Vertebral Displacements and Muscle Activity During Manual Therapy: Distinct Behaviors Between Spinal Manipulation and Mobilization

Isabelle Pagé, DC, MSc, PhD,[a] Éric Biner, BSc,[b] and Martin Descarreaux, DC, MSc, PhD[c]

Abstract

Objective: The purpose of this study was to compare vertebral displacements (absolute and relative) and muscle responses induced by spinal manipulative therapy of short (spinal manipulation) and long (spinal mobilization) impulse duration.

Methods: Twenty-five healthy adults (without thoracic pain) were recruited for this crossover study. Six spinal manipulative therapies (255 N peak force) of different impulse durations (100, 125, 200, 500, 1000, and 1500 ms) were delivered to each participant's T7 transverse process using a mechanical device. Impulse duration effect on the vertebral displacement (absolute displacement of T6, T7, and T8 and relative displacement between T7 and T6 and between T7 and T8) and the thoracic muscle response (surface electromyography) were assessed using mixed-model analyses of variance and predefined linear trend analyses.

Results: Results showed a linear increase in the absolute vertebral displacement for T8 ($P = .002$) and a linear decrease in the T7/T6 and T7/T8 relative displacement ($P < .0001$) when impulse duration was increased. The data of 24 participants were available for electromyography analysis. A significant main effect of impulse duration on surface electromyography response was observed ($P < .0001$, $\eta_p^2 = 0.43$). Planned comparisons for a linear trend between these variables revealed a negative relationship ($P < .0001$). Only 13 of the 24 participants with available data presented a muscle response at every impulse duration.

Conclusion: These results support the assumption that spinal manipulation and spinal mobilization might operate under distinct mechanisms. (J Manipulative Physiol Ther 2018;41:753-761)

Key Indexing Terms: *Manipulation, Spinal; Musculoskeletal Manipulations; Electromyography; Biomechanical Phenomena*

Introduction

Complementary and alternative medicine presents an estimated use rate as high as 75% among patients with back and neck pain.[1] Osteopathy and chiropractic are among the most commonly reported complementary and alternative medicine, and back pain constitutes the most frequent reason for spinal manipulative therapy (SMT) utilization.[2] Although SMT, including both spinal manipulation and spinal mobilization, now is recommended by guidelines for the management of neck and back pain,[3-5] the mechanisms underlying its effects are not yet fully established.

Although more than a decade ago the National Institutes of Health Research highlighted the necessity to determine and compare the neurophysiological responses to various types of manual therapies, especially between those of high and slow velocity,[6] studies remain mainly focused on SMT of high velocity (ie, spinal manipulation). Indeed, no study conducted in humans has yet compared the neurophysiological responses to SMTs that include velocities of both spinal manipulation and spinal mobilization.

Clinical effects associated with SMT are believed to be explained partly by the vertebral displacement and the muscle response generated during the procedure.[7,8] The

[a] Department of Anatomy, Université du Québec à Trois-Rivières, Trois-Rivières, Québec, Canada.
[b] Department of Chiropractic, Université du Québec à Trois-Rivières, Trois-Rivières, Québec, Canada.
[c] Department of Human Kinetics, Université du Québec à Trois-Rivières, Trois-Rivières, Québec, Canada.
Corresponding author: Isabelle Pagé, DC, MSc, PhD, Department of Anatomy, Université du Québec à Trois-Rivières, 3351 boul. des Forges, C.P. 500, Trois-Rivières, Québec, Canada, G9H 5H7. Tel.: +1 819 376 5011 x3791. (e-mail: *Isabelle.page1@uqtr.ca*).
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magnitude of these neuromechanical responses has been shown to be associated to several SMT kinetic parameters. Indeed, SMT is characterized by specific kinetics for which the magnitude differs based on the patient, the clinician's characteristics, and the chosen procedure (spinal manipulation or spinal mobilization).[9] These kinetics parameters include a preload force (newton [N]), a peak force (N), an impulse duration (ie, time from the preload to the peak force, ms), and the rate of force application (ie, the velocity, N/s).

Since 2010, studies have provided insight on vertebral displacement and the muscle response induced by spinal manipulations of various dosages.[10-14] Overall, a linear and positive relationship between the rate of force application and the muscle response amplitude, and a linear and positive relationship between the total force applied (preload to peak force) and the vertebral displacement of the contacted vertebra and its adjacent vertebrae, has been observed.[10-12,14] Moreover, varying the impulse duration (from 125 to 175 ms) does not seem to affect the magnitude of the vertebral displacement.[14] Studies conducted in animal models also support these findings. For instance, Reed et al showed an increase in the muscle spindle discharge frequency with the increase in the impulse velocity through either a decrease in the impulse duration or in the preload force.[15,16] Regarding the vertebral displacement, Colloca et al showed a linear and positive relationship with the impulse force using adolescent Merino sheep models.[17] Their results also suggest a decrease in the vertebral displacement with very short impulse durations (10 ms) compared with spinal manipulations using an impulse duration of 100 and 200 ms, which generate similar displacements.[17]

Studies conducted in humans and including impulse durations corresponding to spinal mobilizations are sparse. Lee et al showed higher relative vertebral displacements (relative displacement between L4 and L5 and between L3 and L4) during a spinal mobilization with an impulse duration of 15 seconds (30 seconds for a complete cycle of a spinal mobilization) compared with an impulse duration of 250 ms (0.5 seconds for a complete cycle of a spinal mobilization).[18] To our knowledge, the muscle activity or the muscle spindle discharge during spinal mobilizations has not been investigated.

Understanding the distinctive mechanisms underlying spinal manipulation and spinal mobilization clinical effects may help identify patients most likely to respond to one specific type of SMTs, and thus support clinicians in their selection of the appropriate treatment option for a patient. The purpose of the present study was, therefore, to determine and compare the absolute and relative vertebral displacement and the muscle response amplitude induced by SMTs of high (spinal manipulation) and low (spinal mobilization) velocity. Based on the available evidence, it was hypothesized that the muscle response amplitude and the relative vertebral displacement would be dependent on the impulse duration, but the latter will not affect the absolute vertebral displacement.

Methods

Participants

Twenty-five healthy adults participated in 2 experimental sessions over a period of 48 hours. Volunteers were excluded if they had reported any significant pain or discomfort in the thoracic region in the past year and if they presented a diagnosed scoliosis or any contraindication to SMT. A physical evaluation was performed to confirm their eligibility. Once included, all participants gave their informed written consent according to the ethics approval from the Université du Québec à Trois-Rivières Human Research Ethics Committee (No. CER-17-235-07.03). All experiments were performed in accordance with relevant guidelines and regulations.

Experiment

Participants rested facedown on a treatment table (Techniques Tables Ltd, model TT5001029, Ontario, Canada) for approximately 30 minutes. Surface electromyography (sEMG) electrodes were applied bilaterally over the erector spinae muscles (2 cm laterally from T5 and T7 spinous processes). A wireless system (Trigno, Delsys Inc, Natick, Massachusetts) that includes 2 relative sEMG inputs with 2 patented stabilizing references was used for muscle activity recording. The sEMG signals were recorded at 2000 Hz using EMGworks 4.2 software (Delsys Inc). Before applying electrodes, the participant's skin was shaved, gently abraded with fine-grade sandpaper (Red Dot Trace Prep, 3M, St. Paul, Minnesota), and cleaned with alcohol swabs. Light-emitting kinematic markers (Optotrack Certus, NDI Measurement Sciences, Waterloo, Ontario, Canada) also were applied on the spinous processes of T6, T7, and T8 to estimate the displacement of these vertebrae during the impulse phase of each SMT. Kinematic data were recorded at 300 Hz using NDI First Principles (NDI Measurement Sciences). Figure 1 illustrates the positioning of sEMG electrodes and kinematic markers.

sEMG Normalization Trial

Before each experimental session's first SMT, participants completed an sEMG normalization trial. Lying prone on the treatment table, participants were asked to move upward until their iliac crests reached the edge of the table. Participants then were stabilized using a belt at the level of their ankles and were asked to maintain this position for 10 seconds with their arms crossed over their shoulders. The sEMG signals were recorded throughout this normalization trial.

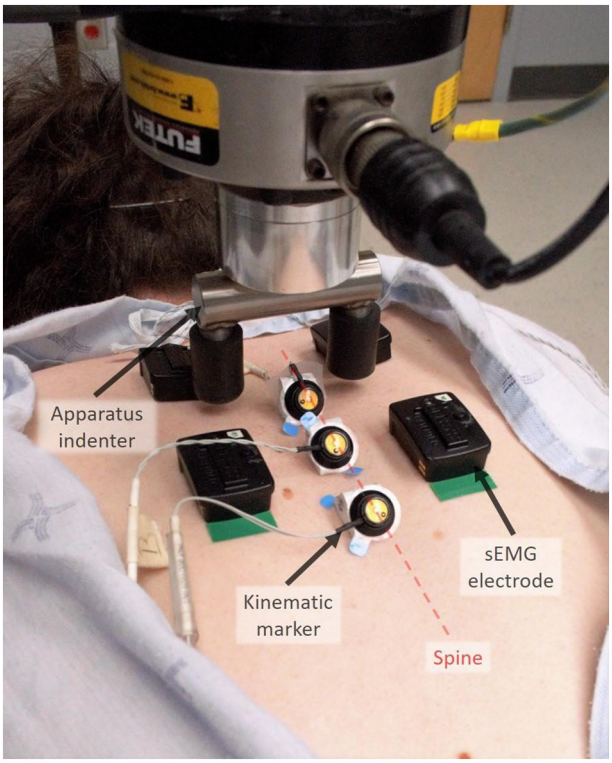

Fig 1. *Picture of the experimental setup. The sEMG electrodes were positioned on both sides of the spine just below and above the indenter tips. Light-emitting kinematic markers were positioned over T6, T7, and T8 spinous processes, and wooden boards were used to angle the markers toward the camera.* sEMG*, surface electromyography.*

SMT Trials

A total of 6 different SMTs were executed on each participant (3 per session). Spinal manipulative therapies were executed using a mechanical device with a servo-linear motor (Linear Motor Series P01-48×360, LinMot Inc., Zurich, Switzerland) by contacting T7 transverse processes. A detailed description of the device and of its safety features are reported in another article.[19] A twin-tip padded rod (θ tip = 10 mm; distance between the center of the tips = 56 mm) was used to contact the T7 transverse processes. The thoracic erector spinae muscle response (sEMG) and the vertebral displacement of T6, T7, and T8 were recorded during each trial. All SMTs consisted of a 20-N preload force for 1000 ms, followed by an impulse leading to a peak force of 255 N. Figure 2 shows a typical SMT force-time profile. The SMTs differed in their impulse duration and rate of force application: 100 ms (2300 N/s), 125 ms (1840 N/s), 200 ms (1150 N/s), 500 ms (460 N/s), 1000 ms (230 N/s), and 1500 ms (153 N/s). The order of the 6 SMTs was randomized using an online scheme generator (randomization.com) to avoid a sequencing effect. A 5-minute rest was provided between each SMT. After each trial, participants were asked to rate their discomfort during the procedure using a 0-100 visual analog scale (0, no discomfort; 100, extreme discomfort).

Analysis

Descriptive Analysis. The results for the participants' characteristics descriptive analysis are reported as means with standard deviation (SD) for parametric data (height and weight) or median and interquartile ranges (IQRs) for nonparametric data (age and body mass index). The mean (SD) of the discomfort intensity during each SMT also was computed. All statistical analyses were computed using Statistica 8 (Statsoft, Tulsa, Oklahoma), and statistical significance was set at $P \leq .05$.

Vertebral Displacement Analysis. A custom-made MATLAB (MathWorks, Natick, Massachusetts) script was developed to compute the total displacement in z-axis (ie, posterior to anterior displacement) of T6, T7, and T8 kinematic markers during each SMT impulse phase (ie, from preload to peak force). The relative displacement also was computed by subtracting T6 and T8 absolute displacements from T7 absolute displacement (relative T7/T6 displacement and relative T7/T8 displacement). These values represent the intersegmental displacement between the contacted vertebra (T7) and the adjacent vertebrae (T6 and T8).

A mixed-model analysis of variance (ANOVA) was computed to evaluate the impulse duration effect on the contacted vertebra (T7) and the adjacent vertebrae (T6 and T8) absolute displacements. Absolute displacement was subjected to a mixed-model ANOVA comparing responses across 6 impulse durations (100 ms, 125 ms, 200 ms, 500 ms, 1000 ms, and 1500 ms) and 3 spinal levels (T6, T7, and T8). A similar analysis was computed to assess the effect of the impulse duration on the absolute value of the relative displacement using a 6 (impulse duration) × 2 (pairs of vertebrae: |T7/T6| and |T7/T8|) mixed-model ANOVA. Planned comparisons for a linear trend then were computed to explore the dose–response relationship between vertebral displacement (absolute and relative) and impulse duration.

Muscle Activity Analysis. A MATLAB program was developed to compute the muscle response amplitude during each SMT. The sEMG data first were digitally band-pass filtered using a second-order Butterworth filter in the frequency bandwidth of 40 to 400 Hz. A low cutoff of 40 Hz was chosen to filter the electrocardiogram signal. The root mean square (RMS) value, representing the muscle response amplitude, then was computed during 2 independent time windows: (1) during the impulse phase, and (2) from the muscle response onset until its return to its initial value. This second time window was visually identified by one of the investigators on the RMS signal through a series of 10 samples sliding window with a 5-sample overlapped. Each resulting RMS value then was normalized using the sEMG signal obtained during the normalization trial of the

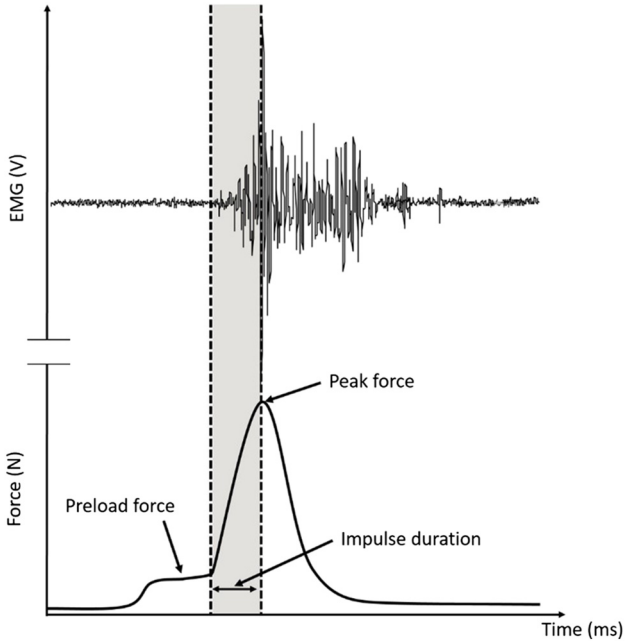

Fig 2. *Example of a typical spinal manipulative therapy force-time profile and the associated electromyography (EMG) recorded response. Rate of force application is obtained by dividing the peak force by the impulse duration (N/s).*

corresponding experimental session. The sEMG signal of the normalization trial was submitted to a similar filtering procedure, and RMS values between the 7th and the 10th second of the trial were computed. The RMS value of each electrode obtained during a SMT then was divided by the corresponding electrode RMS value obtained during the normalization trial and was used for subsequent analyses (nRMS).

Because nRMS data were non-normally distributed, further analyses were computed using the natural logarithm of these data. To assess the effect of the impulse duration on the muscle response amplitude, transformed nRMS values were submitted to ANOVAs. The transformed nRMS values during the automatically and the manually marked time windows were independently submitted to a 6 (impulse duration) × 4 (electrodes) mixed-model ANOVA. Planned comparisons for linear trends were computed to explore the dose–response relationship between the muscle response and the impulse duration. To compare the muscle response obtained using the automated and the manual marking procedures, Pearson's estimated value obtained from Kendall τ rank correlation coefficient was calculated. The importance of the correlation was evaluated as being strong ($r \geq 0.70$), good ($0.50 \leq r < 0.70$), moderate ($0.30 \leq r < 0.50$), or poor ($r < 0.30$).[20]

In addition to the analysis of the muscle response amplitude, the effect of the impulse duration on the delay between the impulse onset and the muscle response onset was explored. A semi-automatized MATLAB script thus was developed to calculate the time difference between the impulse onset (automated determination) and the muscle response onset (manual marking).

Results

Participant Characteristics

Participants included 13 men and 12 women with a median age of 24 years (IQR = 5 years) and a median body mass index of 23.33 kg/m^2 (IQR = 3.26 kg/m^2). Participants presented a mean weight of 72.78 kg (SD = 12.30 kg) and a mean height of 1.73 m (SD = 0.09 m). The 6 SMTs were delivered to all participants, and percentages of discomfort (mean, SD, range) were estimated at 19.5% (13.5, 0-46) for the 100-ms impulse duration, 18.5% (12.6, 0-50) for the 125 ms, 17.1% (12.3, 0-40) for the 200 ms, 21.0% (15.1, 0-60) for the 500 ms, 26.6% (13.8, 0-46) for the 1000 ms, and 27.8% (17.3, 0-65) for the 1500 ms.

Vertebral Displacement

Mixed-model ANOVA for the dependent variable absolute displacement showed a significant main effect of spinal levels ($F_{2, 48} = 75.79$, $P < .0001$, $\eta_p^2 = 0.76$), a significant interaction effect between impulse duration and spinal levels ($F_{10, 240} = 15.73$, $P < .0001$, $\eta_p^2 = 0.40$), and a marginally significant main effect of impulse duration ($F_{5, 120} = 2.22$, $P = .07$, $\eta_p^2 = 0.08$). Planned comparisons for a linear increase in absolute displacement from short (100 ms) to long (1500 ms) impulse duration were computed. These analyses revealed a significant linear trend for T8 ($P = .002$), a marginally significant trend for T7 ($P = .07$), and a nonsignificant trend for T6 ($P = .59$). Bonferroni post hoc tests revealed that T6 absolute displacement was similar between all durations except between 125 ms (17.68 ± 2.45 mm) and both 500 ms (16.88 ± 2.35 mm) and 1000 ms (16.83 ± 2.87 mm). The absolute displacement remained significantly higher for T6 vs T7 and for T7 vs T8 for all impulse durations with the exception of the 1000-ms impulse duration. Absolute displacement for T6, T7, and T8 are reported in Table 1.

Mixed-model ANOVA for relative displacement showed a significant main effect of impulse duration ($F_{5, 120} = 15.11$, $P < .0001$, $\eta_p^2 = 0.39$). Planned comparisons revealed a linear decrease in the relative displacement from 125-ms to 1000-ms impulse duration ($F_{1,24} = 21.69$, $P < .0001$). Similar intervertebral displacement was observed between the 100- and 125-ms impulse duration (2.08 ± 0.74 mm vs 2.09 ± 0.77 mm) and between the 1000 and 1500 ms (1.19 ± 0.84 mm vs 1.23 ± 0.95 mm). These results were consistent between the pairs of vertebrae (ie, there was a nonsignificant main effect of the pairs of vertebrae: $F_{1, 24} = 2.02$, $P = .17$, $\eta_p^2 = 0.08$), and no interaction between the pairs of vertebrae and the impulse duration was observed ($F_{5, 120} = 0.39$, $P = .86$,

Table 1. *Absolute Displacement for T6, T7, and T8 and Absolute Value of the Relative Displacement Between T7/T6 and T7/T8 (mm) Induced by Each SMT Impulse Duration*

Displacement	100 ms	125 ms	200 ms	500 ms	1000 ms	1500 ms
Absolute Displacement (mm)						
T6	17.28 ± 2.45	17.68 ± 2.45	17.17 ± 2.35	16.88 ± 2.35	16.83 ± 2.85	17.37 ± 3.2
	(16.27-18.30)	(16.67-18.70)	(16.20-18.14)	(15.91-17.84)	(15.65-18.02)	(16.04-18.69)
T7	15.08 ± 1.9	15.5 ± 2.05	15.32 ± 1.8	15.64 ± 2.1	16.18 ± 2.5	16.09 ± 3.1
	(14.31-15.86)	(14.65-16.34)	(14.57-16.07)	(14.77-16.52)	(15.16-17.21)	(14.81-17.38)
T8	13.19 ± 1.55	13.56 ± 1.7	13.64 ± 1.55	14.56 ± 2.3	15.48 ± 2.75	15.2 ± 3.3
	(12.55-13.82)	(12.85-14.28)	(12.99-14.29)	(13.61-15.52)	(14.35-16.61)	(13.84-16.55)
Relative Displacement (mm)						
T7/T6	2.27 ± 1.05	2.25 ± 1.05	1.92 ± 1.15	1.48 ± 1.1	1.26 ± 1.1	1.36 ± 1.3
	(1.84-2.69)	(1.82-2.69)	(1.45-2.38)	(1.01-1.94)	(0.80-1.71)	(0.82-1.90)
T7/T8	1.89 ± 0.9	1.93 ± 0.85	1.68 ± 0.9	1.33 ± 0.9	1.12 ± 0.75	1.09 ± 0.75
	(1.53-2.26)	(1.59-2.28)	(1.31-2.04)	(0.95-1.71)	(0.80-1.44)	(0.78-1.40)

SMT, spinal manipulative therapy.
Mean ± standard deviation (95% confidence interval) is reported.

$\eta_p^2 = 0.02$). Relative displacement for T7/T6 and T7/T8 are reported in Table 1.

The Muscle Response

Automatically Marked Time Window. Data from 1 participant had to be excluded owing to technical difficulties during recording. The mixed-model ANOVA using the natural logarithm of the remaining nRMS showed a significant main effect of impulse duration on the muscle response amplitude ($F_{5, 115} = 17.36$, $P < .0001$, $\eta_p^2 = 0.43$). Planned comparisons for a linear trend between these variables revealed a significant negative relationship ($F_{1, 23} = 32.14$, $P < .0001$). No significant main effect of the electrode localization was observed ($F_{3, 69} = 1.20$, $P = .32$, $\eta_p^2 = 0.05$). The mean nRMS was about 3-fold higher during the 100-ms impulse duration (mean = 0.60, 95% CI = 0.38-0.95) compared with the 1500-ms impulse duration (mean = 0.23, 95% CI = 0.14-0.35). Figure 3 illustrates typical muscle response profiles based on the impulse duration.

Manually Marked Time Window. As observed in Figure 3, the impulse duration does not include the entire EMG response. The same analysis therefore was computed de novo using the natural logarithm of the nRMS obtained during the manually determined time window. From the 25 available participants' data, 1 participant's data had to be excluded. Moreover, no muscle response onset could be detected in 11 participants (Table 2), resulting in the inclusion of 13 participants with complete data. The resulting mixed-model ANOVA revealed a significant main effect of impulse duration ($F_{5, 60} = 6.58$, $P < .0001$, $\eta_p^2 = 0.35$), no main effect of electrode localization ($F_{3,36} = 0.42$, $P = .74$, $\eta_p^2 = 0.03$), and no significant interaction between these 2 variables ($F_{15,180} = 1.08$, $P = .38$, $\eta_p^2 = 0.08$). Similarly to the response occurring during the SMT impulse, planned comparisons revealed a significant negative relationship between transformed nRMS and SMT impulse duration ($F_{1, 12} = 12.22$, $P = .004$). However, the difference between the mean response to the 100-ms impulse duration (mean = 0.65, 95% CI = 0.33-1.27) was reduced to a 2-fold increase when compared with the 1500-ms impulse duration (mean = 0.32, 95% CI = 0.18-0.57). The nRMS values obtained using the automated and the manual marking procedures showed significant and almost perfect association between both procedures (estimated Pearson's correlation: $0.90 \leq r \leq 0.99$).

Moreover, ANOVA analysis regarding the effect of impulse duration on the delay between the impulse onset and the muscle response onset showed a significant main effect of the impulse duration ($F_{5, 50} = 27.11$, $P < .0001$, $\eta_p^2 = 0.73$). Planned comparisons for a linear trend revealed a significant positive linear relationship between these variables ($P < .0001$). The mean delay was around 50 ms

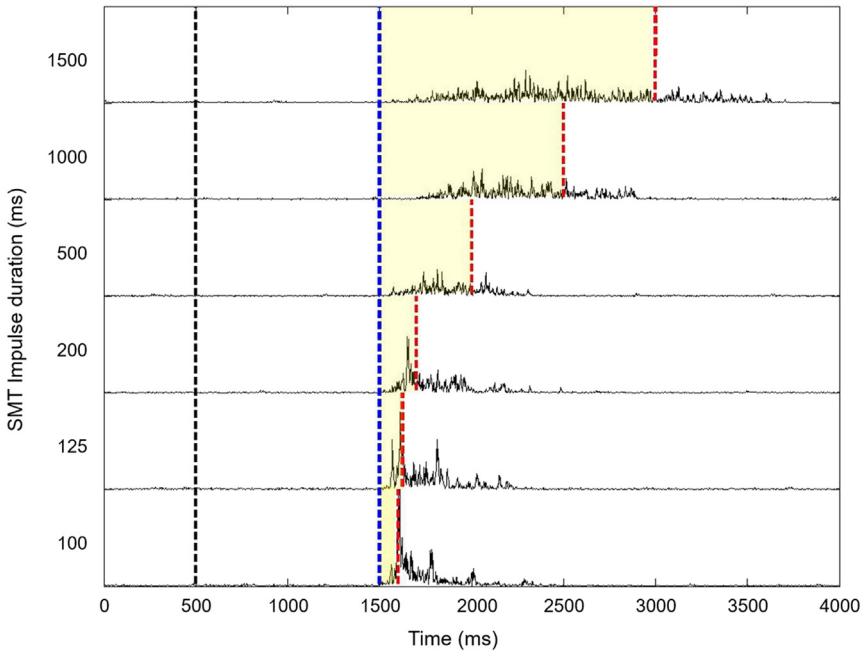

Fig 3. *Electromyography response profiles (nRMS signal, scales adjusted to the peak nRMS value of the 100-ms SMT) for each SMT impulse duration of a participant presenting a dose–dependent response. The preload phase occurred between the first 2 vertical lines (between 500 and 1500 ms), whereas the third vertical line represents the reach of the peak force.* nRMS*, normalized root mean square;* SMT*, spinal manipulative therapy.*

(95% CI = 30-70 ms) with the 100-ms impulse duration, and it increased to around 340 ms (95% CI = 230-450 ms) with the 1500-ms impulse duration. Owing to the equipment acquisition frequency, an error of ±13 ms exists in muscle response delay values.

Discussion

The current study provides new insight into the neurophysiological mechanisms underlying spinal manipulations and spinal mobilizations. To our knowledge, this is the first study to systematically investigate vertebral displacements and muscle responses to a wide span of SMT impulse durations while keeping the magnitude of the peak force and the preload force constant. In the thoracic spine, spinal manipulation impulse duration has been reported to range between 117 ms (SD = 21)[21] and 280 ms (SD = 110),[22] whereas rate of force application seems to vary between 1368 N/s (SD = 327)[23] and 4191.3 N/s (SD = 635.8),[22] and preload force from 24 N [23] to 180 N.[22] Spinal mobilization is a therapy defined as the application of a load, without a preload force, in an oscillating manner over a period, usually 30 seconds, repeated 3× to 4× to a single vertebra, thus including impulse duration that can be up to 5 seconds.[24] Peak forces of both spinal manipulations and spinal mobilizations are highly variable. Thoracic manipulation peak forces can range from 238 N (SD = 46)[23] to 815 N (SD = 105),[22] whereas these values are estimated to be between 10 and 330 N for a spinal mobilization.[24] In the current study, a peak force situated in the lower range of reported peak forces (ie, a peak force of 255 N) was chosen. This choice was made for safety purposes, considering the smaller surface contact (4 cm^2) than the typical surface contact used by a clinician (34.8 ± 8.9 cm^2).[23] Moreover, although a spinal mobilization usually is executed without a preload force, one was included in the current study because the goal was to evaluate the effect of impulse duration (all other components of the therapy were thus standardized). Although not entirely meeting the definition of a spinal mobilization, the 3 longest impulse durations included in the current study defined spinal mobilizations, whereas the 3 shortest impulse durations defined spinal manipulations. Overall, the results of the current study showed significant differences in the neuromechanical responses to SMT of high and low velocities, which supports the common belief in the manual therapy field that spinal manipulations and mobilizations yield different clinical effects.

The results revealed a higher absolute vertebral displacement of the rostral vertebra (ie, T6) than the contacted vertebra (ie, T7), which might be explained by the thoracic spine biomechanics. Indeed, the transverse pedicles of mid-thoracic vertebrae present an angle with the spine midline that can be up to 50°,[25] thus applying a posterior-to-anterior load over the tip of the transverse processes mainly would result in a sagittal rotation of the contacted vertebra over the inferior one. Although not investigated in the current study, rotation induced during SMT might be of interest and therefore should be included in future research. Moreover, compared to the lumbar and cervical spine, the thoracic spine and the rib cage constitute a rigid anatomic structure protecting the vital organs. The

Table 2. *Number of Participants Not Presenting a Muscle Response That Could Be Visually Determined*

Variable	100 ms (n = 24)	125 ms (n = 24)	200 ms (n = 24)	500 ms (n = 24)	1000 ms (n = 24)	1500 ms (n = 24)
Number of participants without muscle response (%)	3 (13)	3 (13)	3 (13)	9 (38)	10 (42)	11 (46)

thoracic wall includes diverse articular capsules and ligaments, allowing fewer movements between vertebrae and between a vertebra and its adjacent ribs.[26] Consequently, a force applied to the tissue situated next to a spinous process would be in a large amount transfer to this vertebra. The thoracic zygapophyseal joints also contribute to the thoracic spine stability by limiting the range of flexion and anterior translation while facilitating rotation explaining the overall small but significant differences in absolute vertebral displacement between spinal levels.[26]

The current results also showed that longer impulse durations increase the absolute vertebral displacement of the contacted (ie, T7) and the caudal adjacent (ie, T8) vertebrae but do not modify the displacement of the vertebra located next to the apparatus indenter tips (ie, T6). These results differ from previous results, suggesting an association between the impulse duration and the vertebral displacement.[14] In a previous study, although peak forces and preload forces were identical to the ones used in the current study, the impulse duration was limited to values characterizing spinal manipulations (125 to 275 ms), which may have prevented the identification of a significant linear relationship. Interestingly, Colloca et al showed, using an animal model, higher absolute vertebral displacement with very short impulse duration of 10 ms compared to longer ones of 100 and 200 ms.[17] However, the spinal manipulations delivered by the mechanical device used in Colloca et al included a peak force of 80 N and rates of force application of 8000 N/s (10-ms impulse duration), 800 N/s (100-ms impulse duration), and 400 N/s (200-ms impulse duration), whereas the present study involved rate of force application ranging from 170 N/s (1500 ms) to 2550 N/s (100 ms). The current study aimed to evaluate neuromechanical responses to SMTs as delivered by clinicians (nonmechanically assisted), for which the rate of force application has been reported to be lower than 5000 N/s in the thoracic spine.[22] Relationships among responses and SMT impulse duration and rate of force application might be different during SMT with doses that were not evaluated in the current study.

In addition to absolute vertebral displacements, relative vertebral displacements between T6 and T7 and between T7 and T8 were calculated. The results revealed a decrease in relative vertebral displacements with the increase in the impulse duration, suggesting that spinal mobilization effects are not limited to the contacted area but spread to caudal and rostral levels. However, the relation between the impulse duration and the relative displacement does not seem to be linear. Indeed, in the current study, the change in the relative displacement mostly occurred between the 125-ms and 1000-ms impulse duration. Similarly, Lee et al showed that a "slow" rate mobilization of 10 N/s (150 N applied in 15 ms) results in higher relative vertebral displacements than "fast" rate spinal mobilizations of 600 N/s (150 N applied in 250 ms).[18] Overall, these results may suggest that clinical effects of spinal mobilizations are not related to the production of a movement between the contacted and the adjacent vertebrae, which is supported by the conclusion of a recent review investigating spinal mobilization mechanisms of action.[7] How faster loading of spinal tissues and the related intervertebral movement are responsible for specific clinical effects of spinal manipulations remains to be determined.

Regarding muscle responses to SMT, the current results revealed that a 100-ms impulse duration SMT induces a muscle response amplitude of 2- to 3-fold higher than a 1500-ms impulse duration SMT. In addition to being in accordance with previous study results,[10-14] such dose–response relationship is supported by studies conducted in animals.[15,27,28] Interestingly, more than half of the participants in the current study did not show a muscle response that could be clearly identified. Such a pattern already has been observed in previous research involving instrumented or manual SMT techniques. For instance, an sEMG response has been observed in 68% of the 108 SMTs delivered using an instrument.[29] Using a similar protocol but delivering SMT manually (SMT duration not reported), Herzog et al observed an sEMG response after all SMTs.[30] In a pilot study (n = 2), the same researcher observed an absence of sEMG response during slow SMTs (3- to 5-second duration).[31] Finally, Currie et al reported inconsistent surface and indwelling EMG responses during side-lying diversified lumbar spinal manipulations.[32] These inconsistencies between studies support the assumption that there is a rate of force application threshold over which a muscle response is triggered.[14,27] Overall, these results highlight that the muscle response constitutes a distinctive characteristic between spinal manipulations and spinal mobilizations.

Manual marking of muscle responses also provided the opportunity to calculate the delay between the onset of the muscle response and the onset of the SMT impulse. Results showed an increase in the response delay (50-340 ms) with the increase in the impulse duration (from 100 to 1500 ms). Unfortunately, few studies have quantified the delay between the onset of the SMT impulse and the onset of the muscle response. Moreover, methods used to analyze sEMG data as well as the definition of a muscle response onset are different in each study, which limits potential comparisons. Similar to the value reported in the current study, Currie et al obtained highly variable delays in response to lumbar SMTs.[32] They reported delays varying between 0 and 397 ms in participants with and

without low back pain but, unfortunately, they did not report the SMT biomechanical parameters. In response to manually delivered thoracic SMTs (148 N preload; 400 N peak force, 100-ms impulse duration), Herzog et al reported a delay of 50 to 100 ms, while their slow SMT (3- to 50-second impulse duration) did not generate EMG responses.[31] Based on their results, these authors suggested that EMG responses to SMT constitute muscle spindle mediated reflexes. If their hypothesis holds true, this would explain the lower amplitude of muscle responses as impulse duration increases, since these structures are less sensitive to slower muscle elongation.[33]

Limitations

Although an estimation of posterior-to-anterior translations of vertebrae using surface kinetics markers has been shown to yield similar results to an estimation obtained using markers inserted in the bone,[34] it cannot be ruled out that small estimation errors could have occurred. Although transverse process identification was conducted by an experienced clinician and using a validated palpation method,[25] further studies should consider including imaging to confirm SMT contact points. Spinal mobilization usually is defined by the application of a load in an oscillating manner[24]; the effects of a single indentation compared to multiple indentations remain to be evaluated. Finally, an automated threshold method to detect the muscle response onset was not considered in the current study owing to the limited number of participants, but should be considered in future investigations to ensure standardization.[35]

Conclusion

Distinct neurophysiological responses are generated by spinal manipulations and spinal mobilizations. For an identical applied force, spinal manipulations induce greater intervertebral displacements as well as higher muscle responses than spinal mobilizations. These results support the assumption that distinct mechanisms underlie these SMTs. The clinical effect of spinal manipulations and spinal mobilizations should further be investigated independently.

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Contributorship Information

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

Practical Applications

- Spinal manipulation and mobilization generate distinctive neuromechanical responses.
- Short impulse duration generates greater intervertebral movement than long impulse duration.
- Short impulse duration generates muscle response of greater amplitude than long impulse duration.
- A muscle response is not observed in some individuals.
- Spinal manipulation and mobilization should be investigated independently.

References

1. Murthy V, Sibbritt D, Adams J. An integrative review of complementary and alternative medicine use for back pain: a focus on prevalence, reasons for use, influential factors, self-perceived effectiveness and communication. *Spine J.* 2015;15(8):1870-1883.
2. Hurwitz EL. Epidemiology: spinal manipulation utilization. *J Electromyogr Kinesiol.* 2012;22(5):648-654.
3. Bussieres AE, Stewart G, Al-Zoubi F, et al. The treatment of neck pain-associated disorders and whiplash-associated disorders: a clinical practice guideline. *J Manipulative Physiol Ther.* 2016;39(8):523-564 [e527].
4. Southerst D, Marchand AA, Cote P, et al. The effectiveness of noninvasive interventions for musculoskeletal thoracic spine and chest wall pain: a systematic review by the Ontario Protocol for Traffic Injury Management (OPTIMa) Collaboration. *J Manipulative Physiol Ther.* 2015;38(7):521-531.
5. Wong JJ, Cote P, Sutton DA, et al. Clinical practice guidelines for the noninvasive management of low back pain: a

systematic review by the Ontario Protocol for Traffic Injury Management (OPTIMa) Collaboration. *Eur J Pain.* 2017;21(2):201-216.
6. Khalsa PS, Eberhart A, Cotler A, Nahin R. The 2005 conference on the biology of manual therapies. *J Manipulative Physiol Ther.* 2006;29(5):341-346.
7. Aguirrebena IL, Newham D, Critchley DJ. Mechanism of action of spinal mobilizations: a systematic review. *Spine (Phila Pa 1976).* 2016;41(2):159-172.
8. Bialosky JE, Bishop MD, Price DD, Robinson ME, George SZ. The mechanisms of manual therapy in the treatment of musculoskeletal pain: a comprehensive model. *Manual Ther.* 2009;14(5):531-538.
9. Triano JJ. Biomechanics of spinal manipulative therapy. *Spine J.* 2001;1(2):121-130.
10. Nougarou F, Dugas C, Deslauriers C, Page I, Descarreaux M. Physiological responses to spinal manipulation therapy: investigation of the relationship between electromyographic responses and peak force. *J Manipulative Physiol Ther.* 2013;36(9):557-563.
11. Nougarou F, Dugas C, Loranger M, Page I, Descarreaux M. The role of preload forces in spinal manipulation: experimental investigation of kinematic and electromyographic responses in healthy adults. *J Manipulative Physiol Ther.* 2014;37(5):287-293.
12. Nougarou F, Page I, Loranger M, Dugas C, Descarreaux M. Neuromechanical response to spinal manipulation therapy: effects of a constant rate of force application. *BMC Complement Altern Med.* 2016;16(1):161.
13. Page I, Nougarou F, Descarreaux M. Neuromuscular response amplitude to mechanical stimulation using large-array surface electromyography in participants with and without chronic low back pain. *J Electromyogr Kinesiol.* 2016;27:24-29.
14. Page I, Nougarou F, Dugas C, Descarreaux M. The effect of spinal manipulation impulse duration on spine neuromechanical responses. *J Can Chiropr Assoc.* 2014;58(2):141-148.
15. Reed WR, Cao D-Y, Long CR, Kawchuk GN, Pickar JG. Relationship between biomechanical characteristics of spinal manipulation and neural responses in an animal model: effect of linear control of thrust displacement versus force, thrust amplitude, thrust duration, and thrust rate. *Evid Based Complement Alternat Med.* 2013;2013:492039.
16. Reed WR, Long CR, Kawchuk GN, Pickar JG. Neural responses to the mechanical parameters of a high-velocity, low-amplitude spinal manipulation: effect of preload parameters. *J Manipulative Physiol Ther.* 2014;37(2):68-78.
17. Colloca CJ, Keller TS, Harrison DE, Moore RJ, Gunzburg R, Harrison DD. Spinal manipulation force and duration affect vertebral movement and neuromuscular responses. *Clin Biomech (Bristol, Avon).* 2006;21(3):254-262.
18. Lee R, Evans J. Load-displacement-time characteristics of the spine under posteroanterior mobilization. *Aust J Physiother.* 1992;38:115-123.
19. Descarreaux M, Nougarou F, Dugas C. Standardization of spinal manipulation therapy in humans: development of a novel device designed to measure dose-response. *J Manipulative Physiol Ther.* 2013;36(2):78-83.
20. Hazra A, Gogtay N. Biostatistics Series Module 6: correlation and linear regression. *Indian J Dermatol.* 2016;61(6):593-601.
21. Forand D, Drover J, Suleman Z, Symons B, Herzog W. The forces applied by female and male chiropractors during thoracic spinal manipulation. *J Manipulative Physiol Ther.* 2004;27(1):49-56.
22. Cambridge ED, Triano JJ, Ross JK, Abbott MS. Comparison of force development strategies of spinal manipulation used for thoracic pain. *Man Ther.* 2012;17(3):241-245.
23. Herzog W, Kats M, Symons B. The effective forces transmitted by high-speed, low-amplitude thoracic manipulation. *Spine (Phila Pa 1976).* 2001;26(19):2105-2110 discussion 2110-2101.
24. Snodgrass SJ, Rivett DA, Robertson VJ. Manual forces applied during posterior-to-anterior spinal mobilization: a review of the evidence. *J Manipulative Physiol Ther.* 2006;29(4):316-329.
25. Page I, Descarreaux M, Sobczak S. Development of a new palpation method using alternative landmarks for the determination of thoracic transverse processes: an in vitro study. *Musculoskelet Sci Pract.* 2017;27:142-149.
26. Edmondston SJ, Singer KP. Thoracic spine: anatomical and biomechanical considerations for manual therapy. *Man Ther.* 1997;2(3):132-143.
27. Pickar JG, Sung PS, Kang YM, Ge W. Response of lumbar paraspinal muscles spindles is greater to spinal manipulative loading compared with slower loading under length control. *Spine J.* 2007;7(5):583-595.
28. Cao D-Y, Reed WR, Long CR, Kawchuk GN, Pickar JG. Effects of thrust amplitude and duration of high-velocity, low-amplitude spinal manipulation on lumbar muscle spindle responses to vertebral position and movement. *J Manipulative Physiol Ther.* 2013;36(2):68-77.
29. Symons BP, Herzog W, Leonard T, Nguyen H. Reflex responses associated with activator treatment. *J Manipulative Physiol Ther.* 2000;23(3):155-159.
30. Herzog W, Scheele D, Conway PJ. Electromyographic responses of back and limb muscles associated with spinal manipulative therapy. *Spine (Phila Pa 1976).* 1999;24(2):146-152 discussion 153.
31. Herzog W, Conway PJ, Zhang YT, Gal J, Guimaraes AC. Reflex responses associated with manipulative treatments on the thoracic spine: a pilot study. *J Manipulative Physiol Ther.* 1995;18(4):233-236.
32. Currie SJ, Myers CA, Durso C, Enebo BA, Davidson BS. The neuromuscular response to spinal manipulation in the presence of pain. *J Manipulative Physiol Ther.* 2016;39(4):288-293.
33. Matthews PB, Stein RB. The regularity of primary and secondary muscle spindle afferent discharges. *J Physiol.* 1969;202(1):59-82.
34. Gal J, Herzog W, Kawchuk G, Conway P, Zhang YT. Measurements of vertebral translations using bone pins, surface markers and accelerometers. *Clin Biomech.* 1997;12(5):337-340.
35. Currie SJ, Myers CA, Krishnamurthy A, Enebo BA, Davidson BS. Methods of muscle activation onset timing recorded during spinal manipulation. *J Manipulative Physiol Ther.* 2016;39(4):279-287.