in the opposite directions resulting in the confidence intervals not overlapping. The movements in rotation and lateral flexion for each level averaged between 1° and 3°. The large variance indicated by the confidence intervals being at least as large as the mean value precluded being able to detect any differences in pre-treatment mobility between the control and symptomatic locations (Figure 2A).
There was a difference in amount of movement by level where C7/T1 had less movement in rotation and lateral flexion than the other levels.

Figure 2B shows the change in angles from pre- to post-treatment by targeted location. The mean changes pre- to post-treatment at the targeted levels for rotation and lateral flexion increased by 40% (0.86º, CI: 0.24 to 1.48) and 15% (0.52º, CI: -0.17 to 1.21) respectively. For flexion/extension, changes in Euler angles for each group were minimal being less than 0.05º with large confidence intervals. For the non-targeted locations, changes for all axes were less than 0.1º. All confidence intervals included zero indicating no detectable change in movement from pre- to post-treatment.

Contrary to our second hypothesis, when pain categories were considered, no differences were detected between the high and low pain groups. There were no differences in the pre-treatment angular movement between the symptomatic and control locations except in the flexion/extension axis where the symptomatic levels showed slight flexion (0.11º, CI 0.08 to 0.14) while the control location showed slight extension (0.10º, CI 0.09 to 0.11).
Figure 2. Angular movement and facet translations of control and symptomatic locations. For all graphs, the “+” or “o” markers indicate individual motion segments. The darker horizontal lines indicate the 95% CI of the means (thinner horizontal line or solid circle indicate the means). 2A shows the pre-treatment movement of the control and symptomatic sides for each axis. 2B shows the change in angular movement from pre- to post-treatment. Rotation of the symptomatic location is the only movement which increased significantly as indicated by the CI not including zero. 2C shows the pre-treatment translations of the contralateral and ipsilateral facets. 2D shows the change in facet translations from pre- to post-treatment. The means are greater for the symptomatic locations but CIs for both locations include zero.

**Facet Translations**

Four outliers were found on inspection of boxplots, all of which were in the non-marker locations on the contralateral side of the post-treatment measures and all were higher than the range of other values. The measurements were rechecked from the original MRI scans and found to be genuine.
outliers so they were retained in the data for analysis. Figure 2C shows the pre-treatment scans. The translations of the ipsilateral and contralateral sides were similar being 1.60mm (CI: 1.43 to 1.78) and 1.61mm (CI: 1.45 to 1.78) respectively. The means were also similar for the control (1.60mm, CI: 1.46 to 1.74) and targeted (1.66mm, CI: 1.31 to 2.01) levels. The mean translation for C7/T1 facets was less than the other levels for both the ipsilateral and contralateral sides, but the confidence intervals were only non-overlapping for comparisons between the mean translations for C7/T1 and C3/4 and C4/5.

Figure 2C and 2D show the change in facet translations from pre- to post-treatment. The mean change for both the contralateral and ipsilateral facets were positive, however the width of the confidence intervals being at least four times the mean change, precluded being able to be confident of there being a real change. No differences were detected in pre-treatment facet translations between the levels deemed to be symptomatic or asymptomatic.

DISCUSSION

The first aim of this study was to determine if there were preferential effects on the segmental movement at a targeted level in patients with neck pain following treatment with localised non-thrust SMT. It was hypothesised that since the total rotation was the same, that the movement of the targeted segment in the post-treatment scan would be greater than the pre-treatment scan. The first hypothesis that the movement at the targeted level would increase post-treatment was supported. The mean change in movement at the targeted location post treatment was greater than zero for Euler angles of rotation and lateral flexion as well as translation of both ipsilateral and contralateral facets, but only for rotation did the confidence intervals not contain zero. The size of the confidence intervals could suggest that the current study was underpowered to detect changes in lateral flexion or facet translations. The second hypothesis that a localised response may be more apparent in patients with lower pain levels was not supported.

Segmental movement
The results indicate that, at least to some extent, SMT has a localised effect on the targeted location during active movement and would suggest that limited segmental mobility contributes to limited AROM in people with neck pain. This is consistent with previous studies that found localised movement to be less in locations where there is spondylosis in symptomatic individuals (Nagamoto et al., 2011).

The current study investigated segmental mobility of the cervical spine using vertebral kinematics during AROM. Another way of evaluating segmental mobility is using translational passive movements such as posterior-anterior (PA) movements where increased stiffness in PA movements is consistent with decreased mobility in the underlying motion segment (Tuttle & Hazle, 2018). The results of several studies using PA movements have been comparable to the results in the current study. PA stiffness has been found to be greater in the cervical spine at locations that are more tender (Tuttle, Barrett, & Laakso, 2009) or locations that are deemed to be symptomatic (Ingram, Snodgrass, & Rivett, 2015; Tuttle, Barrett, & Laakso, 2008). Furthermore, SMT targeting a symptomatic location resulted in a reduction in PA stiffness only at the targeted location and a corresponding increase in AROM (Tuttle et al., 2008). It appears that segmental movement, whether assessed by active movement in the current study or passive movement in previous studies, improves preferentially at targeted locations following SMT.

The 9° or greater improvement that occurred following treatment in all except 2 of 18 participants in this study cannot be accounted for by increased movement at a single motion segment. Similar to the limitations of AROM that occur in patients with a radiculopathy, it appears that limited segmental mobility only directly accounts for part of the reduction of AROM that occurs in people with NSNP. Other factors that contribute to the reduction of AROM may include systemic or regional neurophysiological responses (Bialosky et al., 2017). Alternatively, when AROM reaches the point where the movement at one segment is limited by pain, patients may not have a sufficient ability to differentiate movement to allow other levels to move while the painful one remains immobile.
Segmental kinematics in the lumbar spine seem to be similarly affected by either structural factors or by pain (Seerden et al., 2021). For both the cervical and lumbar spines, either reduced structural mobility or pain appear to be able to limit segmental movement during AROM. The findings of the current study would suggest that segmental limitation occurs and impacts on the kinematics of the cervical spine in ways that are perhaps somewhere between what would occur in a very painful condition such as a cervical radiculopathy and in a non-painful structural limitation such as following a surgical fusion.

**Local vs general treatments**

Currently, the most accepted paradigm for the effects of SMT is that impaired mobility results from muscular responses to pain. Mechanical stimuli from SMT then produces neurophysiological effects on pain and thereby reduces patient impairments (Bialosky et al., 2017). There is however considerable disagreement whether SMT has localised or generalised effects and, as a result, whether treatments should be specifically targeted (Bialosky et al., 2012). Although a thorough discussion of this topic is far beyond the scope of this paper, there are difficulties with both of the current concepts of generalised and local effects of SMT.

Responder and segmental decision processes are two of the main reasoning approaches used by physiotherapists in treating patients with musculoskeletal conditions (Bialosky et al., 2012). Responder decision processes suggest that patients with a certain pattern are likely to respond to a given treatment approach. This process formed the basis for clinical prediction rules in the past few decades which have been criticised for there often being a lack of a rational relationship between the predictors and their effect (Bialosky et al., 2017). The idea of a generalised effect is based on the idea that the therapeutic effect of SMT is mediated by the central nervous system (Schmid, Brunner, Wright, & Bachmann, 2008) and is supported by findings that diffuse neurophysiological responses with the potential to produce analgesic effects occur following SMT (Bialosky et al., 2017). Other studies have found that these particular neurophysiological responses do not actually have an effect.
on pain (Soon et al., 2010) and, even when the neurophysiological responses are found to occur and patients improve with SMT, the neurophysiological responses are short lived and do not appear to be related to the presence or extent of patient improvement (Lascurain-Aguirrebeña, Newham, Casado-Zumeta, Lertxundi, & Critchley, 2019; Lascurain-Aguirrebeña, Newham, Galindez-Ibarbengoetxea, et al., 2019).

The idea of the presence of localised segmental dysfunction and a localised effect of treatment has been central to the teaching of most approaches to SMT and forms the basis for what has been referred to as a segmental decision process. There are a number of difficulties with this process including the unreliability of motion palpation to detect dysfunction (Bialosky et al., 2012). There has also been a suggestion that if alterations of movement do exist that they can be related to anatomical factors such as tropism (asymmetry of the orientation of the facets). A secondary of analysis of the data from the current study, however, indicates that the extent of tropism is unlikely to impact on segmental movement (Tuttle, Evans, & Sperotto dos Santos Rocha, 2021).

Although it still relies on a number of ‘black box’ elements, a mechanism for SMT has been previously proposed where mechanical input from the therapist results in a generalised neurophysiological pain mediating response and that for ‘responders’ it may not matter what specific treatment is used or where it is applied (Bialosky et al., 2017). The current study and others described above suggest that SMT does, at least to some extent, have segmental effects. It may therefore be reasonable to expect that it does matter where a treatment is applied because the effects of treatment to one location are likely to be different to the effects of treatment to another location.

It is important to reiterate that the findings of this study are about patterns of changes in movement and cannot be construed to indicate the mechanisms for those changes – they clarify the relationship between inputs and outputs, but do not provide us with a glimpse inside the black box.

**Implications for clinical practice**
With the lack of a clear mechanism for how SMT works, we can consider there to be a “black box” where the inputs and outputs may be known, but what happens within the box is not. As a result, many therapists, whether they use a responder or segmental decision process consider it reasonable to use a patient response model were assessment of change in patient functional limitations or active impairments guides further decision making (Tuttle, 2009).

Even though there is not a clear cause and effect mechanism for the relationship between limitation of segmental mobility and limitations of AROM, there is a correlation between them. As a result, changes in segmental mobility can be expected to correspond with changes in AROM. A reflection-in-interaction approach has been proposed (Tuttle & Hazle, 2019) where rather than SMT treatments being pre-determined from a priori findings (such as patterns in a patient’s history and physical assessments), SMT treatments can be informed in real time by changes in factors considered to be related to patient symptoms (such as segmental stiffness, pain, or muscle tone).

The current study provides further support for this reflection-in-interaction approach where a given SMT technique can be continually adjusted to maximise the change in segmental stiffness with the testable expectations that it will maximise the change in impairments on reassessment after the treatment and change in functional limitations.

The findings in the current study that only movement in a rotational axis was significantly increased following treatment should not be taken to indicate a preferential change only occurs in segmental rotation. Lateral flexion and facet translations were also more likely than not to have increased, but it is not possible to be 95% confident of there being a real change in those movements.

**Limitations**

The complexities of addressing the questions in this study were not fully appreciated at the outset. What is apparent is that it is probably not possible to predict the way that a specific limitation of an individual motion segment would impact on either AROM or segmental kinematics in other motion segments. Only rotational AROM was investigated in the current study and other effects may have
been apparent if other axes of movement were considered. Changes in segmental mobility may also have been more apparent if one could evaluate movement through range rather than only to a specific point in AROM, but this too has its own difficulties (Qu et al., 2019). The lack of specific inclusion/exclusion criteria is both a strength and weakness of this study. Finally, it is important to reiterate that this study in no way provides any indication of the mechanism for either limitation of segmental mobility in patients with neck pain or their response to SMT.

Summary and conclusions

Since one rarely has access to kinematics before someone develops symptoms of neck pain, this study took the opposite approach by considering how the kinematics changed following improvement in symptoms following SMT. The findings were that limitation of individual segmental movements occur in people with neck pain and that those limitations of movement at a targeted location improved preferentially after targeted SMT. This study does not suggest answers to other aspects of the puzzle. Specifically, it does not provide any further clarity on the mechanisms of SMT.

The implications for clinical practice are that it seems reasonable 1) to use a segmental decision process in patients with neck pain and 2) to apply a reflection-in-interaction approach to the application of SMT where moment to moment changes in segmental mobility can be used to guide decisions on moment-to-moment adjustments in technique.


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Highlights:

- Spinal manual therapy preferentially effects kinematics at the targeted level
- This study provides support for specifically targeted manual therapy treatment
- Findings are consistent with localised changes in PA passive stiffness