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Characterization of thoracic spinal manipulation and mobilization forces in older adults

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ABSTRACT

Background: Spinal mobilization and spinal manipulation are common interventions used by manual therapists to treat musculoskeletal conditions in older adults. Their force-time characteristics applied to older adults' thoracic spine are important considerations for effectiveness and safety but remain unknown. This study aimed to describe the force-time characteristics of posterior-to-anterior spinal mobilization and manipulation delivered to older adults' thoracic spine.

Methods: Twenty-one older adults (≥65 years) with no thoracic pain received posterior-to-anterior thoracic spinal mobilization and/or manipulation with the force characteristics a chiropractor deemed appropriate. Six-degree-of-freedom load cells and an instrumented treatment table recorded the force characteristics of both interventions at the clinician-participant and participant-table interfaces, respectively. Preload force, total peak force, time to peak and loading rate were analyzed descriptively.

Findings: Based on data from 18 adults (56% female; average: 70 years old), mean resultant spinal mobilization forces at the clinician-participant interface were: 220 ± 51 N during preload, 323 ± 67 N total peak force, and 312 ± 38 ms time to peak. At the participant-table interface, mobilization forces were 201 ± 50 N during preload, 296 ± 63 N total peak force, and 308 ± 44 ms time to peak. Mean resultant spinal manipulation forces at the clinician-participant interface were: 260 ± 41 N during preload, 470 ± 46 N total peak force, and 165 ± 28 ms time to peak. At the participant table interface, spinal manipulation forces were 236 ± 47 N during preload, 463 ± 57 N total peak force, and 169 ± 28 ms time to peak.

Interpretation: Results suggest older adults experience unique, but comparable force-time characteristics during spinal mobilization and manipulation delivered to their thoracic spine compared to the ones delivered to younger adults described in the literature.

1. Introduction

Spinal pain, including cervical, thoracic and lumbar pain, is the leading cause of disease burden worldwide (Cieza et al., 2020). Compared to cervical and lumbar spine, thoracic spine pain has been described to be equally disabling and have similar consequences, despite of its lower prevalence (Johansson et al., 2017; Leboeuf-Yde et al., 2012, 2011). Spinal pain prevalence is highest in older adults, peaking between 80 and 89 years of age. While some older adults can remain functional with pain, spinal pain in older adults is often more disabling than in younger people, severely limits their physical ability and decreases their social well-being (de Luca et al., 2017b; Hartvigsen et al., 2006; Leveille et al., 1999; Weiner et al., 2003). Being older and having spinal pain is related to poorer health-related outcomes and non-recovery (Scheele et al., 2013), and while associated with a 13% increased risk of mortality per years lived, the relationship attenuated and became non-significant when adjusted for physical functional ability and depressive symptoms (Fernandez et al., 2017).

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Conservative interventions are used commonly by older people to manage their spinal pain and include massage, exercise prescription and manual therapy such as spinal mobilization (MOB) and spinal manipulative therapy (SMT) (de Luca et al., 2017a; Hondras et al., 2009; Ozsoy et al., 2019; Schulz et al., 2019). In fact, older adults are high consumers of manual therapy with a 20.3% lifetime utilisation rate of chiropractic care (Beliveau et al., 2017; French et al., 2013; Hurwitz, 2012; Mior et al., 2019). The most common diagnosis within older adult chiropractic encounters is reported to be back problems (56%), with SMT and MOB being the most commonly provided intervention, across all conditions, for older adults (de Luca et al., 2021). There is, however, a paucity of evidence on spinal MOB and SMT in older adults with respect to their force-time characteristics and therapeutic mechanisms. This information is of great importance for clinicians to understand the implications of forces applied to an older adult's spine and assist with clinical decision making related to intervention risk/benefits.

While MOB is characterized by the application of a cyclic, rhythmic, low-velocity force to the intervertebral joint, SMT is characterized by a single application of a dynamic force with a high-velocity, low-amplitude thrust (Bronfort et al., 2004). In each case, these forces are applied to a targeted region of the spine and cause a mechanical deformation of the specific spine region and surrounding tissues (Herzog, 2010; Herzog et al., 1993; Pickar and Bolton, 2012; Triano, 2001). This mechanical loading of spinal structures triggers biomechanical and neurophysiological responses that are hypothesized to contribute to its therapeutic effect (Bialosky et al., 2009; Fritz et al., 2011; Pickar, 2002). Clinically, operational parameters of MOB and SMT procedures (e.g., patient position, technique and intended direction, magnitude and rate of force application) are taught to be modified to suit the specific needs of the patient, especially in special populations (such as older adults) (Triano and McGregor, 1997). More specifically, given the age-related changes observed frequently in older adults, these patients are perceived to present unique characteristics that warrant careful considerations during physical examination and treatment, including manual therapy interventions (Hawk et al., 2017). Consequently, forces applied to older adults have been suggested to be modified as higher forces may load osseous structures that could potentially be contraindicated in the presence of severe bone-weakening processes (Hawk et al., 2017). Indeed, previous work by Funabashi et al. suggest that modifying the characteristics of forces applied during SMT can alter the forces experienced by spinal tissues (Funabashi et al., 2018, 2017b, 2017a). Although the characteristics of forces applied during MOB and SMT have been reported in young adults and pediatric populations (Cambridge et al., 2012; Downie et al., 2010; Snodgrass et al., 2006; Triano et al., 2017), there has been no investigation of MOB and SMT force characteristics applied in older adults. If the characteristics of all forces acting on older adults' spine during these techniques were quantified, a clearer understanding of these techniques' biomechanics could be elucidated thereby advancing our current knowledge regarding the safety and underlying mechanisms of MOB and SMT, with potential significant implications for these interventions' training and education.

Therefore, the aim of this study was to characterize the forces acting on older adults during clinical thoracic spine MOB and SMT. Specifically, this study aimed to a) characterize force-time data at the clinician-participant interface during clinical thoracic spine MOB and SMT in older adults; b) characterize the force-time data recorded at the participant-table interface during the same interventions and population; c) characterize the difference between the forces measured at the clinician-participant and participant-table interfaces; and d) compare the MOB and SMT force-time characteristics used in older adults to the ones used in younger adults reported in the literature. Thoracic MOB and SMT were specifically chosen for this investigation given its posterior-to-anterior force application, which facilitates the biomechanical quantification of MOB and SMT forces in comparison to other techniques that usually combine movements of flexion or extension, lateral bending and rotation of the spine in addition to the force application.

2. Methods

This was a cross-sectional observational study conducted at the Canadian Memorial Chiropractic College's (CMCC) Human Performance Laboratory between September and November 2019. This study was reviewed and approved by CMCC's Research Ethics Board (study #1904B01) and all participants provided a written informed consent prior to participating in the study.

2.1. Participants

Participants (≥65 years old) with no thoracic spinal pain were recruited from the CMCC Leslie Campus clinic. Potential participants were attending CMCC clinic to receive treatment for other conditions (e.g., hip and knee conditions). Participants were excluded if they had a body mass index (BMI) greater than 30 kg/m^2; self-reported: a history of heart or lung disease, any cognitive impairment disorder, spinal malignancy, spinal infection, history of cancer in the last 5 years, medically diagnosed osteopenia or osteoporosis, inflammatory spondylopathy, auto-immune disorder, current use of prescribed corticosteroid medication; or were non-English speakers.

2.2. Study protocol

Participants' demographic information including age and sex were recorded along with anthropometric measurements of height, weight, BMI and waist circumference. A standardized assessment that would be normally performed in clinical practice consisting of a brief history of the participant's overall health and pain (e.g. to ensure the participant did not present any contraindications to SMT and MOB), subjective (e.g., palpation of T1-T12 spinous and bilateral transverse processes) and objective (e.g., global spinal flexion, extension, lateral flexion and rotation ranges of motion) physical assessments were conducted by a single licensed chiropractor with 35 years of clinical experience in treating older adults. If a posterior-to-anterior MOB and/or SMT were deemed clinically appropriate, the participant was asked to lie down on a force plate-embedded treatment table (details below) in a prone position with the upper border of the shoulders aligned with the edge of the plinth. The provider then applied 5 cycles of a grade IV MOB with the force characteristics the chiropractor deemed clinically appropriate to the thoracic spine in a posterior-to-anterior direction at approximately 1 Hz frequency of oscillation. To participants that SMT was also deemed clinically appropriate, a single posterior-to-anterior SMT with the force characteristics the chiropractor would normally apply in their clinical practice was then applied at the thoracic spine 20 min after MOB application to prevent any potential cumulative effects of providing consecutive manual techniques to the same participant. During the 20 min break, participants were instructed to adopt any comfortable position, preferably sitting down and/or performing light walks, and avoid fast movements. The force-time characteristics during MOB and SMT at both the clinician-participant and participant-table interfaces were recorded simultaneously (details below). The level in which MOB and SMT were applied were categorized into upper (T1–T4), mid (T5–T8) or lower (T9–T12) thoracic region and recorded. Technique and hand contact used during both MOB and SMT application were chosen by the provider (clinical judgement) and recorded. Participants' self-reported level of comfort during MOB and SMT application were also recorded. If a thoracic MOB nor SMT were not deemed appropriate, the participant was excluded from the study.

2.3. Instrumentation

2.3.1. Kinetic

A pair of six degree-of-freedom load cells (Mini45, ATI Industrial

Automation Inc., Apex, NC, USA) were used to measure and record the three-dimensional forces and moments applied by the clinician at the clinician-participant interface. Custom load cell mounting platforms were produced using a 3D printer (Airwolf3D HDL, Airwolf 3D, Costa Mesa, CA, USA) and firmly mounted onto each load cell to mimic the clinician's clinical hand contact (hypothenar eminence) as well as to ensure participant comfort during MOB and SMT application. For unilateral techniques, one load cell was placed between the provider's hand and the participants' back. For bilateral contact, two load cells were used – one for each hand.

The force sensing table technology (FSTT®, Toronto, ON, Canada) was used to measure the forces at the participant-table interface. The FSTT® is composed of a Leander 900 Z Series treatment table (Leader Healthcare Technologies, Lawrence, KS, USA) with an embedded AMTI force plate (OR6–7, Advanced Mechanical Technology Inc., Watertown, MA, USA). The thoracic portion of the treatment table (with embedded force plate) was mechanically independent from the remainder of the treatment plinth. This separation ensured that the force plate would only capture the interaction between the participants' thoracic region and the thoracic portion of the treatment table. Previous research has demonstrated excellent reliability and validity of the FSTT® in measuring forces at the participant-table interface during SMT (Rogers and Triano, 2003).

Analog data from the load cells and force plate were digitally sampled at a rate of 1000 Hz using a ± 10 V range on a 16-bit analog-to-digital conversion board and synchronized with the kinematic data (Optotrak Data Acquisition Unit, Northern Digital Inc., Waterloo, ON, Canada).

2.3.2. Kinematic

Three-dimensional kinematics of the triaxial load cells during the application of MOB and SMT were monitored by an optoelectronic motion capture system (Optotrak Certus, Northern Digital Inc., Waterloo, ON, Canada). A lab coordinate system was defined such that the positive x-axis was directed to the right of the treatment table, the positive y-axis was directed along the length of the treatment table, and the positive z- axis was directed vertically upward. This coordinate system was coincident with the local coordinate system of the FSTT® force plate. For each load cell, a set of three infrared light emitting diodes (IREDs) was adhered to rigid plastic plates that were fastened to the custom-fabricated load cell mounting platforms. A set of four virtual landmarks were digitized on each load cell. Three-dimensional coordinates of these virtual landmarks were continuously monitored throughout data collection by rigid body transformations with the IREDs that were affixed to the respective load cell. This allowed for continuous tracking of the load cell during data collection and facilitated subsequent post-collection data processing. Static three-dimensional coordinates for the corners of the force plate were also determined by digitization. Kinematic data from the IREDs and virtual landmarks were sampled at a rate of 150 Hz (Gudavalli et al., 2013).

2.4. Data processing and analysis

Steps to process the raw kinematic and kinetic data were similar to those employed in previous investigations (D'Angelo et al., 2017; Engell et al., 2019; Howarth et al., 2016). The following is a brief description of these steps. All data were initially imported for processing using Visual3D software (Version 5.02.03, C-Motion Inc., Germantown, MD, USA). Digital voltages from the load cells and force plate were converted to units of force (Newtons) using the manufacturer-specified calibration matrices. Rigid body transformations were used so that forces from the load cells were transformed into the force plate's reference frame.

For MOB, the following variables were extracted for each of the five cycles: 1) peak preload force was considered the maximum force measured at each cycle's preload, 2) total peak force was considered the maximum force measured at each force application cycle, 3) time to peak was the time from preload to total peak force for each cycle, and 4) loading rate was considered the difference between peak preload force and total peak force divided by the time to peak for each cycle (Fig. 1). The average of the five cycles for each variable was calculated for each participant, which was then used for further analysis. For SMT, peak preload force, total peak force, time to peak and loading rate were also extracted (Fig. 1).

For both techniques, all force variables were extracted along all three axes of the force plate's reference frame using a customized software (MATLAB, The MathWorks Inc., Natick, Massachusetts, USA). Thus, F_x, F_y and F_z corresponded to the forces recorded along the force plate's x-axis, y-axis and z-axis. Respectively, the force plate axes were approximately coincident with the participant's mediolateral, axial and anterior-posterior anatomical axes. The difference of force-time variables measured at both the clinician-participant interface (load cell measurement) and at the participant-table interface (force plate measurement) was calculated (Eq. (1)).

$$F_{diff} = F_{PTint} - F_{CPint} \tag{1}$$

A positive value corresponding to a greater value at the participant-table interface. The resultant vector (F_{res}) at the clinician-participant and participant-table interfaces during MOB and SMT was also calculated (Eq. (2)).

$$F_{res} = \sqrt{\left(F_x^2 + F_y^2 + F_z^2\right)} \tag{2}$$

2.5. Statistical analysis

Quantitative descriptive measures of the participants' characteristics were computed. Shapiro-Wilk normality test was used to analyze the distribution of all variables using R (R Foundation for Statistical Computing, Vienna, Austria). Specifically, descriptive statistics in terms of mean and standard deviation (SD) values are reported for parametric force data and median with range for non-parametric force data.

A qualitative comparison of MOB and SMT force-time characteristics used in older adults recorded in the current study to the ones used in younger adults reported in the literature was conducted by plotting the mean force magnitudes of the current and previous studies.

3. Results

3.1. Participants

Of the 21 participants recruited, three were excluded due to: thoracic spine pain at physical exam, withdrawal of consent and technical issues. Seven participants received MOB only (SMT was not considered clinically appropriate). Therefore, MOB data from 18 participants and SMT data from 11 participants were included in the final analysis. Table 1 presents the demographic characteristics of the participants included in the study.

3.2. Spinal mobilization and spinal manipulative therapy forces

Most MOBs were applied unilaterally (72%) at the mid thoracic region (83%). One participant reported experiencing discomfort/pain during MOB, which subsided immediately after MOB application ceased. Similarly, most SMTs were applied unilaterally (72%) at the mid thoracic region (72%). There were no reports of discomfort/pain during or immediately after SMT application.

Given that a posterior-to-anterior technique was used in both MOB and SMT, the greatest force magnitudes were observed along the z-axis. Table 2 presents the mean (± SD) of F_x and F_y preload force, total peak force, time to peak and loading rate at maximum F_z measured at the clinician-participant and participant-table interfaces during MOB and SMT. The median and range of the difference between MOB and SMT

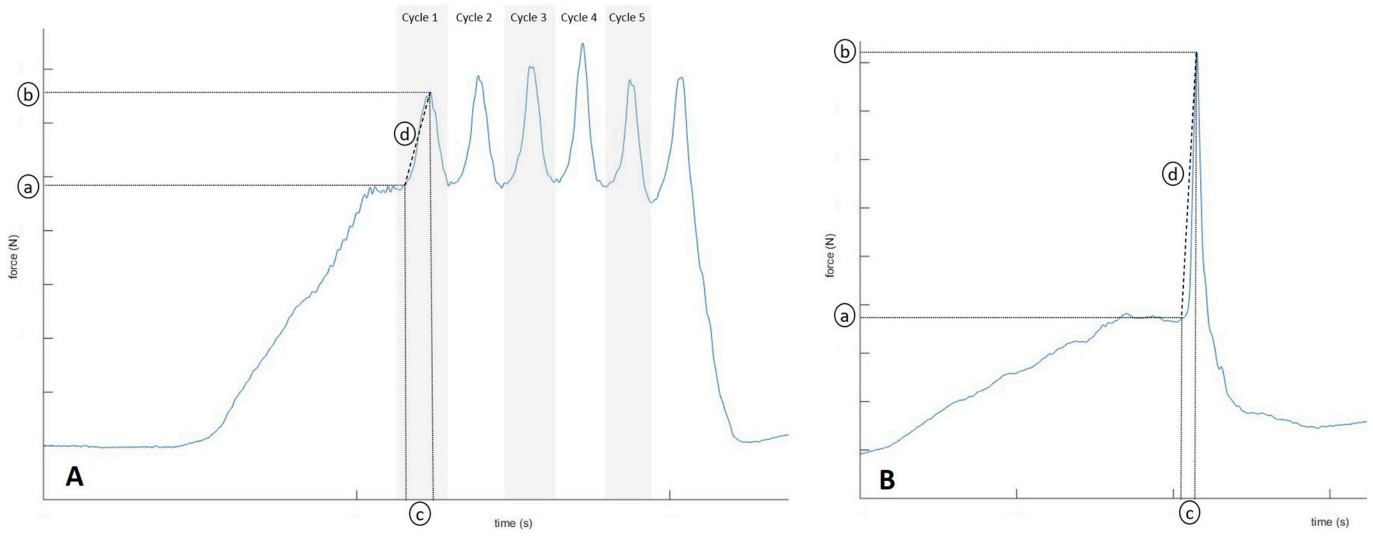

Fig. 1. Force-time graphs of a (A) spinal mobilization and (B) spinal manipulative therapy. Variables include preload force (a); total peak force (b); time to peak (c); and loading rate (d).

Table 1
Participants characteristics.

Characteristic	MOB ($n = 18$)	SMT ($n = 11$)
Female (n, %)	10 (56%)	4 (36%)
Age (years; mean ± SD)	70.4 ± 4.44	69.4 ± 3.2
Height (m; mean ± SD)	1.67 ± 0.09	1.69 ± 0.10
Weight (kg; mean ± SD)	75.4 ± 12.44	78.3 ± 11.4
BMI (kg/m^2; mean ± SD)	27.3 ± 3.0	27.8 ± 2.9
Waist circumference (m; mean ± SD)	0.95 ± 0.10	0.94 ± 0.11

force-time characteristics measured at the clinician-participant and participant-table interfaces is also shown in Table 2. The maximum resultant vector magnitude (F_{res}) at the clinician-participant and participant-table interfaces during MOB and SMT is also presented in Table 2. Larger forces at the participant-table interface than those at the clinician-participant interface were observed in only 3 participants during MOB (16.6%) and in 4 participants during SMT (36%). Among these, 2 participants presented larger forces at the participant-table interface during both MOB and SMT.

Additionally, during SMT, peak forces at the clinician-participant interface were, on average, 9 ms (±13 ms) sooner than the peak forces at the participant-table interface.

3.3. *Qualitative comparison with previous studies*

Fig. 2 presents preload and total peak force magnitudes of spinal mobilization and spinal manipulative therapy measured in the current study and reported in previous studies with younger adults (Cambridge et al., 2012; Forand et al., 2004; Herzog et al., 2001; Joo et al., 2020; Kirstukas and Backman, 1999; Snodgrass et al., 2006; Van Zoest and Gosselin, 2003) at the clinician-participant and participant-table interfaces for qualitative comparison.

4. Discussion

This is the first study to quantify and describe the force-time characteristics of two manual therapy techniques (MOB and SMT) used commonly in older adults. Specifically, this study reports MOB and SMT force-time characteristics not only at the clinician-participant interface (total peak force 323 N (±67) and 470 N (±46), respectively), but also at the participant-table interface (total peak force 296 N (±63) and 463 N (±57), respectively) to provide a global understanding of the forces acting on the thorax.

The magnitude of applied forces observed in the current study during the application of a clinical MOB was within the range of forces previously reported in the literature. More specifically, a previous review of the literature (Snodgrass et al., 2006) described the magnitude of vertical forces applied to adults with mean age between 26 and 55 years old during varying grades of MOB using unique force measurement instruments. It was shown that vertical forces during a thoracic grade IV MOB ranged from 89.2 N – 499.8 N. Given that a grade IV MOB was also applied in the current study, our results indicate that the peak vertical forces used during MOB grade IV to older adults are comparable to the ones used in younger adults. This is in accordance with a previous study by Harms et al. (1999) which reported that the total forces applied during a lumbar MOB grade IV to younger adults (mean age: 26 years old ±4) and older adults (mean age: 55 years old ±6) were comparable. Despite older adults having reduced spinal compliance, the authors speculate that the similar MOB forces applied in younger and older adults may be more influenced by the applied force magnitude than by the amplitude of joint movement or body deformation (Harms et al., 1999).

Given the frequency of SMT application, several investigations have focused on SMT forces and how they influence the neuromechanical effects observed following SMT. Previous studies have reported SMT force-time characteristics in different regions of the spine (Downie et al., 2010; Pasquier et al., 2019). One study measured force-time characteristics of SMT with similar characteristics to the one applied in the current study, but in adults aged between 18 and 25 years, and reported resultant preload forces of 226 N (±31) and peak forces of 518 N (±48) (Van Zoest and Gosselin, 2003). In the current study, the vertical (F_z) preload and total peak forces (234.9 N (±36.5) and 462.1 N (±52.3), respectively) as well as the resultant preload and peak forces (260 N (±41.7) and 470.1 N (±46.4), respectively) measured at the clinician-participant interface were comparable to the ones previously reported in the literature. On the participant-table interface, previous studies using similar measurement instrument (i.e., force plate) reported preload forces between 157.7 N to 299.6 N and total peak forces of between 432.3 N and 625.4 N in adults younger than 30 years old (Cambridge

Table 2

Mean (±SD) of force-time characteristics at clinician-participant, participant-table interfaces in each of the three axes of motion during spinal mobilization and manipulative therapy. F_x and F_y values correspond to the force-time characteristics at the time of maximum F_z values. Difference in force-time characteristics between interfaces during each technique and the resultant vector magnitude in each interface.

		Clinician-participant interface				Participant-table interface				Difference between interfaces[*,ˆ]			
		Fx (medio-lateral)	Fy (cranio-caudal)	Fz (antero-posterior)	F_{result}	Fx (medio-lateral)	Fy (cranio-caudal)	Fz (antero-posterior)	F_{result}	Fx (medio-lateral)	Fy (cranio-caudal)	Fz (antero-posterior)	F_{result}
Spinal Mobilization	Preload force (N)	16.3 (±21.6)	16.1 (±21.5)	201.6 (±33.2)	220.7 (±51.4)	21.1 (±15.6)	21.4 (±15.8)	187.2 (±37.4)	201.9 (±50.4)	5.3 (−33.2–34.4)	6.1 (−32.7–34.5)	−18.2 (−34.8–15.0)	−18.2 (−73.1–28.8)
	Total peak force (N)	28.7 (±28.6)	28.5 (±28.8)	299.9 (±45.9)	323.2 (±67.4)	32.1 (±21.9)	32.1 (±21.8)	274.7 (±47.3)	296.7 (±63.8)	5.9 (−37.0–38.1)	6.0 (−37.0–38.1)	−27.5 (−56.8–24.0)	−24.5 (−107.7–31.0)
	Time to peak (ms)	329.3 (±72.2)	330.7 (±74.5)	336.4 (±40.5)	312.7 (±38.2)	317.1 (±111.2)	306.9 (±118.8)	284.5 (±40.9)	308.6 (±44.5)	−23.4 (−189.5–231.8)	−38.0 (−213.9–287.3)	−59.5 (−103.2–34.7)	−1.1 (−51.7–61.5)
	Loading rate (N/s)	42.8 (±32.9)	42.2 (±31.0)	304.4 (±68.4)	339.1 (±84.9)	40.6 (±27.2)	43.5 (±31.8)	325.4 (±84.5)	325.4 (±81.7)	−2.74 (−42.6–44.0)	0.9 (−44.3–40.7)	13.3 (−43.0–70.4)	−18.4 (−93.1–77.8)
Spinal Manipulation	Preload force (N)	15.3 (±32.6)	11.3 (±21.9)	234.9 (±36.5)	260.0 (±41.7)	18.0 (±23.6)	4.4 (±28.0)	214.9 (±38.7)	236.9 (±47.2)	16.1 (−33.5–23.5)	1.0 (−46.5–15.6)	−23.8 (−45.0–8.9)	−23.2 (−69.6–19.7)
	Total peak force (N)	24.6 (±47.7)	41.9 (±57.1)	462.1 (±52.3)	470.1 (±46.4)	12.1 (±59.6)	43.4 (±45.4)	455.8 (±59.7)	463.2 (±57.0)	−3.3 (−130.4–28.3)	6.5 (−47.7–46.0)	−13.4 (−50.1–54.8)	−15.2 (−47.8–56.5)
	Time to peak (ms)	121.1 (±32.8)	127.3 (±43.6)	162.0 (±25.4)	165.3 (±28.2)	143.6 (±43.4)	151.0 (±49.6)	164.0 (±29.2)	169.8 (±28.6)	13.5 (−40.0–104)	29.0 (−98.5–85.5)	2.5 (−28.0–23.0)	6.0 (−46.5–31.5)
	Loading rate (N/s)	248.1 (±226.3)	68.5 (±237.8)	1412.0 (±159.2)	1644.5 (±314.2)	181.9 (±186.0)	18.0 (±231.2)	1490.9 (±273.7)	1639.4 (±238.1)	−5.5 (−521.7–176.5)	−13.0 (−695.0–109.6)	108.5 (−133.6–314.8)	9.4 (−292.9–323.7)

[*] Median (range).

[ˆ] Negative value indicates a greater value at the clinician-participant interface.

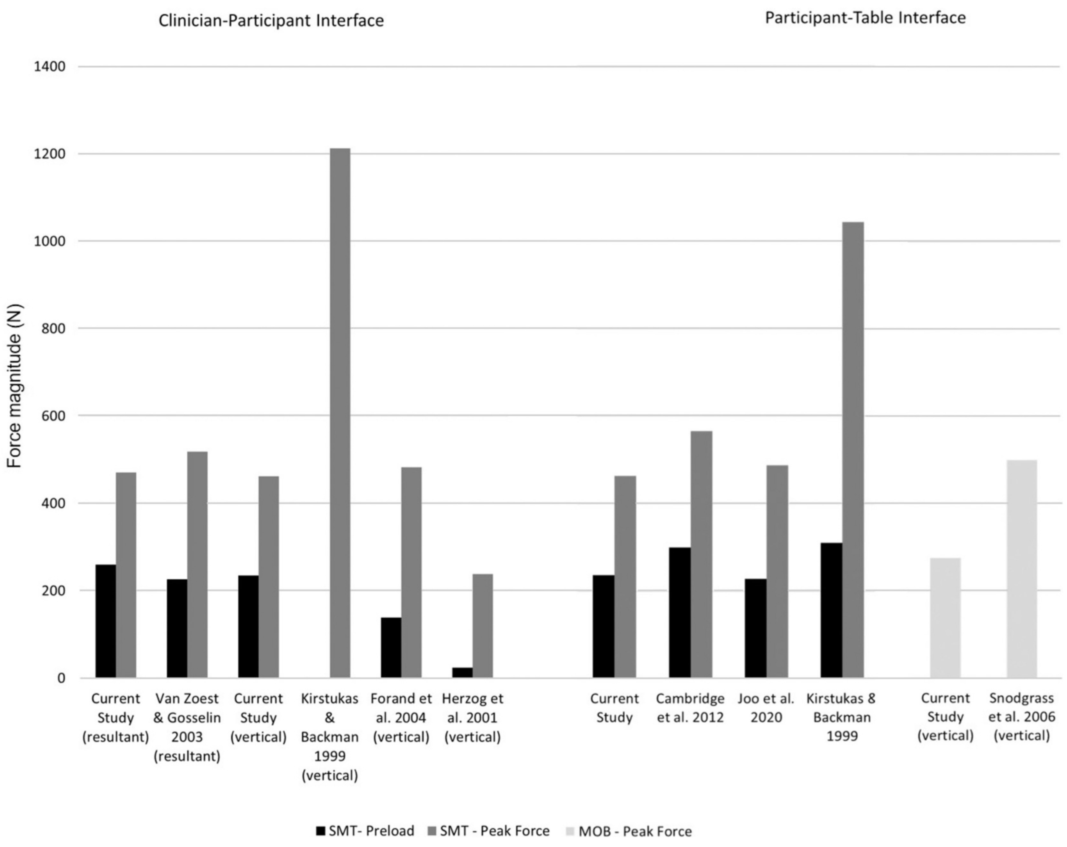

Fig. 2. Preload and total peak force magnitudes of spinal mobilization and spinal manipulative therapy measured in the current study and reported in previous studies at the clinician-participant and participant-table interfaces. MOB = spinal mobilization; SMT = spinal manipulative therapy.

et al., 2012; Joo et al., 2020). Although trending towards the lower force range, comparable SMT preload and total peak forces were observed at the participant-table interface in this study. Similar to MOB, this indicates that the force-time characteristics used during a clinical SMT in older adults are similar to the ones experienced by younger adults.

It has been described that practitioners usually adapt the forces they apply based on the patients' presentation (Triano and McGregor, 1997). Given the neurologic and musculoskeletal age-related changes commonly present in older adults, specific consideration during the physical examination and manual treatment are required (Hawk et al., 2017). Consequently, SMT forces applied to older adults are believed to be either lower (when treating a more fragile patient) or higher (when treating a stiffer patient). The observation that the SMT forces applied to older adults were comparable to the ones applied in younger adults may reflect the heterogeneity in size (i.e., height and weight) of patients and study participants, regardless of their age. Specifically, studies investigating SMT forces included younger adults with average heights of 1.66 m–1.81 m, and weights of 63 kg–88 kg, which are comparable to the height and weight of older adult participants included in this study. It is well-known, however, that older adults present age-related musculoskeletal changes, such as muscle mass loss and degeneration of joint structures (Boss and Seegmiller, 1981; Loeser, 2010). Unfortunately, such body characteristics (e.g., muscle mass, joint degeneration level, bone mineral density, etc.) are not commonly recorded for sample characterization if the study is not specifically focusing on them. Therefore, it is not possible to ascertain if these force-time profiles differed between the current and previous studies. This raises the possibility that age may play a smaller role in practitioners' SMT force decision-making process, and other characteristics, such as muscle mass and joint compliance, are greater influencers on the magnitude of SMT force to be applied.

The magnitude of SMT forces has been suggested to be a potential contributor to adverse events observed following thoracic SMT including in older adults (Puentedura and O'Grady, 2015; To et al., 2020). Specifically, although most adverse events experienced by older adults following SMT are mild and transient (e.g., increased stiffness and pain), more severe events, such as spinal cord injuries and rib fractures, have also been reported and are suggested to be related to the use of high SMT forces (Hondras et al., 2009; Maiers et al., 2015; Puentedura and O'Grady, 2015; To et al., 2020). To focus on rib fractures, previous cadaveric biomechanical studies have reported failure tolerances for the ribs of older adults (61–99 years old) ranging between 16 N–165 N in a frontal motor vehicle collision (Agnew et al., 2015; Kang et al., 2020). During impacts to the back, which would be more similar to the loading characteristics of a SMT, forces to produce rib fractures ranged between 1690 N–7400 N (Forman et al., 2015) which are considerably larger than the forces observed in this study. Of note, the SMT forces observed in this study were measured at the clinician-participant and participant-table interfaces, whereas previous biomechanical studies measured the forces at the rib itself. Therefore, the force magnitudes reported in this study cannot be directly compared to the ones reported in previous studies and further studies are needed to investigate the SMT's force-time characteristics necessary to cause rib fractures.

Given the rib geometry and the viscoelastic behaviour of spinal structures, rib displacement or deflection and the rate of force application are fundamental when investigating rib fractures and spinal structures injuries. Specifically, previous biomechanical studies reported that with a dynamic loading rate of 1.5 m/s–5.5 m/s, a 10%–32%

displacement or deflection of initial rib length was observed at the time of rib fracture (Agnew et al., 2015; Forman et al., 2015; Kang et al., 2020). Thorax deflection was not measured in the current study and although SMT force loading rate was recorded, caution should once again be taken considering the differences in location of loading rate measurement between studies and specimen condition (bare rib versus a living person with soft tissue and thorax content). Despite this, a previous study (Funabashi et al., 2016) quantified that the loading rate of a posterior to anterior SMT applied to the lumbar spine of cadaveric porcine was 0.04 m/s, which is notably smaller than the ones used in biomechanical studies that investigated rib fractures. Future studies are needed to elucidate SMT's biomechanical risks to cause rib fractures and other spinal injuries.

A recent study in asymptomatic young participants (mean age: 24 years old ±2.7) measured SMT force-time characteristics at the clinician-participant and participant-table interfaces and observed that forces at the participant-table interface were greater than the ones at the clinician-participant interface during MOB and SMT in most participants (Mikhail et al., 2020). Similar findings were observed in a recent study conducted in our lab where forces at the participant-table were, on average, 14% larger than forces at the clinician-participant interface (unpublished data). Interestingly, results from the current study showed greater forces at the clinician-participant interface than the ones at the participant-table interface in most participants. This suggests the potential unique biomechanical behaviour of older adult thoraxes in comparison to the ones of asymptomatic younger adults during MOB and SMT dynamic loading. General age-related degenerative changes have been reported in the literature (Sharma and Goodwin, 2006), as well as its influence on the biomechanics of the ribs and the overall thoracic region (Agnew et al., 2015; Brown et al., 2008; Forman et al., 2015; Kang et al., 2020; Okada et al., 2019). Apart from thoracic biomechanical behaviour, intervention and participant characteristics have been observed to influence the difference between forces measured at the clinician-participant and participant-table interfaces: where lower SMT loading rates (intervention) and larger thoracic thickness (participant) were correlated with a smaller difference between forces at both interfaces (Mikhail et al., 2020). Therefore, it can be speculated that the degenerative changes occurring in older adults, in combination with the intervention and other participant specific characteristics may influence the forces acting on internal tissues during MOB and SMT, which seems to be distinct from the ones observed in younger adults. This, in turn, provides evidence that further investigations should focus on this special population. These studies should be conducted to elucidate how conservative interventions, such as MOB and SMT, should be tailored to older adults and the safety of MOB and SMT in this population.

4.1. *Limitations*

Limitations include a sample size of 18 older adults that did not have thoracic pain. Therefore, results might not be generalizable to older adults with thoracic pain, as MOB and SMT forces applied to older adults presenting thoracic pain might have differing characteristics. However, this was the first study to quantify the force-time characteristics of clinical MOB and SMT applied to older adults and future studies will investigate MOB and SMT forces in a symptomatic sample. Additionally, all MOB and SMTs were performed to older adults by a single clinician and performance of other clinicians may apply interventions with different force-time characteristics. The comparison between MOB and SMT force magnitudes described in the current study with the ones reported in previous studies is limited due to methodological differences and should be interpreted with caution. Finally, this study was conducted in a laboratory setting and the instrumentation required to measure MOB and SMT force-time characteristics might have influenced the clinician's performance of these procedures. More specifically, the placement of triaxial loadcells between the clinician's hands and the participants' back may have potentially decreased the tactile feedback clinicians commonly report during manual therapies. Despite of that, MOB and SMT with force-time characteristics that are representative of what is used in the clinician's practice was applied and quantified.

5. Conclusion

This study quantified the force-time characteristics of clinical MOB and SMT applied to older adults. At the clinician-participant interface, total peak force was, on average, 323 N during MOB and 470 N during SMT. The difference between total peak forces measured at the clinician-participant and participant-table interfaces were, on average, 24 N during MOB and 15 N during SMT, with larger forces observed at the clinician-participant interface. Results suggest older adults experience unique, but comparable force-time characteristics during MOB and SMT delivered to their thoracic spine compared to the ones delivered to younger adults described in the literature. Future work regarding MOB and SMT's safety and effectiveness for older adults with back pain are warranted.

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Declaration of Competing Interest

The authors have no conflicts of interest to declare.

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