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Original article

No difference in pressure pain threshold and temporal summation after lumbar spinal manipulation compared to sham: A randomised controlled trial in adults with low back pain

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ABSTRACT

Background: Changes in quantitative sensory tests have been observed after spinal manipulative therapy (SMT), particularly in pressure pain thresholds (PPT) and temporal summation (TS). However, a recent systematic review comparing SMT to sham found no significant difference in PPT in patients with musculoskeletal pain. The sham-controlled studies were generally low quality, and conclusions about other quantitative sensory tests could not be made.

Objectives: We aimed to perform a sham-controlled study with the specific objective of investigating changes in PPT and TS short-term after lumbar SMT compared to sham manipulation in people with low back pain.

Methods: This was a double-blind randomised controlled trial comparing high-velocity low-amplitude lumbar SMT against sham manipulation in participants with low back pain. Primary outcome measures were PPT at the calf, lumbar spine and shoulder, and TS at the hands and feet. These were measured at baseline, then immediately, 15 min and 30 min post-intervention.

Results: Eighty participants (42 females) were included in the analyses (mean age 37 years), with 40 participants allocated to each intervention group. Significant between-group differences were only observed for calf PPT, which could be explained by a decrease in PPT (increased sensitivity) after SMT and an increase after sham. Feet TS decreased significantly over time after both SMT and sham, and any other changes over time were inconsistent.

Conclusions: Our results suggest that lumbar SMT does not have a short-term hypoalgesic effect, as measured with PPT and TS, when compared to sham manipulation in people with low back pain.

1. Introduction

1.1. Background

Many individuals with spinal pain undergo spinal manipulative therapy (SMT) in an attempt to relieve their symptoms. SMT is now included in many international guidelines, particularly for the management of non-specific low back pain (LBP) (Almeida et al., 2018). Unravelling how SMT affects spinal pain may facilitate better targeting of SMT and improved clinical outcomes.

It has been suggested that reduction in pain sensitivity in response to SMT (manipulation-induced hypoalgesia) may be a mechanism contributing to the clinical pain relief some people report after SMT (Randoll et al., 2017; Bialosky et al., 2009a; Zafereo and Deschenes, 2015). This area of research predominantly focuses on assessing quantitative sensory testing (QST) outcomes, in particular pressure pain threshold (PPT) and temporal summation (TS). PPT is the threshold at which gradually increasing pressure causes pain (Fischer, 1990). PPT has been found to be decreased in a variety of musculoskeletal pain conditions (Arendt-Nielsen et al., 2018; Cruz-Almeida and Fillingim, 2014). It does not appear to correlate directly with subjective pain severity (Hübscher et al., 2013), but there is limited evidence that

Abbreviations: HVLA, high-velocity low-amplitude; PPT, pressure pain threshold; SMT, spinal manipulative therapy; TS, temporal summation; QST, quantitative sensory testing

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changes in PPT may be responsive to subjective changes in neck pain (Walton et al., 2014). TS is a measure of how subjective pain severity changes over a series of painful stimuli repeated at intervals of 3 s or less (Herrero et al., 2000). The severity typically increases ('summation'), and this increase appears to be heightened in a variety of chronic pain conditions (Arendt-Nielsen et al., 2018; Cruz-Almeida and Fillingim, 2014).

1.2. Previous research

A recent systematic review with meta-analysis in musculoskeletal pain populations concluded there was low-quality evidence that SMT did not result in greater changes in PPT compared to sham (Aspinall et al., 2019a), which is in contrast to a systematic review in asymptomatic participants that concluded SMT resulted in increased PPT (decreased sensitivity) compared to sham (Honoré et al., 2018). Several reviews have also concluded that PPT increases in the short term following SMT compared to baseline, although there are conflicting conclusions about whether these changes occur regionally (close to the site of SMT and in neurologically related regions, e.g. the low back and lower limb for lumbar SMT) or systemically (Aspinall et al., 2019a; Coronado et al., 2012; Voogt et al., 2015).

Studies in asymptomatic and symptomatic populations have observed significant attenuation of TS in the short term after lumbar SMT at the feet but not at the hands (Penza et al., 2017; George et al., 2006; Bialosky et al., 2009b), and after thoracic SMT at both the feet and hands (Bishop et al., 2011). Since none of these studies compared SMT to sham manipulation, the meaning of the apparent difference between hand and feet TS is unknown.

The vast majority of studies investigating PPT and TS after SMT measure the outcomes before and at only one time point after intervention, typically within 5 min (Aspinall et al., 2019a; Honoré et al., 2018). Thus the time course of any changes in PPT and TS after SMT is unknown. For example, hypoalgesia may develop gradually over a longer time period, or may quickly peak and then return to baseline. The time course has implications for the clinical relevance of changes in PPT and TS. A review in musculoskeletal pain populations noted that other types of QST have been tested in limited studies, with only suprathreshold heat response changing after SMT in a single study (Aspinall et al., 2019a). We have chosen to focus on PPT and TS, since they have the most evidence for changes over time after SMT.

The literature in this area suffers from numerous shortfalls. In musculoskeletal pain populations, there are few sham-controlled studies (none assessing TS), and most are low quality with sham interventions that involve holding the participant in a pre-manipulative position, without assessing the believability or credibility of the sham (Aspinall et al., 2019a). It is generally accepted that a portion of the pain relief associated with manual therapies is attributable to non-specific factors including placebo (Bialosky et al., 2009a, 2017), thus comparing SMT to a credible sham intervention is important. Additionally, it has been pointed out that numerous prior studies in musculoskeletal pain populations do not appear to be adequately powered, and very few attempt to control for the potential impact of psychosocial variables (e.g. pain catastrophising) on outcomes (Aspinall et al., 2019a).

1.3. Rationale and research questions

With these gaps in mind, we aimed to perform a high-quality study in a LBP population to investigate short-term changes in PPT and TS after lumbar SMT compared to a credible sham intervention. We intended to investigate the time course of any changes with multiple repeated measures post-intervention, as well as the location of any changes by measuring at multiple testing sites. Our research questions were as follows:

1. Do PPT (measured at the lumbar spine, calf, and shoulder) and TS (measured at the feet and hands) change in the 30 min following lumbar SMT compared to sham manipulation, in people with LBP?
2. Do PPT and TS change from baseline to post-intervention in each group, and if so, which testing sites are affected?

2. Methods

This manuscript contains a planned primary analysis using a subset of data from a trial, and only the relevant methods and data for the above research questions are reported here. The study was a double-blind two-arm randomised controlled trial, which was prospectively registered with ANZCTR (ACTRN12617001094369) and received approval from the Murdoch University Human Research Ethics Committee (approval 2017/177).

2.1. Participants

Participants were recruited from the Murdoch University campus and from the general public, in Perth, Western Australia, using electronic university-wide announcements, campus flyers, and Facebook advertising. The study was open to individuals aged 18–60 years who could say 'yes' to the statement 'I have been bothered by lower back pain at some time in the last 12 months'. However, participants did not need to have current LBP.

Exclusion criteria were: a) suspected or confirmed contraindication to high-velocity low-amplitude (HVLA) lumbar SMT (e.g. recent lumbar disc herniation, active lumbar radiculopathy, osteoporosis, inflammatory arthritis, history of lumbar spine surgery), and b) any other condition that might affect pain sensitivity measurements (upper or lower limb sensory changes, neurological condition, fibromyalgia or chronic widespread pain, or skin conditions at any of the QST testing sites). These were identified by self-report, or clinical suspicion by the assessor based on history and examination. Participants were asked not to take pain-relieving medications, recreational drugs, or excessive alcohol in the 24-h prior to participating, and not to have chiropractic treatment for seven days prior. Additionally, participants could not be chiropractic students or chiropractors, to reduce issues with expectancy bias and to improve blinding.

2.2. Procedure

Participants attended the university campus. All visits were performed in the same temperature-controlled research room. At the visit, participants completed informed consent and a questionnaire on demographic information, LBP intensity, LBP trajectory, pain catastrophising, and anxiety. These characteristics were to aid in describing the participants, assessing randomisation success, and to potentially include as modifiers during statistical analyses. Anxiety and pain catastrophising were measured since PPT may be influenced by both anxiety (Rhudy and Meagher, 2000) and pain catastrophising (Walton et al., 2014), and TS may also be influenced by anxiety (Robinson et al., 2004). Participants were informed that they would receive one of two possible chiropractic treatments and were unaware that they might receive a sham manipulation. A focused LBP history and physical examination were performed by the assessor, including ranges of motion, orthopaedic and neurological tests. Participants were instructed on the QST procedure and given at least two practice attempts for each QST on one forearm, before lying prone on a treatment table. The assessor ensured the participant was comfortable and marked the five QST sites on the skin bilaterally. Baseline QST was then performed. A full round of QST took roughly 10 min to complete. All QST was conducted by the same assessor, the first author, who had substantial prior experience with PPT and TS testing.

Next, the assessor left the room to remain blind to the intervention and a treating clinician entered. Participants were randomly allocated

to one of two groups: a) an HVLA SMT targeting the L5 segment or b) a sham lumbar intervention. Random allocation was achieved using sequentially numbered, sealed, opaque envelopes containing the randomisation code, created by a researcher not involved in participant interaction. The randomisation sequence was generated using an online random number generator with 40 in each group.

Following the intervention the assessor re-entered the room and tested QST immediately, then 15 and 30 min post-intervention. Participants waited quietly between measurement rounds. On the following day (roughly 24 h later if possible), each participant was contacted by phone to answer a number of pre-determined questions about blinding.

2.3. Questionnaires and telephone interview

The self-reported LBP intensity questionnaire asked participants about their current LBP intensity, average LBP (when in pain) over the last 24 hrs, worst LBP in the last 24 hrs, and best LBP in the last 24 hrs, on 0 to 10 numerical rating scales (NRS) where 0 = no pain and 10 = worst pain imaginable.

The Visual Trajectory Questionnaire asked participants to self-identify their pattern of LBP using visual and written descriptions (Dunn et al., 2017). Participants were asked to select the one that most closely matched their LBP experience over the preceding year. There were five options: a) a single LBP episode, b) multiple LBP episodes, c) milder LBP most of the time with flare-ups, d) LBP most of the time that fluctuates, and e) severe LBP most of the time (Dunn et al., 2017). This questionnaire has shown acceptable criterion validity compared to LBP trajectories based on frequent text messages, as well as face and construct validity (Dunn et al., 2017). Participants were dichotomised as episodic or persistent LBP sufferers based on their response, where a) and b) were categorised as episodic, and c) through e) were categorised as persistent.

The Pain Catastrophizing Scale included 13 items asking about aspects of negative thoughts and feelings that people may experience during painful events. It is scored from 0 to 52, with a higher score indicating greater catastrophising. It has shown internal consistency, construct validity, and discriminative ability between a clinical pain population and community population (Osman et al., 2000).

The Patient Reported Outcomes Measurement Information System (PROMIS®) Short Form v1.0 –Anxiety 6a asked participants to rate how frequently they experienced six feelings associated with anxiety over the previous seven days. Raw scores were converted to a T-score (conversion information available from PROMIS), with a mean of 50 and standard deviation of 10 based on the general population in the United States. The short form is internally consistent with the full length questionnaire (Pilkonis et al., 2011), and has been reported to have good discriminative ability and to be responsive to change in various clinical populations (Schalet et al., 2016). A study in surgical patients found the questionnaire to have high concurrent validity when compared to a diagnostic anxiety questionnaire (Purvis et al., 2018).

The blinding question asked participants to respond with 'yes' or 'no' to "*Do you think you received a real treatment?*"

2.4. Quantitative sensory testing procedures

During each round of QST, PPT was measured first followed by TS. PPT was measured following a circuit (Bisset et al., 2015), measuring each site three times bilaterally at the following locations: a) mid-belly of the medial gastrocnemius, b) 2 cm adjacent to the L5 spinous process, and c) mid-belly of the middle deltoid. TS was measured by alternating between sides to take three measurements at each site bilaterally, at the following locations: a) middle of the anterior transverse arch of the plantar feet, and b) middle of the proximal transverse arch of the palmar hands.

PPT was measured following a standard protocol (Fischer, 1987), using a calibrated digital pressure algometer (Wagner FPIX 50, USA) with a circular 1 cm^2 rubber probe connected to a laptop. The probe was placed perpendicularly to the skin and pressure increased at a rate of 500 g/sec with the assessor visually monitoring the real-time force reading on the digital display. The participant was asked to say "Yes" as soon as the sensation of pressure became painful. The assessor then removed the algometer and the threshold was recorded electronically by the laptop. For data analysis, the final two measures were averaged (Lacourt et al., 2012).

TS was elicited using a painful pinprick stimulus (Neuropen with Neurotips, Owen-Mumford). We pre-tested the protocol and device (Aspinall et al., 2019b). Each stimulus was delivered by pressing the sharp tip into the testing site until markers on the Neuropen lined up. A single stimulus was given, followed by a series of five stimuli at a rate of one per second (with the assistance of a metronome), in the same 1 cm^2 area of skin. The participant verbally rated the severity of pain and sharpness of the first stimulus and the final stimulus on a 101-point NRS (0 = no pain, 100 = worst pain imaginable). TS was calculated for each participant by subtracting the mean first pinprick rating from the mean final pinprick rating.

2.5. Interventions

The active intervention involved an HVLA SMT using a side-lying technique targeting the L5 vertebra on one side. The participant was placed in a side-lying position, with the target side up, superior leg bent at the hip and knee, and arms folded. The clinician then stabilised the participant through their upper arm while rotating the thoracolumbar spine. A rapid anterior thrust targeting the L5 mamillary process was delivered with the hypothenar aspect of the clinician's contact hand, in conjunction with the clinician's body drop (Bergmann and Peterson, 2011).

The sham intervention involved similar positioning to the real SMT, but contacting over the upper medial gluteal musculature with a broad non-specific palm contact. The participant's spine was kept relatively neutral with around 90° hip flexion, to minimise tension on the spine. A slow, gentle, non-specific 'thrust' was delivered into the gluteal musculature in conjunction with a small 'body drop' from the clinician. The sham was intended to mimic the active intervention in positioning and hands-on contact, and to give the participant the perception that 'something happened'. This technique has been used in a previous trial and demonstrated acceptable ability to deceive participants (Chaibi et al., 2015). See Fig. 1 for photographs.

The intervention targeted either the participant's most symptomatic side, or, if their symptoms were central or equal bilaterally, was randomly allocated to left or right. Clinicians could perform the intervention a second time if they felt the first was unsuccessful (if delivering the SMT) or unconvincing (if delivering the sham). They recorded whether a second thrust was performed and whether they heard a cavitation occur.

Seven chiropractors were involved in delivering interventions in this study (for logistical reasons). Each had at least 3 years' clinical experience and regularly used the SMT technique applied in this study. All clinicians were trained individually or in groups of two on the procedure, while remaining blind to the specific objectives of the study. They were instructed in detail on the active and sham interventions, and to remain polite and professional while avoiding altering participants' expectations. They were each provided with reference cards before each intervention to aid their recall of the procedure, and a video recording of the sham manipulation for reference.

2.6. Statistical analysis

In order to detect a 15% change (effect size 0.64) in lumbar PPT with 80% power and alpha at 5%, a sample size of 40 per group was required (Waller et al., 2015, 2016). Data were analysed using Stata/IC

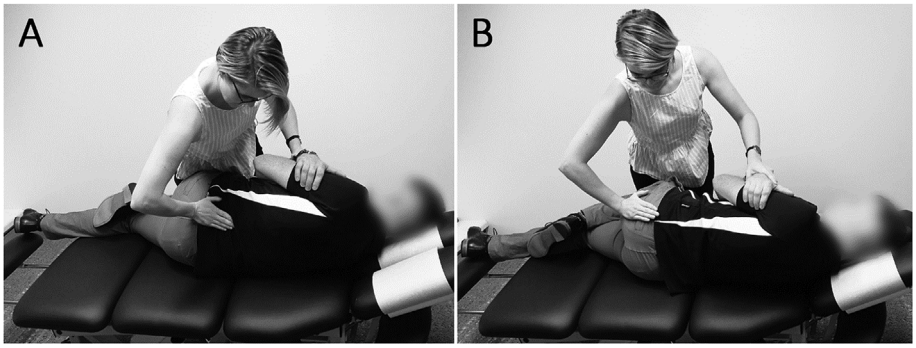

Fig. 1. Photographs of interventions, a) spinal manipulative therapy, b) sham manipulation.

v15.1 (StataCorp, USA). Descriptive data are reported as mean and standard deviation, or median and interquartile range, and range (if continuous), or frequency distribution (if categorical). Univariate comparisons of baseline characteristics between intervention groups where done with chi-square tests (categorical data) and independent t-tests (continuous data).

After graphical inspection, PPT and TS data were observed to be significantly left-skewed with numerous outliers. Log-normal transformation was most appropriate for PPT. For TS, adding a constant value of 12 (making all values positive) followed by log-normal transformation resulted in approximately normally distributed data.

Univariate linear regression models were used to test for modifying covariates including sex, age, anxiety, pain catastrophising, subjective LBP at baseline, and LBP trajectory. Generalised linear mixed models with log link, including random intercept subject effects, random slope time effects, and sex and age as fixed effects were used to analyse log-transformed PPT site data between groups. The same models were used for hand TS, excluding age as a fixed effect. Linear mixed models were used for raw feet TS outcome data between groups (due to non-convergence of the generalised linear mixed models), with random intercept subject effects, random slope time effects, and sex and age as fixed effects. As mixed models use maximum likelihood estimation methods, all participants were included in the analyses, regardless of missing data points.

All QST data are summarised using unadjusted marginal means, adjusted marginal means, 95% confidence intervals, and *p* values.

3. Results

See Fig. 2 for a participant flow chart. Eighty-one individuals participated in the study and received an intervention between Oct 2017 and July 2018. One participant was uncontactable for the 24 h phone call, thus was excluded completely from data analysis. Due to computer error in recording data, there were some missing PPT data. For two participants, all baseline PPT data were missing, and for three other participants, all 30 min PPT data were missing. These data were left as missing during analyses, since mixed models allow for inclusion of participants with some missing data. For six participants, some individual PPT measures (e.g. second round at baseline) were missing. These data were imputed by using the measurement at that time point that was not missing.

Some harms occurred during the study. Nine participants reported an increase in LBP or post-treatment soreness, and four of these also had some thigh pain. Six of these participants received SMT and three received the sham intervention.All of these complaints resolved within several days. All harms were considered to be mild to moderate and not alarming.

3.1. Participant characteristics

See Table 1 for a summary of baseline participant characteristics. The mean age of participants was 37 years, with 42 females. There were no statistically significant differences in baseline participant characteristics between treatment groups. Participants were predominantly recruited through university student announcements (n = 38, 48%) and Facebook advertising (n = 22, 28%). The majority (n = 51, 64%) reported having seen a chiropractor previously. Of the participants in the SMT and sham groups respectively, 33 (82.5%) and 25 (62.5%) believed they received a real treatment, suggesting the sham was successful at deceiving the majority of participants.

3.2. Manipulation vs. sham

See Tables 2 and 3 and Figs. 3 and 4 for between-group results for PPT and TS. For PPT, there was a statistically significant Time x Group difference at the calf immediately and 15 min post-intervention. There was no significant Time x Group difference at the calf at 30 min, or at the lumbar spine and shoulder at any time point. For TS, there were no statistically significant Time x Group differences at the hands or feet at any time point.

3.3. Change over time

See Tables 2 and 3 for within-group results. In the SMT group, calf PPT decreased significantly from baseline to immediately post-intervention only, and in the sham group, calf PPT increased significantly from baseline to all follow-up time points. In both the SMT and sham groups, lumbar PPT did not change significantly over time. In both the SMT and sham groups, shoulder PPT increased significantly from baseline to immediately post-intervention only.

In both the SMT and sham groups, hand TS decreased significantly from baseline to 30 min post-intervention only. In the SMT group, feet TS decreased significantly from baseline to all follow-up time points, and in the sham group, feet TS decreased significantly from baseline to 15 and 30 min post-intervention.

4. Discussion

4.1. Summary

This study aimed to address the paucity of high-quality sham-controlled studies investigating short-term changes in QST after lumbar SMT. The only significant between-group difference we observed was in calf PPT, which could be explained by the significant decrease in PPT after SMT (increased sensitivity) and concurrent increase after sham (decreased sensitivity). Changes from baseline in each group were inconsistent and occurred in both SMT and sham groups for PPT and hand TS. There was a consistent decrease in feet TS from baseline after SMT

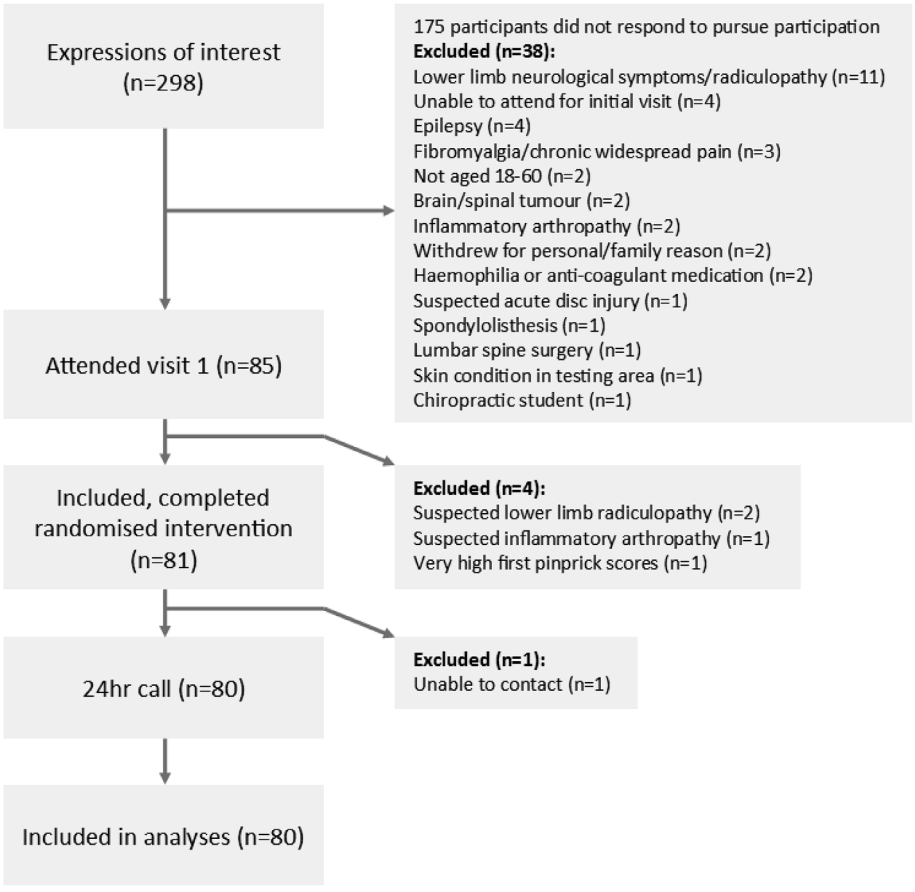

Fig. 2. Participant flow chart.

Table 1
Baseline participant characteristics.

	Overall (n = 80)	SMT group (n = 40)	Sham group (n = 40)	Group differences *p* value
Age in years, mean (SD, range)	37 (SD 13, 18–59)	38 (SD 13, 18–59)	35 (SD 12, 18–57)	.211
Sex	42 female (52%) 38 male (48%)	22 female (55%) 18 male (45%)	20 female (50%) 20 male (50%)	.654
LBP trajectory	57 persistent (71%) 23 episodic (29%)	28 persistent (70%) 12 episodic (30%)	29 persistent (72%) 11 episodic (28%)	.805
LBP severity on 0–10 NRS, mean (SD, range), median (IQR)				
Current LBP	2.6 (SD 1.8, 0–7), 3.0 (IQR 3.0)	2.7 (SD 2.0, 0–7), 3.0 (IQR 3.0)	2.5 (SD 1.7, 0–6), 2.0 (IQR 2.8)	.547
Average LBP in previous 24 h	3.9 (SD 2.0, 0–8), 4.0 (IQR 3.0)	3.9 (SD 2.2, 0–8), 4.0 (IQR 3.8)	3.9 (SD 1.9, 0–7), 4.0 (IQR 2.0)	.871
Worst LBP in previous 24 h	4.9 (SD 2.4, 0–10), 5.0 (IQR 4.0)	4.9 (SD 2.5, 0–10), 5.0 (IQR 4.0)	4.9 (SD 2.3, 0–9), 5.0 (IQR 3.8)	.963
Best LBP in previous 24 h	1.4 (SD 1.8, 0–7), 1.0 (IQR 2.0)	1.4 (SD 1.8, 0–7), 0.5 (IQR 2.0)	1.5 (SD 1.7, 0–7), 1.0 (IQR 2.0)	.708
Pain Catastrophizing Scale score (0–52)	14.0 (SD 9.5, 0–40)	15.3 (SD 9.8, 0–40)	12.7 (SD 9.2, 0–40)	.220
PROMIS Anxiety T-score	53.7 (SD 8.9, 39.1–74.1)	53.6 (SD 10.0, 39.1–74.1)	53.8 (SD 7.8, 39.1–71.3)	.926
Calf PPT in kg/cm^2, mean (SD), median (IQR)	4.3 (SD 2.6), 3.7 (IQR 3.5)	4.5 (SD 2.5), 3.9 (IQR 3.7)	4.2 (SD 2.7), 3.5 (IQR 3.7)	.581
Lumbar PPT in kg/cm^2, mean (SD), median (IQR)	5.3 (SD 3.3), 4.2 (IQR 4.5)	5.4 (SD 3.3), 4.4 (IQR 4.1)	5.2 (SD 3.4), 3.9 (IQR 5.0)	.746
Shoulder PPT in kg/cm^2, mean (SD), median (IQR)	3.0 (SD 2.1), 2.5 (IQR 2.3)	3.1 (SD 2.1), 2.5 (IQR 2.0)	3.0 (SD 2.1), 2.5 (IQR 2.5)	.819
Hand TS on 0–100 NRS, mean (SD), median (IQR)	8.7 (SD 10.9), 5.1 (IQR 12.9)	7.9 (SD 9.6), 5.0 (IQR 11.8)	9.4 (SD 12.1), 5.3 (IQR 14.5)	.747
Feet TS on 0–100 NRS, mean (SD), median (IQR)	12.9 (SD 13.5), 10.1 (IQR 16.8)	12.2 (SD 14.0), 9.2 (IQR 14.7)	13.7 (SD 13.2), 10.8 (IQR 16.5)	.732

Abbreviations: IQR = interquartile range, LBP = low back pain, NRS = numerical rating scale, PPT = pressure pain threshold, SD = standard deviation, SMT = spinal manipulative therapy, TS = temporal summation.

Table 2
Within-group and between-group results for pressure pain threshold.

Testing site and time	Unadjusted PPT, Mean (CI)		Adjusted PPT, Mean (CI)		Within-group adjusted difference from baseline, Mean difference (CI)				Between-group (Time × Group interaction), *p* value
	SMT	Sham	SMT	Sham	SMT	*p* value	Sham	*p* value	
Calf (kg/cm^2)									
Baseline	4.49 (3.68–5.30)	4.16 (3.29–5.03)	4.66 (3.89–5.43)	3.96 (3.30–4.61)	–	–	–	–	–
Immediate	4.25 (3.57–4.92)	4.41 (3.48–5.34)	4.40 (3.70–5.10)	4.28 (3.61–4.96)	−0.26 (−0.51–−0.01)	.039*	0.33 (0.11–0.54)	.003*	< .001*
15min	4.28 (3.66–4.91)	4.42 (3.51–5.33)	4.42 (3.73–5.11)	4.27 (3.61–4.93)	−0.24 (−0.54–0.06)	.118	0.31 (0.05–0.58)	.020*	.006*
30min	4.41 (3.74–5.08)	4.58 (3.59–5.57)	4.60 (3.89–5.32)	4.35 (3.68–5.02)	−0.06 (−0.42–0.31)	.756	0.39 (0.06–0.73)	.022*	.066
Lumbar (kg/cm^2)									
Baseline	5.41 (4.36–6.47)	5.17 (4.05–6.28)	5.45 (4.42–6.48)	5.08 (4.12–6.05)	–	–	–	–	–
Immediate	5.43 (4.37–6.49)	5.36 (4.21–6.50)	5.58 (4.55–6.61)	5.36 (4.37–6.35)	0.14 (−0.16–0.44)	.367	0.28 (−0.01–0.57)	.056	.467
15min	5.53 (4.40–6.66)	5.23 (4.12–6.33)	5.75 (4.69–6.80)	5.25 (4.28–6.22)	0.30 (−0.09–0.69)	.128	0.17 (−0.20–0.54)	.367	.679
30min	5.53 (4.49–6.57)	5.41 (4.29–6.54)	5.52 (4.49–6.55)	5.25 (4.27–6.23)	0.07 (−0.42–0.57)	.776	0.17 (−0.31–0.64)	.499	.776
Shoulder (kg/cm^2)									
Baseline	3.09 (2.42–3.77)	2.99 (2.30–3.68)	3.07 (2.56–3.58)	2.88 (2.40–3.36)	–	–	–	–	–
Immediate	3.23 (2.50–3.96)	3.19 (2.42–3.97)	3.37 (2.82–3.92)	3.12 (2.61–3.63)	0.30 (0.11–0.49)	.002*	0.24 (0.06–0.41)	.008*	.748
15min	3.14 (2.54–3.74)	3.18 (2.36–4.01)	3.19 (2.67–3.71)	3.10 (2.60–3.60)	0.12 (−0.12–0.36)	.317	0.22 (−0.01–0.44)	.056	.529
30min	3.19 (2.58–3.80)	3.35 (2.46–4.24)	3.23 (2.69–3.78)	3.10 (2.58–3.61)	0.16 (−0.14–0.47)	.294	0.21 (−0.08–0.51)	.152	.775

*p < .05. Abbreviations: CI = 95% confidence interval, PPT = pressure pain threshold, SMT = spinal manipulative therapy.

Table 3
Within-group and between-group results for temporal summation.

Testing site and time	Unadjusted TS, Mean (CI)		Adjusted TS, Mean (CI)		Within-group adjusted difference from baseline, Mean difference (CI)				Between-group (Time × Group interaction) *p* value
	SMT	Sham	SMT	Sham	SMT	*p* value	Sham	*p* value	
Hand (0–100 NRS)									
Baseline	8.33 (5.17–11.50)	9.18 (5.34–13.02)	8.02 (5.06–10.98)	8.07 (5.09–11.04)	–	–	–	–	–
Immediate	7.90 (4.17–11.63)	7.86 (3.59–12.14)	8.26 (5.36–11.17)	7.97 (5.11–10.84)	0.24 (−1.18–1.67)	.737	−0.09 (−1.46–1.28)	.895	.739
15min	7.13 (3.64–10.62)	8.74 (4.21–13.27)	7.11 (4.36–9.86)	9.03 (6.03–12.03)	−0.91 (−2.55–0.74)	.279	0.96 (−0.68–2.60)	.251	.115
30min	5.73 (2.66–8.80)	6.69 (3.83–9.56)	5.22 (2.63–7.80)	5.29 (2.68–7.90)	−2.80 (−4.75–−0.85)	.005*	−2.78 (−4.75–−0.80)	.006*	.979
Feet (0–100 NRS)									
Baseline	12.50 (8.03–16.98)	13.48 (9.31–17.66)	12.32 (8.09–16.56)	13.66 (9.43–17.90)	–	–	–	–	–
Immediate	9.90 (5.98–13.83)	11.85 (7.10–16.60)	9.72 (5.98–13.47)	12.03 (8.28–15.77)	−2.60 (−4.68–−0.52)	.014*	−1.64 (−3.71–0.44)	.122	.521
15min	9.34 (5.86–12.81)	8.58 (5.18–11.98)	9.16 (5.81–12.51)	8.76 (5.41–12.11)	−3.17 (−5.61–−0.72)	.011*	−4.90 (−7.35–−2.46)	< .001*	.325
30min	8.40 (5.18–11.63)	7.59 (4.72–10.46)	8.22 (5.13–11.32)	7.77 (4.68–10.86)	−4.10 (−7.06–−1.14)	.007*	−5.90 (−8.86–−2.93)	< .001*	.401

*p < .05. Abbreviations: CI = 95% confidence interval, NRS = numerical rating scale, SMT = spinal manipulative therapy, TS = temporal summation.

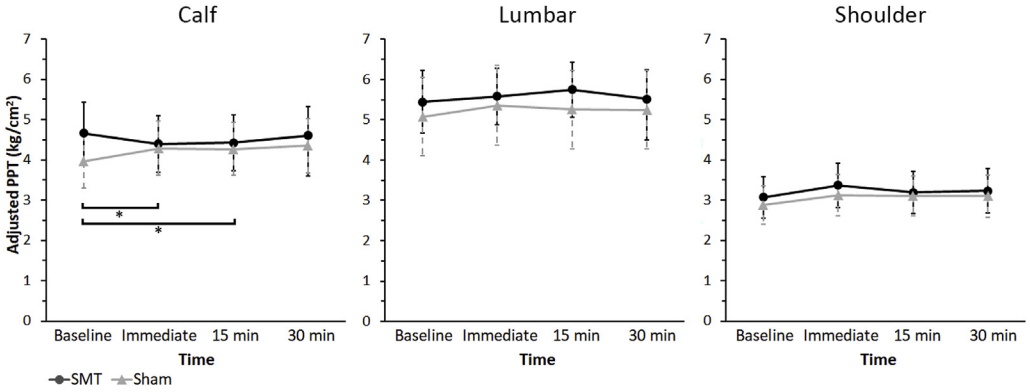

Fig. 3. Change in pressure pain threshold over time by intervention group.
* = significant between-group (time x group) effect. Abbreviations: PPT = pressure pain threshold.

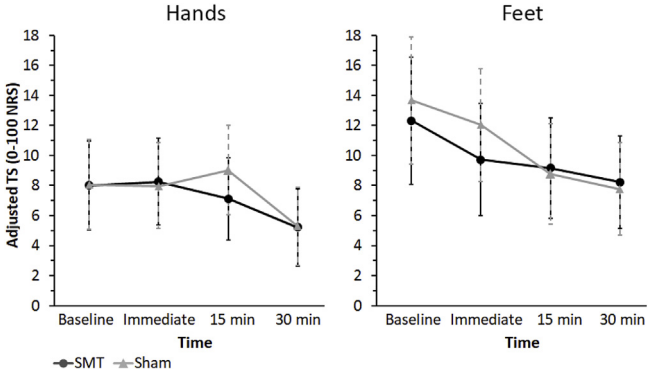

Fig. 4. Change in temporal summation over time by intervention group.
Abbreviations: NRS = numerical rating scale, TS = temporal summation.

and sham.

4.2. Explanation and comparisons

The between-group differences observed in change in calf PPT appear to be explained by regression to the mean in both groups. Our data otherwise indicate there is no difference in change in PPT and TS after lumbar SMT compared to sham. Any changes in PPT and TS may therefore be attributable to non-specific effects including expectations, the patient-clinician interaction, hands on contact, and positioning, rather than being unique to SMT. Without a no-treatment control group, we cannot exclude normal variations over time or changes in response to the study protocol as potential explanations for our observations.

Our results support the finding from a recent systematic review with meta-analyses in musculoskeletal pain populations that there is no difference in change in PPT after SMT compared to sham (Aspinall et al., 2019a). The review also concluded that PPT increases systemically within-group after SMT, which conflicts with the findings in this study since we found no consistent within-group change in PPT. The majority of the PPT studies included in the review used cervical or thoracic SMT (Aspinall et al., 2019a), while studies using lumbar SMT have mostly found that PPT does not change over time, as in our study. These lumbar SMT studies are in asymptomatic (Orakifar et al., 2012; Thomson et al., 2009), chronic LBP (de Oliveira et al., 2013; Côté et al., 1994), and exercise-induced LBP populations (Gay et al., 2014). Only one study, in asymptomatic participants, has observed an increase in PPT after lumbar SMT (Dorron et al., 2016). This apparent discrepancy suggests there could be a difference in how PPT changes after lumbar SMT compared to cervical or thoracic SMT, which deserves further attention.

No authors of any systematic reviews have made robust conclusions regarding changes in TS after SMT to date. Our study appears to be the first to have compared SMT against sham manipulation when evaluating TS, finding no difference. This is in the face of observations from our study, and from others in asymptomatic (Penza et al., 2017; George et al., 2006) and LBP populations (Bialosky et al., 2009b), of short-term attenuation of feet TS after lumbar SMT.

4.3. Methodological considerations

This is one of few sham-controlled double-blind studies investigating manipulation-induced hypoalgesia, specifically in a symptomatic population. Our sham intervention was based on a procedure that has been successfully used previously (Chaibi et al., 2015), and attempts to fulfil three of the four features of a sham SMT that should be accounted for (participant and therapist positioning, movements of the participant's body, and mechanical thrust) (Puhl et al., 2017). It could be argued that the sham may not be inert, since it involved physical contact and movement of the participant's body. We are of the opinion, however, that a sham which is structurally similar to SMT allows for equivalence of factors including physical contact, positioning, time taken to perform the procedure, and the participant-clinician interaction (Puhl et al., 2017). An experienced biostatistician with no interest in the outcome of the study was involved with all analyses.

It may be argued that the generalisability of this study is limited since interventions were given to a pre-determined segment. In clinical settings, SMT is typically applied to a painful or 'dysfunctional' vertebral joint determined through joint palpation and other physical examination procedures. However, since it appears that targeting a 'dysfunctional' segment does not result in superior hypoalgesic outcomes (Millan et al., 2012), we chose to pre-specify the target segment for SMT in the interests of standardisation and repeatability.

We used seven different clinicians to deliver the interventions, which was necessary from a logistical perspective. We were careful to ensure clinicians understood the protocol and interventions, but we did not perform any monitoring to ensure adherence to the protocol. We recognise that this likely introduced some variability in the interventions and in the interactions with participants. However, using multiple clinicians may also be beneficial in minimising the effects of particularly skilled or unskilled clinicians. We also acknowledge that allowing clinicians a second attempt at the intervention if they felt the first was unsuccessful potentially introduces a variable dose component, however this was allowed in both intervention groups to improve uniformity.

Since our blinding question did not offer participants an "I don't know" response option, we were unable to assess blinding success with a statistical blinding index method. However, we were confident that our sham was acceptable given the majority of participants believed

they had received a real treatment. It may have been valuable to ask participants about the credibility of the intervention. We also acknowledge that measuring a wider range of QST types may have provided additional insight into this topic.

5. Conclusion

We found that lumbar SMT did not lead to greater short-term changes in PPT or TS compared to sham manipulation in people with low back pain. This suggests that lumbar SMT does not have a specific hypoalgesic effect on these types of quantitative sensory tests. Sham-controlled studies investigating cervical and thoracic SMT may help clarify potential differences in hypoalgesic responses between spinal regions.

Conflicts of interest

All authors declare that they have no competing interests.

Ethical approval

This study had ethical approval from the Murdoch University Human Research Ethics Committee (approval 2017/177).

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Clinical trials registry

This trial was prospectively registered with ANZCTR (ACTRN12617001094369).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.msksp.2019.05.011.

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