JASON M. BENECIUK, PT, DPT, FAAOMPT[1] • MARK D. BISHOP, PT, PhD[2] • STEVEN Z. GEORGE, PT, PhD[2]

Effects of Upper Extremity Neural Mobilization on Thermal Pain Sensitivity: A Sham-Controlled Study in Asymptomatic Participants

• **STUDY DESIGN:** A single-blinded, quasi-experimental, within- and between-sessions assessment.

• **OBJECTIVES:** To investigate potential mechanisms of neural mobilization (NM), using tensioning techniques in comparison to sham NM on a group of asymptomatic volunteers between the ages of 18 and 50.

• **BACKGROUND:** NM utilizing tensioning techniques is used by physical therapists in the treatment of patients with cervical and/or upper extremity symptoms. The underlying mechanisms of potential benefits associated with NM tensioning techniques are unknown.

• **METHODS AND MEASURES:** Participants (n = 62) received either a NM or sham NM intervention 2 to 3 times a week for a total of 9 sessions, followed by a 1-week period of no intervention to assess carryover effects. A-delta (first pain response) and C-fiber (temporal summation) mediated pain perceptions were tested via thermal quantitative sensory testing procedures. Elbow extension range of motion (ROM) and sensory descriptor ratings were obtained during a neurodynamic test for the median nerve. Data were analyzed with repeated-measures analysis of variance (ANOVA).

• **RESULTS:** No group differences were seen for A-delta mediated pain perception at either immediate or carryover times. Group differences were identified for immediate C-fiber mediated pain perception ($P = .032$), in which hypoalgesia occurred for the NM group but not the sham NM group. This hypoalgesic effect was not maintained at carryover ($P = .104$). Group differences were also identified for the 3-week and carryover periods for elbow extension ROM ($P = .004$), and for the participant sensory descriptor ratings ($P = .018$), in which increased ROM and decreased sensory descriptor ratings were identified in participants in the NM group but not the sham NM group.

• **CONCLUSION:** This study provides preliminary evidence that mechanistic effects of tensioning NM differ from sham NM for asymptomatic participants. Specifically, NM resulted in immediate, but not sustained, C-fiber mediated hypoalgesia. Also, NM was associated with increased elbow ROM and a reduction in sensory descriptor ratings at 3-week and carryover assessment times. These differences provide potentially important information on the mechanistic effects of NM, as well as the description of a sham NM for use in future clinical trials.

• **LEVEL OF EVIDENCE:** Therapy, level 2b. *J Orthop Sports Phys Ther 2009;39(6):428-438. doi: 10.2519/jospt.2009.2954*

• **KEY WORDS:** *manual therapy, neurodynamic testing, temporal summation*

Neural mobilization (NM) is a part of manual therapy that has been reported to be an effective intervention for certain conditions,[23,29,32,43] including carpal tunnel syndrome[55] and low back pain.[11] Other investigators, however, have reported that NM provides no additional benefits when compared to other interventions.[56,65] A recent systematic review of randomized controlled trials involving NM has suggested that there is limited evidence for the use of NM in the treatment of certain upper-quarter conditions.[24] Specifically, incorporating NM in the treatment of patients with carpal tunnel syndrome,[1,3,47] cervicobrachial pain,[21,20] and lateral epicondylalgia[71] has been associated with decreased ratings of pain and disability. Many of these studies are considered to be of "moderate" methodological quality, based on criteria from the Physiotherapy Evidence Database (PEDro) scale. Conversely, other studies are "limited" in methodological quality[1] and, therefore, only provide preliminary evidence for the use of NM.[24] While the clinical literature

[1]Rehabilitation Science Doctoral student, Department of Physical Therapy, University of Florida, Gainesville, FL. [2]Assistant Professor, Department of Physical Therapy, Brooks Center for Rehabilitation Studies, Center for Pain Research and Behavioral Health, University of Florida, Gainesville, FL. This study was supported by a grant (R21 AT002796) awarded to Dr Steven Z. George from The National Institutes of Health (NIH)/National Center for Complementary and Alternative Medicine (NCCAM). Dr Mark D. Bishop was supported by the same grant. The University of Florida Institutional Review Board approved this study. Address correspondence to Jason M. Beneciuk, University of Florida, Department of Physical Therapy, PO Box 100154, Gainesville, FL 32610-0154. E-mail: beneciuk@phhp.ufl.edu

provides preliminary support of NM, the effects and underlying mechanisms of NM are unknown,[7,31] and investigation of such factors could provide valuable information to the ambiguous clinical literature.

Mechanisms of NM have been primarily supported by theoretical concept.[10,25,57] NM has been demonstrated to produce mechanical effects in terms of nerve strain and excursion in cadaveric studies[12,15] and recent in vivo studies.[16] Although limited in the literature, another potential effect of NM is on autonomic function. Increased blood flow velocity within the radial artery[52] and decreased skin temperature of the hand[51] have been suggested during neurodynamic testing procedures, similar to NM tensioning interventions.

There are different methods of delivering NM, including "sliding" and "tensioning" techniques.[6,14,57] Sliding techniques involve combinations of movements that result in elongation of the nerve bed at one joint, while reducing the length of the nerve bed at an adjacent joint.[15,16,57] These techniques are suggested to be less aggressive in nature compared to tensioning techniques, which involve increasing the distance between each end of the nerve bed via elongation.[57] It has been demonstrated that these techniques exert different biomechanical effects on the nervous system.[12,15] For example, in a cadaveric study[15] sliding techniques resulted in less strain and larger longitudinal excursion of the median nerve at the wrist when compared to tensioning techniques. Differences in clinical theories also exist when comparing these NM techniques. For example, sliding techniques have been theorized to play a role in the dispersion of inflammatory products and limiting fibroblastic activity.[15] Moreover, tensioning techniques have been suggested to play a role in reducing intraneural swelling and circulatory stasis by altering intraneural pressure associated with these techniques.[15]

Specific to the purposes of the current study, the hypoalgesic effects of NM utilizing tensioning techniques have not been reported as they have been for spinal manipulative therapy.[22,30,70] When determining hypoalgesia, the use of a sham group in study designs strengthens the ability to separate specific mechanistic effects from nonspecific effects.[33,70] Therefore, to determine the association between NM tensioning techniques and hypoalgesia, sham techniques that do not specifically stress tissues would serve as an appropriate comparison group.[39] Sham NM techniques would also be a good comparison for other parameters, such as range of motion (ROM) and reports of sensory descriptors typically measured during neurodynamic testing.

Therefore, the aims of the present study were 3. First, we investigated if immediate hypoalgesic effects occurred in participants receiving NM utilizing a tensioning technique or a sham NM technique via thermal pain sensitivity testing. The rationale for using thermal testing was to allow comparison to a previous study involving spinal manipulation.[30] Second, we investigated if there were any group differences (NM versus sham NM) in elbow extension ROM or sensory descriptors during the neurodynamic test for the median nerve over time. Finally, we investigated if there were lasting carryover effects for hypoalgesia, ROM, or sensory descriptors following NM tensioning application. We hypothesized participants receiving a NM tensioning technique would demonstrate hypoalgesic effects via thermal pain sensitivity testing, increased elbow extension ROM, and decreased sensory descriptor ratings in comparison to those receiving sham NM.

We tested these effects in a group of asymptomatic participants for several reasons. First, we wanted to determine the hypoalgesic effects for asymptomatic participants receiving NM by use of tensioning techniques, as per our previous studies involving spinal manipulation.[4,30] Second, symptomatic individuals can experience continuous, nociceptive input that is likely to result in enhanced pain sensitivity in comparison to asymptomatic individuals.[30,60,61,63,74] With asymptomatic individuals we were able to control levels of nociceptive input, and such control may not be feasible in symptomatic individuals. Third, the use of asymptomatic individuals eliminates commonly encountered confounding variables associated with clinical conditions, including concomitant physical therapy interventions (eg, exercise or modalities) and pain medications.[30]

METHODS

Participants

This sample consisted of 62 undergraduate and graduate students (46 females; mean ± SD age, 23.7 ± 3.9 years) who responded to advertisements posted throughout a Health Science Center of a large research university. Per inclusion criteria, subjects were between 18 and 50 years of age, not currently experiencing any neck or dominant upper extremity symptoms, did not have a history significant for a chronic painful condition, and were not using pain relievers. Eligible participants were also required to speak and comprehend English so they could respond to verbal questions, comprehend questionnaires, and understand instructions during the procedures of the study. Prior to participating in any study-related procedures, participants read and signed an informed consent form approved by the University of Florida Institutional Review Board. Potential participants were verbally screened for current painful conditions involving their neck or dominant upper extremity and for chronic pain conditions (ie, fibromyalgia) or current use of pain relievers.

Procedures

Participants completed a demographic questionnaire, and psychological factors known to influence pain reporting were measured to determine if there were baseline group differences that could potentially influence results. Thermal pain sensitivity, elbow ROM, and sen-

sory descriptors during neurodynamic testing were collected prior to the initial intervention. Thermal pain sensitivity measures were collected again immediately following the initial session, ninth session, and 1 week following the ninth session. In addition, neurodynamic testing measures were obtained during the ninth session and 1 week following the ninth session. The rationale for obtaining measures 1 week following the ninth session was to determine if there were any lasting carryover effects after a 1-week period with no NM provided.

Self-Report Questionnaires Several self-report questionnaires were administered to determine if the groups differed on important variables that might influence thermal pain responses. These questionnaires are described as follows. The Pain Catastrophizing Scale (PCS) utilizes a 13-item, 5-point Likert scale, with higher scores indicating elevated levels of catastrophizing.[45,64,67] The Fear of Pain Questionnaire (FPQ-9) utilizes a 9-item, 5-point Likert scale, with higher scores indicating elevated levels of fear.[42,46,54,69] The Tampa Scale of Kinesiophobia-General Population (TSK-G) utilizes a 12-item, 4-point Likert scale, with higher scores indicating elevated levels of fear of movement and injury/reinjury.[34,38,72] The State-Trait Anxiety Inventory, the trait portion of the State Anxiety Inventory, utilizes a 20-item, 4-point Likert scale, with higher scores indicating elevated levels of anxiety.[2,58]

Specific Questions Several specific questions were administered to determine if the groups differed on important variables that could influence thermal pain responses. These descriptions were rated on a 10-cm visual analog scale (VAS), with "none" and "most severe imaginable" as scale anchors. Definitions were provided to describe the difference between "threatened" and "challenged." These questions are as follows: "Describe your current level of fear about the pain you are about to feel," "Describe your current level of anxiety about the pain you are about to feel," "Describe how threatened you are about the pain you are about to feel," and "Describe how challenged you are about the pain you are about to feel."

Thermal Pain Sensitivity Quantitative sensory testing was performed as per previously established protocols involving thermal stimuli.[30,50,53,59,62,63] Thermal stimuli may be used to differentially affect A-delta and C-fiber nociceptive input.[48,50,63] Thermal stimuli were delivered via contact thermode and a computer-controlled neurosensory analyzer (TSA-2001; Medoc, Ltd, Ramat Yishai, Israel) with a handheld, peltier-element–based stimulator. Participants were familiarized to the thermal stimuli and pain-rating devices with a practice session prior to actual testing. This practice session has previously been described in detail elsewhere.[30] Thermal pain threshold and tolerance temperatures (°C) and pain intensity ratings (numerical rating scale [NRS]; potential range, 0-100) were obtained from this practice session.

During testing, stimuli were applied to the participants' dominant sides, and stimulus sites included the volar surface of the forearm just distal to the elbow joint (first pain response) and the thenar eminence of the hand (temporal summation). These anatomical locations were selected based on the purported segmental (C6-C8, T1) and peripheral (median nerve) innervation of skin in these regions.

First Pain Response Heat stimuli of 3 seconds duration were applied to the skin of the participants' dominant forearm. The temperature increased rapidly (10°C/s) from baseline to a randomly presented peak of 45°C, 47°C, 49°C, or 51°C. Participants were asked to rate their first pain intensity felt. These ratings are believed to be primarily mediated by input from A-delta fibers.[48,50] The exact stimulation site over the forearm slightly varied (approximately 5 cm distally) between stimuli exposure and the interval between stimuli was at least 60 seconds to avoid carryover effects from the preceding thermal stimulus. Participant response to thermal stimuli was determined with a mechanical slide algometer for evoked pain intensity, which was anchored on the left with "no pain sensation," representing 0, and on the right with "most intense pain sensation imaginable," representing 100. The investigator (J.B.) operated the algometer until the participant verbally indicated the algometer reading indicated the evoked pain intensity. The thermode was maintained in place by the participant until the trial was completed or participants physically removed the thermode, whichever occurred first. This ensured that participants had the ability to remove the thermode in cases when the temperatures were not tolerated.

Temporal Summation A train of 10 consecutive heat pulses, of less than 1-second duration, at an interstimulus interval of 3 seconds, was delivered to the thenar eminence of the participants' dominant hand. The stimulation site was not varied at the hand because only 1 train of stimuli was delivered, and therefore carryover effects were not a concern. An interstimulus interval of 3 seconds was selected to ensure the development of temporal summation.[48,50] Participants were asked to rate their second pain intensity associated with all 10 heat pulses, and temporal summation was defined as the difference between the fifth and second pain rating for purposes of our analysis. Temporal summation is believed to be primarily mediated by C-fiber input.[48,50] For temporal summation, a NRS was used for evoked pain intensity because of the rapid sequence of ratings. The NRS ranged from 0 to 100, with 0 representing "no pain" and 100 representing "worst pain intensity imaginable."

Neurodynamic Testing A neurodynamic test for the median nerve was performed similar to those reported in the literature.[10,18,19,26,57] The participant was positioned supine and the cervical spine was positioned in approximately 25° of contralateral lateral flexion or when the first sense of increased resistance was perceived by the investigator, whichever occurred first. This option was provided to account for participants where a first sense of resistance was perceived by the

investigator prior to achieving 25° of contralateral lateral flexion of the cervical spine. This was followed by the following consecutive positioning procedures: (1) the application of passive scapular depression until a sense of resistance was perceived by the investigator; (2) 90° of combined shoulder abduction and external rotation; combined forearm supination, wrist extension, finger extension until a sense of resistance was perceived by the investigator; (3) elbow extension was then applied until a sense of resistance was perceived by the investigator or when shoulder girdle elevation was noted. A research assistant recorded elbow extension ROM with a universal goniometer; (4) the participant was asked to actively slide the head back to a neutral position; (5) the investigator applied additional elbow extension until a sense of resistance was perceived or when shoulder girdle elevation was noted. Again, a research assistant recorded elbow extension ROM, as previously described. Participants rated predetermined sensory descriptors during the application of neurodynamic testing procedures. Sensory descriptors were rated via a 10-cm VAS during step 3 described above. The sensory descriptors included those previously reported in the literature for various neurodynamic tests: "stinging," "tingling,"[17,73] "tightness,"[73] "sharpness,"[73] and "numbness."[68] A preliminary factor analysis indicated that all 5 sensory descriptors loaded on to a single latent variable, which was an expected finding for a group of asymptomatic participants. The factor analysis findings indicated that data reduction was appropriate, and, for our analyses, the 5 sensory descriptor VAS scores were averaged to create a single sensory description variable (ie, average of VAS scores for stinging, tingling, tightness, sharpness, and numbness).

Design

A quasi-experimental design was used in this study. The initial 31 participants were assigned to receive NM utilizing a tensioning technique, while a second cohort of 31 participants were assigned to receive a sham NM technique. All participants were blinded to their group assignment, while the investigator was aware of participant group assignment. Participants received intervention 2 to 3 times per week until they completed 9 sessions (mean ± SD days, 32.2 ± 9.2). This time frame had to be adjusted based on individual participant scheduling conflicts where they could not commit to 3 sessions per week.

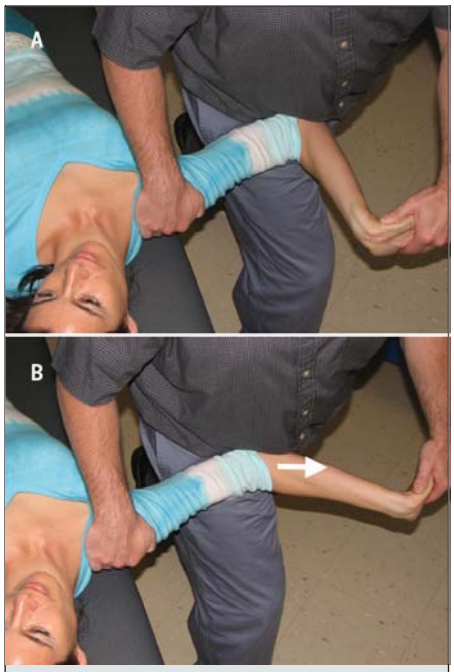

FIGURE 1. Prepositioning consisted of placing the participant in the neurodynamic test position. Neural mobilization exercise 1 consisted of 10 cycles of (A) passive elbow flexion and (B) extension (arrow). An initial sense of resistance perceived by the investigator was used as a sign to alternate directions.

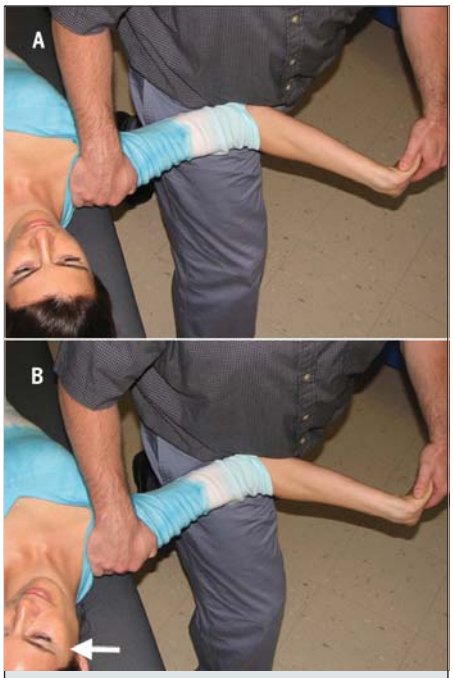

FIGURE 2. Prepositioning consisted of the participant being placed in the neurodynamic test position. Neural mobilization exercise 2 consisted of positioning the elbow in (A) extension and (B) having the participant actively perform 10 cycles of contralateral cervical lateral-flexion (arrow) from a neutral position. Participants were asked to only encounter an initial sense of resistance when moving into the direction of lateral flexion.

Intervention

Participants Who Received Neural Mobilization Participants in the NM group received a combination of techniques previously described in the literature for treatment of upper extremity and cervicobrachial conditions.[10] These conditions may involve ischemia or inflammation of neural tissue, which have the potential to alter the normal physiology of the nervous system.[57] The NM tensioning technique consisted of 2 exercises. The first exercise involved passively positioning the participant in the neurodynamic testing position. As the position was assumed, 10 cycles of passive elbow flexion/extension, at a rate of approximately 6 seconds per cycle (3 seconds into extension and 3 seconds into flexion), were provided (**FIGURE 1**). Upon moving from elbow flexion to extension, an initial sense of resistance perceived by the investigator was used as a sign to alternate directions. Following the 10th cycle, a static hold was maintained while in elbow extension for 10 seconds. The second exercise involved the same initial neurodynamic test positioning, with the exception of any cervical components (ie, the cervical spine was positioned in a neutral position). Instead of mobilizing the elbow, the participant was asked to perform active movements, consisting of cervical lateral flexion away from the test extremity, to and from a neutral position (**FIGURES 2**). Participants were

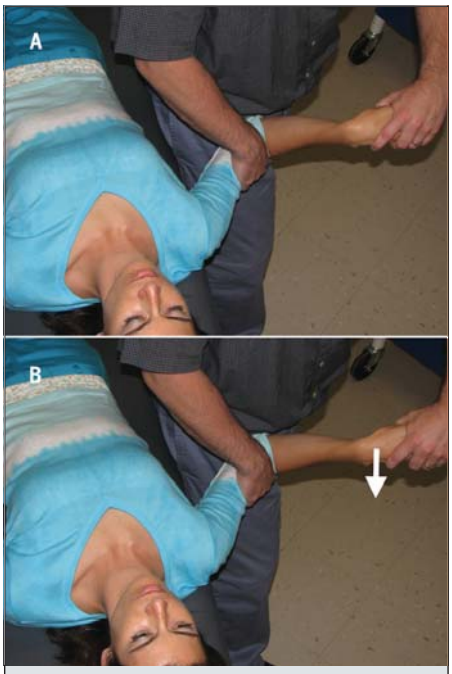

FIGURE 3. Prepositioning for the sham neural mobilization technique consisted of the following: (1) a neutral cervical spine; (2) 45° of shoulder abduction without scapula depression; (3) 45° of shoulder external rotation combined with 45° of elbow flexion with forearm pronation. This was immediately followed by 10 cycles of passive wrist (A) flexion and (B) extension (indicated by arrow). Upon moving from wrist flexion to extension, an initial sense of resistance perceived by the investigator was used as a sign to alternate directions.

TABLE 1 Descriptive Statistics*

Variable	NM (n = 31)	Sham NM (n = 31)	*P* Value
Age (y)	23.3 (2.8)	24.2 (4.7)	0.388
Sex (n, % female)	23 (74.2)	23 (74.2)	1.000
Worst pain ever experienced†	5.9 (1.9)	6.8 (2.5)	0.120
Fear about pain about to feel†	2.1 (2.1)	2.0 (2.1)	0.848
Anxiety about pain about to feel†	2.0 (2.2)	1.4 (1.7)	0.305
Threat about pain about to feel†	1.4 (1.5)	1.3 (1.8)	0.757
Challenged about pain about to feel†	2.2 (1.4)	2.1 (1.8)	0.723
Catastrophizing‡	14.0 (6.6)	16.2 (8.4)	0.239
Fear of pain§	12.9 (5.9)	14.1 (5.7)	0.397
Kinesiophobia‖	23.3 (4.7)	23.1 (4.5)	0.848
Anxiety¶	34.7 (6.6)	33.1 (6.4)	0.345
Pain threshold (°C)	44.5 (2.3)	44.3 (2.4)	0.747
Pain threshold rating†	18.1 (13.2)	30.1 (21.4)	0.007
Pain tolerance (°C)	47.9 (1.7)	47.3 (2.1)	0.193
Pain tolerance rating†	36.6 (21.2)	54.5 (21.4)	0.002

Abbreviation: NM, neural mobilization.
** All data are reported as mean (SD) ratings, unless otherwise indicated.*
† Numerical rating scale (potential range, 0-100).
‡ Pain Catastrophizing Scale (potential range, 0-52).
§ Fear of Pain Questionnaire, 9-item (potential range, 0-36).
‖ Tampa Scale of Kinesiophobia, general version (potential range, 12-48).
¶ State-Trait Anxiety Inventory (potential range, 20-80).

TABLE 2 Between-Session Group Measures*

Variable	Baseline	Posttreatment 1
First pain (47°C)†		
NM	24.4 (17.8)	21.3 (18.6)
Sham NM	33.5 (25.6)	27.4 (20.3)
First pain (49°C)†		
NM	38.7 (22.0)	33.4 (26.5)
Sham NM	45.6 (27.4)	37.1 (26.9)
Temporal summation†		
NM	5.5 (10.1)	0.7 (7.0)
Sham NM	3.1 (9.2)	5.0 (7.2)

Abbreviation: NM, neural mobilization.
** All data are reported as mean (SD) ratings.*
† Numeric rating scale ratings (0-100)

asked to only encounter an initial sense of resistance when moving into the direction of lateral flexion. This was repeated for a total of 10 cycles. Following the 10th cycle, a static hold was maintained while in lateral flexion for 10 seconds.

Participants Who Received Sham Neural Mobilization Participants in the sham NM group received a treatment consisting of maneuvers that mimic the NM treatment but believed not to stress the neural tissues in the upper extremity.[1,8,9,10,37] The sham NM consisted of passively positioning the participants in the following consecutive positions: (1) a neutral cervical spine (0° of lateral flexion), (2) 45° of shoulder abduction without scapula depression, and (3) 45° of shoulder external rotation combined with 45° of elbow flexion with forearm pronation. This was immediately followed by 10 cycles of passive wrist flexion/extension at a rate of approximately 6 seconds per cycle (3 seconds into extension and 3 seconds into flexion) (**FIGURE 3A** and **3B**). Upon moving from wrist flexion to extension, an initial sense of resistance was used as a sign to alternate directions. Following the 10th cycle, a static hold was maintained while in wrist flexion for 10 seconds.

Data Analysis

All data analyses were performed using SPSS 15.0 for Windows (SPSS Inc, Chicago, IL) at a type I error rate of 0.05. Descriptive statistics were generated for the demographic, psychological, and pain threshold and tolerance levels. Baseline variables were considered for covariates

if both of the following conditions were met: (*a*) group differences in baseline variable (ie, demographic, psychological, or pain threshold tolerance levels) and (*b*) same baseline variable was correlated with a dependent variable (ie, temporal summation).

Our purposes were investigated by testing for group-by-time interactions for first pain response, temporal summation, neurodynamic testing elbow ROM, and neurodynamic testing sensory descriptors. Dependent measures of the immediate response to NM were first pain responses for 47°C and 49°C, and temporal summation. Consistent with our previous studies on spinal manipulation,[4,30] immediate response data for 45°C and 51°C were not presented because they lack sensitivity to changes from pain treatment due to being subthreshold or at tolerance for a majority of the participants respectively. These variables were tested using 2-by-2 mixed-model (between-group, within-time) analyses of variance (ANOVAs), with time factors of baseline and session 1. Carryover effects for first pain responses at 47°C and 49°C, and temporal summation, were tested using 2-by-4 mixed-model (between-group, within-time) ANOVAs, with time factors of baseline, sessions 1 and 9, and 1 week after session 9. Changes in neurodynamic testing elbow ROM measures and sensory descriptor ratings were tested using separate 2-by-3 mixed-model (between-group, within-time) ANOVAs, with time factors of baseline, session 9, and 1 week after session 9.

TABLE 3 BETWEEN-SESSION GROUP MEASURES*

Variable	Baseline	Posttreatment 9	Follow-up†
Elbow extension ROM‡			
NM	137.4 (13.7)	145.6 (17.8)	145.6 (16.6)
Sham NM	129.0 (14.4)	125.0 (8.7)	123.4 (9.8)
Sensory descriptors‡§			
NM	1.6 (1.2)	1.1 (0.9)	1.0 (0.6)
Sham NM	2.7 (1.4)	3.1 (1.7)	3.1 (2.3)

Abbreviations: NM, neural mobilization; ROM, range of motion.
** All data are reported as mean (SD).*
† Occurred 1 week after session 9.
‡ Recorded during the neurodynamic test for the median nerve, where 180° is full elbow extension.
§ Visual analog scale ratings (0-10).

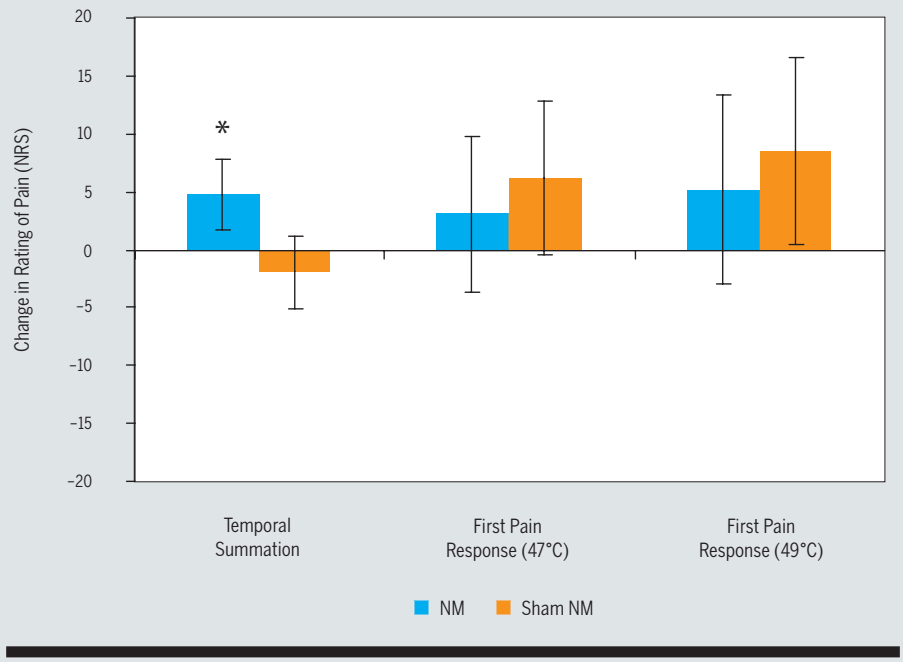

FIGURE 4. Immediate within session A-delta and C-fiber mediated pain change for induced pain. Abbreviations: NM, neural mobilization; NRS, numerical rating scale (potential range, 0-100). Negative numbers indicate an increase in pain (hyperalgesia). Error bars are 2 standard errors. *Significant group-by-time interaction for temporal summation hypoalgesia (P = .032).

RESULTS

Participant Characteristics

The 2 groups did not significantly differ on demographics, previous pain ever experienced, self-ratings of fear, anxiety, threat, and challenge for the thermal pain, self-report psychological questionnaires, and temperature of threshold and tolerance (**TABLE 1**). Independent sample t testing revealed significant group differences on pain threshold (P = .007) and tolerance (P = .002) ratings, and were also significantly correlated with the thermal pain sensitivity measures used as dependent variables (r^2 = 0.106 to 0.376). Therefore, threshold and tolerance ratings were used as covariates for the thermal pain sensitivity analyses. Mean measures for thermal pain sensitivity ratings, elbow extension ROM, and sensory descriptor ratings during their respective testing sessions are summarized in **TABLES 2** and **3**.

Thermal Pain Sensitivity (Immediate Effects)

There were no significant group-by-time interactions for first pain hypoalgesia at either 47°C ($F_{1,58}$ = 0.961, P = .331, partial η^2 = 0.016) or at 49°C ($F_{1,58}$ = 0.641, P = .427, partial η^2 = 0.011). There was, however, a main effect for time at 49°C ($F_{1,58}$ = 5.23, P = .026, partial η^2 = 0.083), with both the participants in the NM group (mean ± SD NRS rating, 5.2 ± 15.1) and

those in the sham NM group (NRS rating, 8.5 ± 14.0) demonstrating first pain hypoalgesia from baseline to session 1. In contrast, there was a significant group-by-time interaction for temporal summation hypoalgesia ($F_{1,58}$ = 4.84, P = .032, partial η^2 = 0.077) (**FIGURE 4**). Participants in the NM group demonstrated inhibition of temporal summation (mean ± SD NRS rating for hypoalgesia, 4.8 ± 9.7), while participants in the sham NM group demonstrated facilitation of temporal summation (NRS rating for hyperalgesia, −1.9 ± 11.8).

Thermal Pain Sensitivity (Carryover Effects)

There were no significant group-by-time interactions for first pain hypoalgesia at either 47°C ($F_{3,162}$= 0.300, P = .825, partial η^2 = 0.006) or at 49°C ($F_{2.556,137.999}$ = 1.100, P = .346, partial η^2 = 0.020). In addition, there were no significant hypoalgesia main effects at either temperature. Similarly, there were no significant group-by-time interactions for temporal summation hypoalgesia ($F_{2.636,142.366}$ = 2.152, P = .104, partial η^2 = 0.038) or main effects for temporal summation hypoalgesia ($F_{2.636,142.366}$ = 0.599, P = .595, partial η^2 = 0.011).

Neurodynamic Testing Elbow ROM

There was a significant group-by-time interaction for elbow extension ROM during neurodynamic testing ($F_{1.587,87.290}$ = 6.734, P = .004, partial η^2 = 0.109) (**FIGURE 5**). Participants in the NM group demonstrated increased ROM measures (mean ± SD elbow extension ROM, 8.6° ± 17.2°), while participants in the sham NM group demonstrated decreased ROM measures (−5.7° ± 13.0°). These group differences were observed at session 9 and maintained at the 1 week postintervention carryover session.

Neurodynamic Testing Sensory Descriptors

There were significant group-by-time interactions for changes in sensory descriptors ($F_{1.836,102.791}$ = 4.360, P = .018, partial η^2 = 0.072) (**FIGURE 6**). Participants in the NM group demonstrated decreased ratings for sensory descriptors (mean ± SD VAS rating change, 0.6 ± 1.1), while participants in the sham NM group demonstrated increased ratings (−0.4 ± 2.3). These group differences were observed at session 9 and maintained at the 1 week postintervention carryover session.

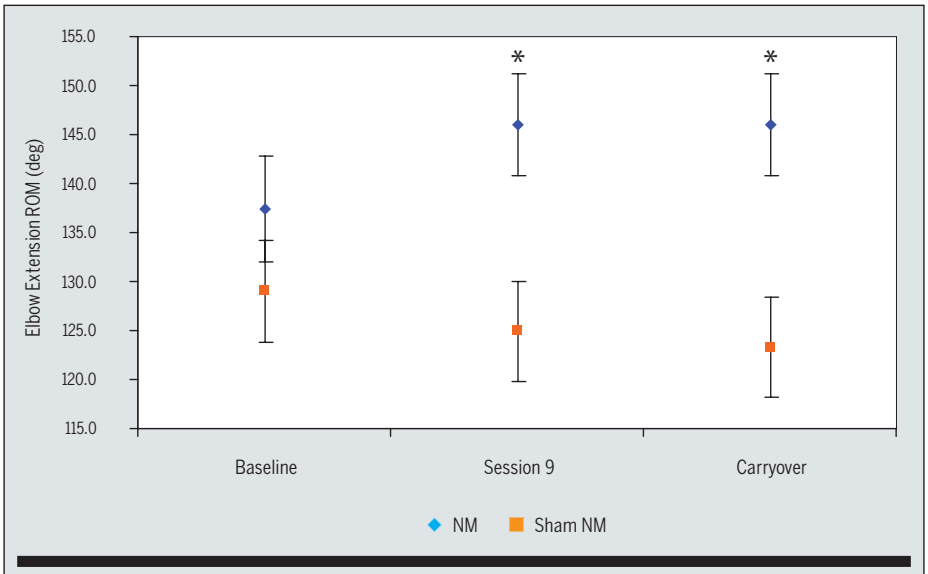

FIGURE 5. Changes in elbow extension range of motion (ROM) by neural mobilization (NM) group. Full elbow extension is 180°, therefore smaller values indicate less elbow extension. Error bars are 2 standard errors. *Significant group-by-time interaction for between-session elbow extension ROM during neurodynamic testing (P = .004).

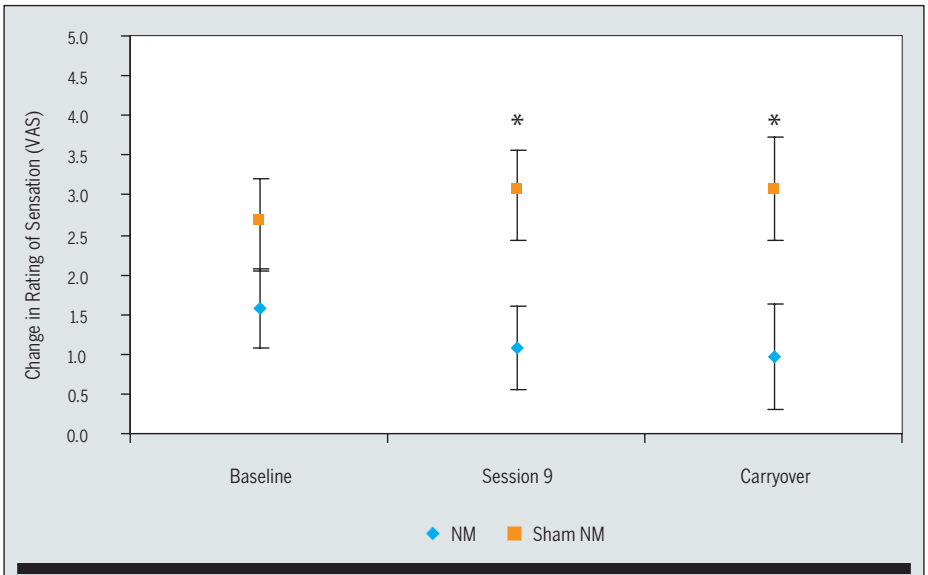

FIGURE 6. Changes in sensory description by neural mobilization (NM) group. Abbreviation: VAS, visual analog scale. Increased values indicate increases in the combined average ratings of "stinging, tingling, tightness, sharpness, and numbness" combined. Error bars are 2 standard errors. Significant group-by-time interaction for sensory descriptors duirng neurodynamic testing (P = .018).

DISCUSSION

This study investigated the immediate and carryover mechanistic effects of NM on thermal pain sensitivity, ROM, and sensory descriptors in asymptomatic participants. Overall, our results suggest that NM utilizing a tensioning technique had an immediate hypoalgesic effect on C-fiber mediated

pain perception via thermal pain sensitivity testing. Furthermore, NM by use of tensioning techniques resulted in improvements in elbow extension ROM and decreased intensity of specific sensory descriptors during neurodynamic testing. This study contributes to the literature by documenting differences between NM tensioning and sham NM intervention in these measures, suggesting that the mechanistic effects of NM are potentially related to anatomical positions that specifically stress neural and/or vascular tissues, rather than nonspecific effects such as expectation of benefit.

Neurophysiological Effects

Neurophysiological effects of spinal manipulation have been previously reported in the literature.[22,30,70] Our results in this current study demonstrate that NM tensioning had an immediate hypoalgesic effect on C-fiber mediated pain perception (temporal summation), but not on A-delta fiber mediated pain perception. This is an interesting finding because the inhibition of temporal summation is similar to what we have observed in studies of spinal manipulation in asymptomatic participants.[4,30] In this current study, temporal summation was used as a proxy measure of "wind-up," which is defined as dorsal horn centralization resulting from tonic, peripheral nociceptive input.[49] While direct measurement of wind-up is not possible in human participants, temporal summation of thermal stimuli has been reported to be an acceptable behavioral measure of this phenomenon.[48]

Enhanced temporal summation of C-fiber mediated pain has been identified in patients with painful conditions in comparison to healthy controls.[41,60,61,63] Therefore, inhibition of temporal summation is believed to have therapeutic value.[5] Inhibition of temporal summation was associated with NM in the current study, suggesting a hypoalgesic mechanism for NM tensioning techniques. Interestingly, this hypoalgesic mechanism converges with one from a previous study of spinal manipulation.[5]

The immediate reductions in temporal summation were detected during the first session only; however, there were no differences in C-fiber or A-delta mediated pain perception at later treatment times. This could indicate that the hypoalgesic effect from NM may be short term, only. However, the fact that asymptomatic individuals were used in this study should also be considered when interpreting the lack of carryover hypoalgesic effects. Unlike individuals with musculoskeletal pain, asymptomatic individuals may have encountered a ceiling effect in regard to their hypoalgesic responses. In other words, hypoalgesic effects may not be expected to occur over extended periods in asymptomatic individuals. In the absence of tissue injury or inflammatory process, nociceptive responses experienced from thermal stimuli may not exert the same physiological and psychological responses as would occur in the presence of actual tissue injury.

Effects on ROM and Sensory Descriptors

The NM tensioning technique also resulted in improvements in ROM and sensory descriptors at 3 weeks and the carryover assessment. Coppieters et al[13] has indirectly confirmed the specificity of the neurodynamic test for the median nerve, thus suggesting the nervous system is the limiting factor during this test. As the NM tensioning technique utilized in this study shares similar characteristics to the neurodynamic test, a plausible explanation may be that increased elbow ROM measures were the result of longitudinal elongation of the nerve bed.[16] Additionally, the possibility that these findings were the result of nonneural effects (eg, musculoskeletal tissue) cannot be ruled out.

Sham Technique

Overall, sham techniques for the study of manual therapy are limited in the literature and, as a result the nonspecific effects of manual therapy, have not been well described.[33,40] The key aspect of a sham technique is that it resembles the actual treatment as closely as possible, without actually including the specific active component.[28,33] Our study provides evidence that the NM tensioning techniques and sham NM share therapist handling, but differ on responses related to temporal summation, ROM changes, and sensory descriptor modification. These data provide promising preliminary evidence that, although similar in appearance, there are key differences in the "active" agents of the 2 NM treatments included in this study. Therefore, the described sham NM may provide the potential to investigate specific versus nonspecific effects in future clinical studies.[33]

Limitations

The primary limitation of this study was the differences in the sham and NM tensioning techniques. Our NM tensioning technique included active cervical motion, while the sham NM technique did not. Given this, we were unable to determine the actual mechanism through which the hypoalgesic changes occurred, as hypoalgesia has been immediately induced in symptomatic individuals using cervical spine mobilization in partial neurodynamic testing positions[70] and following a craniocervical flexion coordination exercise.[44] Nonetheless, the difference between the subjects receiving the NM tensioning and those in the sham NM group suggests that hypoalgesic effects may be related to the application of some component of the NM tensioning technique and not to nonspecific factors like expectation of symptom relief.

Another difference due to the inclusion of cervical movement in the NM technique alone was that the 2 techniques differed in dosage parameters, with the NM receiving more mobilization time. The results of a recently updated systematic review have suggested that there is limited evidence of benefit for active ROM cervical exercises and emphasized the need for phase 2 trials to identify the most effective dosage parameters.[35] Nevertheless, we acknowledge differences in dosage parameters as potential limitations in this study.

Another limitation is that asymptom-

atic individuals were recruited for this study. Therefore, similar findings in symptomatic individuals may not occur. Also, it was impossible to determine if changes in pain perception, ROM, and sensory descriptor ratings were clinically relevant. This study recruited asymptomatic participants and utilized an induced pain protocol, with the goal of investigating potential mechanisms of NM by utilizing a sham controlled design. Determining the clinical effectiveness of NM by use of tensioning techniques was not a primary goal of this study. Additional sensory descriptors reported by symptomatic individuals could have been utilized in this study, including "pulling,"[57] "pins and needles,"[57] "stretch,"[36] and "ache,"[36] which is another potential limitation of this study.

A final limitation of this study is the use of a quasi-experimental design. Quasi-experimental designs are inferior to randomized designs in respect to assumptions made regarding internal validity.[66] Considering that we observed baseline differences in the treatment groups, a true experimental design would have been a stronger methodological choice. For example, the lack of investigator blinding may have influenced neurodynamic testing outcomes and could have been addressed if blinding was implemented in this study. Additionally, participants' expectation of symptom relief prior to intervention was not monitored. This factor may have influenced thermal pain sensitivity and neurodynamic sensory descriptor ratings.[4]

Future Study

Future studies should involve patients with neck and/or upper extremity symptoms and incorporate experimental designs to minimize systematic variation.[27] These future studies should also include clinically relevant outcome measures and longer follow-up times than 1 week. Another possibility for future study is to include a true control group to assess the natural history of clinical conditions. The use of a true control group will allow investigators to analyze the "absolute" effectiveness of NM in relation to specific and sham comparison techniques.[33] Last, future studies involving symptomatic participants should consider modification of the sham NM technique to better match the NM technique on cervical motion (ie, including ipsilateral cervical lateral flexion) and dosage parameters.

CONCLUSIONS

This study suggests immediate differences in temporal summation and 3-week differences in ROM and sensory descriptors when comparing NM utilizing tensioning techniques and sham NM techniques for a cohort of asymptomatic individuals. The results provide information on potential mechanisms associated with NM tensioning techniques and describe a sham NM technique that could potentially be used in future clinical studies. ◉

KEY POINTS

FINDINGS: NM utilizing tensioning techniques had an immediate effect on temporal summation, similar to what has been observed in spinal manipulation, suggesting mechanism of action may be inhibition at the dorsal horn. Also, elbow extension ROM and sensory descriptors differed and were maintained over the 4-week study period.

IMPLICATION: NM tensioning techniques have measurable differences when compared to sham NM in several measures.

CAUTION: The study involved asymptomatic individuals and nonrandomized treatment assignment. As a result, these results are focused on describing potential mechanisms of NM tensioning, not clinical effectiveness of NM tensioning or other NM techniques (eg, sliding). Reproduction of this study in a sample of symptomatic individuals utilizing a randomized experimental design will have a larger impact on clinical practice.

ACKNOWLEDGEMENTS: *Kacie Smith, Anthony Lauretta, and Josh Barabas assisted with data collection.*

REFERENCES

1. Akalin E, El O, Peker O, et al. Treatment of carpal tunnel syndrome with nerve and tendon gliding exercises. *Am J Phys Med Rehabil.* 2002;81:108-113.
2. Barnes LLB, Harp D, Jung WS. Reliability generalization of scores on the Spielberger State-Trait Anxiety Inventory. *Educat Psychol Measure.* 2002;62:603-618.
3. Baysal O, Altay Z, Ozcan C, Ertem K, Yologlu S, Kayhan A. Comparison of three conservative treatment protocols in carpal tunnel syndrome. *Int J Clin Pract.* 2006;60:820-828. http://dx.doi.org/10.1111/j.1742-1241.2006.00867.x
4. Bialosky JE, Bishop MD, Robinson ME, Barabas JA, George SZ. The influence of expectation on spinal manipulation induced hypoalgesia: an experimental study in normal subjects. *BMC Musculoskelet Disord.* 2008;9:19. http://dx.doi.org/10.1186/1471-2474-9-19
5. Boal RW, Gillette RG. Central neuronal plasticity, low back pain and spinal manipulative therapy. *J Manipulative Physiol Ther.* 2004;27:314-326. http://dx.doi.org/10.1016/j.jmpt.2004.04.005
6. Butler DS. *The Sensitive Nervous System.* Unley, Australia: NoiGroup Publications; 2000.
7. Butler DS, Coppieters MW. Neurodynamics in a broader perspective. *Man Ther.* 2007;12:e7-8. http://dx.doi.org/10.1016/j.math.2007.01.001
8. Butler DS, Gifford LS. The concept of adverse mechanical tension in the nervous system. Part 1: testing for "dural tension". *Physiother.* 1989;75:622-629.
9. Butler DS, Gifford LS. The concept of adverse mechanical tension in the nervous system. Part 2: examination and treatment. *Physiother.* 1989;75:629-636.
10. Butler DS, Jones MA. *Mobilisation of the Nervous System.* London, UK: Churchill Livingstone; 1991.
11. Cleland JA, Childs JD, Palmer JA, Eberhart S. Slump stretching in the management of non-radicular low back pain: a pilot clinical trial. *Man Ther.* 2006;11:279-286. http://dx.doi.org/10.1016/j.math.2005.07.002
12. Coppieters MW, Alshami AM. Longitudinal excursion and strain in the median nerve during novel nerve gliding exercises for carpal tunnel syndrome. *J Orthop Res.* 2007;25:972-980. http://dx.doi.org/10.1002/jor.20310
13. Coppieters MW, Alshami AM, Hodges PW. An experimental pain model to investigate the specificity of the neurodynamic test for the median nerve in the differential diagnosis of hand symptoms. *Arch Phys Med Rehabil.* 2006;87:1412-1417. http://dx.doi.org/10.1016/j.apmr.2006.06.012
14. Coppieters MW, Bartholomeeusen KE, Stappaerts KH. Incorporating nerve-gliding techniques in the conservative treatment of cubital tunnel syndrome. *J Manipulative Physiol Ther.* 2004;27:560-568. http://dx.doi.org/10.1016/j.

jmpt.2004.10.006
15. Coppieters MW, Butler DS. Do 'sliders' slide and 'tensioners' tension? An analysis of neurodynamic techniques and considerations regarding their application. *Man Ther.* 2008;13:213-221. http://dx.doi.org/10.1016/j.math.2006.12.008
16. Coppieters MW, Hough AD, Dilley A. Different nerve-gliding exercises induce different magnitudes of median nerve longitudinal excursion: an in vivo study using dynamic ultrasound imaging. *J Orthop Sports Phys Ther.* 2009;39:164-171. http://dx.doi.org/10.2519/jospt.2009.2913
17. Coppieters MW, Stappaerts KH, Everaert DG, Staes FF. Addition of test components during neurodynamic testing: effect on range of motion and sensory responses. *J Orthop Sports Phys Ther.* 2001;31:226-235; discussion 236-227.
18. Coppieters MW, Stappaerts KH, Everaert DG, Staes FF. A qualitative assessment of shoulder girdle elevation during the upper limb tension test 1. *Man Ther.* 1999;4:33-38.
19. Coppieters MW, Stappaerts KH, Staes FF, Everaert DG. Shoulder girdle elevation during neurodynamic testing: an assessable sign? *Man Ther.* 2001;6:88-96. http://dx.doi.org/10.1054/math.2000.0375
20. Coppieters MW, Stappaerts KH, Wouters LL, Janssens K. Aberrant protective force generation during neural provocation testing and the effect of treatment in patients with neurogenic cervicobrachial pain. *J Manipulative Physiol Ther.* 2003;26:99-106. http://dx.doi.org/10.1067/mmt.2003.16
21. Coppieters MW, Stappaerts KH, Wouters LL, Janssens K. The immediate effects of a cervical lateral glide treatment technique in patients with neurogenic cervicobrachial pain. *J Orthop Sports Phys Ther.* 2003;33:369-378.
22. Dishman JD, Bulbulian R. Spinal reflex attenuation associated with spinal manipulation. *Spine*. 2000;25:2519-2524;discussion 2525.
23. Ekstrom RA, Holden K. Examination of and intervention for a patient with chronic lateral elbow pain with signs of nerve entrapment. *Phys Ther.* 2002;82:1077-1086.
24. Ellis RF, Hing WA. Neural mobilization: a systematic review of randomized controlled trials with an analysis of therapeutic efficacy. *J Man Manip Ther.* 2008;16:8-22.
25. Elvey R. Brachial plexus tension tests and the pathoanatomical origin of arm pain. In: Idczak R, ed. *Aspects of Manipulative Therapy.* Melbourne, Australia: Lincoln Institute of Health Sciences; 1980.
26. Elvey R. The investigation of arm pain: signs of adverse reaponses to the physical examination of the brachial plexus and related neural tissues. In: Boyling J, Palastanga N, Jull GA, Lee DG, Grieve GP, eds. *Grieve's Modern Manual Therapy: The Vertebral Column.* New York, NY: Churchill Livingstone; 1994:577-586.
27. Field AP. *Discovering Statistics Using SPSS (Introducing Statistical Methods Series).* 2nd ed. London, UK: SAGE Publications Ltd; 2005.
28. Fulda KG, Slicho T, Stoll ST. Patient expectations for placebo treatments commonly used in osteopathic manipulative treatment (OMT) clinical trials: a pilot study. *Osteopath Med Prim Care.* 2007;1:3. http://dx.doi.org/10.1186/1750-4732-1-3
29. George SZ. Characteristics of patients with lower extremity symptoms treated with slump stretching: a case series. *J Orthop Sports Phys Ther.* 2002;32:391-398.
30. George SZ, Bishop MD, Bialosky JE, Zeppieri G, Jr, Robinson ME. Immediate effects of spinal manipulation on thermal pain sensitivity: an experimental study. *BMC Musculoskelet Disord.* 2006;7:68. http://dx.doi.org/10.1186/1471-2474-7-68
31. Greening J, Leary R. Re: Improving application of neurodynamic (neural tension) and treatments: a message to researchers and clinicians. *Man Ther.* 2007;12:e2; author reply e3-6. http://dx.doi.org/10.1016/j.math.2006.01.004
32. Haddick E. Management of a patient with shoulder pain and disability: a manual physical therapy approach addressing impairments of the cervical spine and upper limb neural tissue. *J Orthop Sports Phys Ther.* 2007;37:342-350. http://dx.doi.org/10.2519/jospt.2007.2458
33. Hancock MJ, Maher CG, Latimer J, McAuley JH. Selecting an appropriate placebo for a trial of spinal manipulative therapy. *Aust J Physiother.* 2006;52:135-138.
34. Houben RM, Leeuw M, Vlaeyen JW, Goubert L, Picavet HS. Fear of movement/injury in the general population: factor structure and psychometric properties of an adapted version of the Tampa Scale for Kinesiophobia. *J Behav Med.* 2005;28:415-424. http://dx.doi.org/10.1007/s10865-005-9011-x
35. Kay TM, Gross A, Goldsmith C, Santaguida PL, Hoving J, Bronfort G. Exercises for mechanical neck disorders. *Cochrane Database Syst Rev.* 2005;CD004250. http://dx.doi.org/10.1002/14651858.CD004250.pub3
36. Kenneally M, Rubenach H, Elvey R. The upper limb tension test: the SLR test of the arm. In: Grant R, eds. *Physical Therapy of the Cervical and Thoracic Spine.* New York, NY: Churchill Livingstone; 1988:167-194.
37. Kleinrensink GJ, Stoeckart R, Mulder PG, et al. Upper limb tension tests as tools in the diagnosis of nerve and plexus lesions. Anatomical and biomechanical aspects. *Clin Biomech (Bristol, Avon).* 2000;15:9-14.
38. Kori SH, Miller RP, Todd DD. Kinesiophobia: a new view of chronic pain behavior. *Pain Management.* 1990;35:35-43.
39. Licciardone JC, Russo DP. Blinding protocols, treatment credibility, and expectancy: methodologic issues in clinical trials of osteopathic manipulative treatment. *J Am Osteopath Assoc.* 2006;106:457-463.
40. Machado LA, Kamper SJ, Herbert RD, Maher CG, McAuley JH. Imperfect placebos are common in low back pain trials: a systematic review of the literature. *Eur Spine J.* 2008;17:889-904. http://dx.doi.org/10.1007/s00586-008-0664-3
41. Maixner W, Fillingim R, Sigurdsson A, Kincaid S, Silva S. Sensitivity of patients with painful temporomandibular disorders to experimentally evoked pain: evidence for altered temporal summation of pain. *Pain*. 1998;76:71-81.
42. McNeil DW, Rainwater AJ, 3rd. Development of the Fear of Pain Questionnaire--III. *J Behav Med.* 1998;21:389-410.
43. Murphy DR, Hurwitz EL, Gregory A, Clary R. A nonsurgical approach to the management of patients with cervical radiculopathy: a prospective observational cohort study. *J Manipulative Physiol Ther.* 2006;29:279-287. http://dx.doi.org/10.1016/j.jmpt.2006.03.005
44. O'Leary S, Falla D, Hodges PW, Jull G, Vicenzino B. Specific therapeutic exercise of the neck induces immediate local hypoalgesia. *J Pain.* 2007;8:832-839. http://dx.doi.org/10.1016/j.jpain.2007.05.014
45. Osman A, Barrios FX, Kopper BA, Hauptmann W, Jones J, O'Neill E. Factor structure, reliability, and validity of the Pain Catastrophizing Scale. *J Behav Med.* 1997;20:589-605.
46. Osman A, Breitenstein JL, Barrios FX, Gutierrez PM, Kopper BA. The Fear of Pain Questionnaire-III: further reliability and validity with nonclinical samples. *J Behav Med.* 2002;25:155-173.
47. Pinar L, Enhos A, Ada S, Gungor N. Can we use nerve gliding exercises in women with carpal tunnel syndrome? *Adv Ther.* 2005;22:467-475.
48. Price DD. *Psychological Mechanisms of Pain and Analgesia.* Seattle, WA: IASP Press; 1999.
49. Price DD, Hayes RL, Ruda M, Dubner R. Spatial and temporal transformations of input to spinothalamic tract neurons and their relation to somatic sensations. *J Neurophysiol.* 1978;41:933-947.
50. Price DD, Staud R, Robinson ME, Mauderli AP, Cannon R, Vierck CJ. Enhanced temporal summation of second pain and its central modulation in fibromyalgia patients. *Pain*. 2002;99:49-59.
51. Quick NE. Measurement of changes in hand temperature during the upper limb tension test using thermal imaging [abstract]. *J Orthop Sports Phys Ther.* 2007;37:A29.
52. Quick NE, Kelly PJ. Changes in blood flow velocity in the radial artery during the upper limb tension test [abstract]. *J Orthop Sports Phys Ther.* 2007;37:A29.
53. Robinson ME, Wise EA, Gagnon C, Fillingim RB, Price DD. Influences of gender role and anxiety on sex differences in temporal summation of pain. *J Pain.* 2004;5:77-82. http://dx.doi.org/10.1016/j.jpain.2003.11.004
54. Roelofs J, Peters ML, Deutz J, Spijker C, Vlaeyen JW. The Fear of Pain Questionnaire (FPQ): further psychometric examination in a non-clinical sample. *Pain*. 2005;116:339-346. http://dx.doi.org/10.1016/j.pain.2005.05.003
55. Rozmaryn LM, Dovelle S, Rothman ER, Gorman K, Olvey KM, Bartko JJ. Nerve and tendon gliding exercises and the conservative management of carpal tunnel syndrome. *J Hand Ther.* 1998;11:171-179.
56. Scrimshaw SV, Maher CG. Randomized con-

trolled trial of neural mobilization after spinal surgery. *Spine*. 2001;26:2647-2652.
57. Shacklock MO. *Clinical Neurodynamics:A New System of Musculoskeletal Treatment.* Edinburgh, UK: Elsevier Health Sciences; 2005.
58. Spielberger CD, Gorsuch RL, Lushene RE, Vagg PR, Jacobs GA. *Manual for the State and Trait Anxiety Inventory (Form Y).* Palo Alto, CA: Consulting Psychologists Press; 1983.
59. Staud R, Price DD, Fillingim RB. Advanced continuous-contact heat pulse design for efficient temporal summation of second pain (windup). *J Pain.* 2006;7:575-582. http://dx.doi.org/10.1016/j.jpain.2006.02.005
60. Staud R, Price DD, Robinson ME, Mauderli AP, Vierck CJ. Maintenance of windup of second pain requires less frequent stimulation in fibromyalgia patients compared to normal controls. *Pain*. 2004;110:689-696. http://dx.doi.org/10.1016/j.pain.2004.05.009
61. Staud R, Robinson ME, Price DD. Temporal summation of second pain and its maintenance are useful for characterizing widespread central sensitization of fibromyalgia patients. *J Pain.* 2007;8:893-901. http://dx.doi.org/10.1016/j.jpain.2007.06.006
62. Staud R, Robinson ME, Vierck CJ, Jr., Cannon RC, Mauderli AP, Price DD. Ratings of experimental pain and pain-related negative affect predict clinical pain in patients with fibromyalgia syndrome. *Pain*. 2003;105:215-222.
63. Staud R, Vierck CJ, Cannon RL, Mauderli AP, Price DD. Abnormal sensitization and temporal summation of second pain (wind-up) in patients with fibromyalgia syndrome. *Pain*. 2001;91:165-175.
64. Sullivan M, Bishop SR, Pivik J. The pain catastrophizing scale: development and validation. *Psych Assess.* 1995;7:524-532.
65. Tal-Akabi A, Rushton A. An investigation to compare the effectiveness of carpal bone mobilisation and neurodynamic mobilisation as methods of treatment for carpal tunnel syndrome. *Man Ther.* 2000;5:214-222. http://dx.doi.org/10.1054/math.2000.0355
66. Trochim W. *Research Methods Knowledge Base.* 2nd ed. Cincinnati, OH: Atomic Dog Publishing; 2000.
67. Van Damme S, Crombez G, Bijttebier P, Goubert L, Van Houdenhove B. A confirmatory factor analysis of the Pain Catastrophizing Scale: invariant factor structure across clinical and non-clinical populations. *Pain*. 2002;96:319-324.
68. Van Hoof T, Vangestel C, Forward M, et al. The impact of muscular variation on the neurodynamic test for the median nerve in a healthy population with Langer's axillary arch. *J Manipulative Physiol Ther.* 2008;31:474-483. http://dx.doi.org/10.1016/j.jmpt.2008.06.007
69. van Wijk AJ, Hoogstraten J. Dutch translation of the Fear of Pain Questionnaire: factor structure, reliability and validity. *Eur J Pain.* 2006;10:479-486. http://dx.doi.org/10.1016/j.ejpain.2005.06.008
70. Vicenzino B, Collins D, Benson H, Wright A. An investigation of the interrelationship between manipulative therapy-induced hypoalgesia and sympathoexcitation. *J Manipulative Physiol Ther.* 1998;21:448-453.
71. Vicenzino B, Collins D, Wright A. The initial effects of a cervical spine manipulative physiotherapy treatment on the pain and dysfunction of lateral epicondylalgia. *Pain*. 1996;68:69-74.
72. Vlaeyen JW, Crombez G. The modified Tampa Scale for Kinesiophobia for use in a non-pain population. *Unpublished authorized Dutch/Flemish version.* 1998.
73. Walsh J, Flatley M, Johnston N, Bennett K. Slump test: sensory responses in asymptomatic subjects. *J Man Manip Ther.* 2007;15:231-238.
74. Winkelstein BA. Mechanisms of central sensitization, neuroimmunology and injury biomechanics in persistent pain: implications for musculoskeletal disorders. *J Electromyogr Kinesiol.* 2004;14:87-93. http://dx.doi.org/10.1016/j.jelekin.2003.09.017

MORE INFORMATION
WWW.JOSPT.ORG

BROWSE Collections of Articles on *JOSPT*'s Website

The *Journal*'s website (**www.jospt.org**) sorts published articles into more than **50 distinct clinical collections**, which can be used as convenient entry points to clinical content by region of the body, sport, and other categories such as differential diagnosis and exercise or muscle physiology. In each collection, articles are cited in reverse chronological order, with the most recent first.

In addition, *JOSPT* offers easy online access to special issues and features, including a series on **clinical practice guidelines** that are linked to the International Classification of Functioning, Disability and Health. Please see **"Special Issues & Features"** in the right-hand column of the *Journal* website's home page.