AWARD WINNING ORIGINAL ARTICLE

Comparison of force-time characteristics of prone cervicothoracic spinal manipulative therapy between chiropractic interns and chiropractors: A cross-sectional study

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ABSTRACT

Objective: Although the force-time characteristics of spinal manipulative therapy (SMT) have been extensively studied, evidence on the maturation of SMT delivered to the cervicothoracic junction is scarce. The aim of this study is to compare the force-time characteristics of a cervicothoracic SMT technique between experienced chiropractors and chiropractic interns.
Methods: Participants performed a total of 18 posterior-to-anterior cervicothoracic SMT on a human-shaped manikin, fixed to an instrumented treatment table. Participants were instructed to execute the technique, contacting either the right or the left side of the manikin, at 3 different levels of force: low, typical, and high. Three-level analysis of variance was used to assess the effect of group (experienced chiropractors or interns), force level, and contact side on force-time characteristics. Variability of these characteristics among participants was also evaluated.
Results: No statistically significant differences were observed in any of the force-time characteristics between chiropractic interns (n = 15) and experienced chiropractors (n = 10), nor on the contact side used to perform the SMT ($p > .05$). Significant effects on force level were noted for all force-time characteristics ($p < .05$), except for impulse duration ($p > .05$). The interns displayed more variability than experienced chiropractors for the force at thrust initiation only ($p = .02$).
Conclusion: This study shows that both chiropractic interns and experienced clinicians deliver SMT to the cervicothoracic junction with similar force-time characteristics. However, final-year students exhibited greater variability in controlling their force just before initiating the thrust, indicating that some aspects of their motor skill may still be developing.

Key Indexing Terms: Spinal Manipulation; Biomechanical Phenomena; Chiropractic; Learning Curve; Kinetics

J Chiropr Educ 2025;39:eJCE-24-10 DOI 10.7899/JCE-24-10

INTRODUCTION

Neck pain is the second most common reason for which adults seek chiropractic care.[1] Among the therapeutic options available for patients with mechanical neck pain, spinal manipulative therapy (SMT) targeting the cervicothoracic junction (C6 to T3) is frequently utilized.[2] Indeed, clinical practice guidelines recommend SMT as an effective approach to reduce pain intensity and disability in spine-related conditions, including neck pain.[3]

Comparisons of SMT force-time characteristics between novice and experienced practitioners have been previously investigated, however with varying results. Although Cohen et al[4] did not observe statistically significant differences between force-time characteristics applied by experienced practitioners and novice practitioners, Descarreaux et al[5] observed significant differences in time to peak force, loading rate, and unloading time. This is further supported by more recent studies consistently reporting significant differences in SMT force-time characteristics suggesting a systematic maturation in SMT performance associated with SMT training and experience.[6,7]

Previous studies have reported that different SMT techniques present unique force-time characteristics.[8,9] Nevertheless, most studies comparing SMT force-time characteristics performed by novice and experienced practitioners focused on SMT delivered to the thoracic spine or cervical spine.[4,5] To our knowledge, the force-time characteristics of SMT delivered to the cervicothoracic junction by experienced clinicians and students have only been measured once.[7] The results of

This paper was selected as a 2024 National Board of Chiropractic Examiners Research Award at the Association of Chiropractic Colleges – Research Agenda Conference.

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Triano et al[7] suggest a systematic maturation of motor skills related to this SMT technique's force-time characteristics as students advance through their education. Specifically, most motor skill development has been observed to level off at the fourth year of training, with no significant further improvements observed in experienced clinicians (at least 5 years of practice).[7]

Teaching strategies for complex motor skills, such as SMT, have advanced significantly in recent years.[10,11] Notably, the use of force-sensing technology to quantify SMT force-time characteristics has become widespread.[11–15] This technology is primarily employed in two key ways: (1) to provide visual feedback that facilitates the development of students' motor skills,[16,17] and (2) to offer various target force ranges for students to match the forces applied by experienced clinicians in practice.[18] Studies have shown that the use of force-sensing technology enhances students' ability to modulate force and reduces intraclinician variability when aiming for specific force levels.[19–21]

Further investigation into the maturation of the motor skills associated with SMT techniques delivered to the cervicothoracic junction may advance the teaching and learning of manual therapy by identifying specific force-time characteristics in interns that may require additional training and attention. Therefore, this study aims to compare the force-time characteristics of posterior-to-anterior cervicothoracic SMT performed by experienced chiropractors (licensed chiropractors with at least 5 years of experience) with those of chiropractic interns (last-year chiropractic students). Our secondary objective is to compare how consistent the forces applied by experienced chiropractors and interns are when delivering this technique. Given that the interns are in their final year of chiropractic studies, it was hypothesized that while the average of force-time characteristics of SMT delivered by interns and clinicians might not differ significantly, interns would exhibit greater variability in their SMT force-time characteristics compared to experienced clinicians.

METHODS

Study Design and Setting

The design of this study was a cross-sectional observational study conducted between May 2022 and April 2023. The manuscript has been written according to the STROBE (STrengthening the Reporting of OBservational studies in Epidemiology) Statement for cross-sectional studies.[22] This study was reviewed and accepted by the Université du Québec à Trois-Rivières (UQTR) research ethics board (CER-22-292-07.13).

Participants

To be included, participants had to be a licensed chiropractor part of the UQTR department of chiropractic faculty with at least 5 years of practice experience or be a last-year student (ie, 5th-year student within their senior internship) within the chiropractic program. All participants had to be familiar with the prone cervicothoracic SMT technique and report being comfortable performing it. Participants were excluded if they sustained an ongoing injury that would prevent them from performing multiple repetitions of the technique. Using the

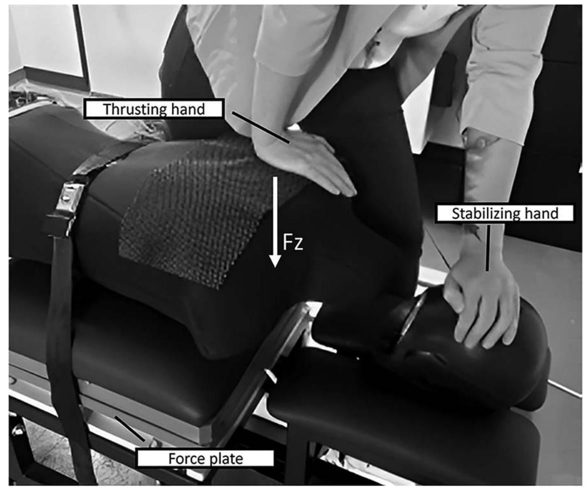

Figure 1 - Experimental setup. A Human Analogue Manikin (HAM, CMCC) was secured to a table using straps, with the thoracic region replaced by a force platform (Force-Sensing Table Technology, FSTT, CMCC). One hand of the participant applied a postero-anterior thrust to the upper thoracic region of the manikin, while the other hand stabilized the manikin's head, which remained unfixed to the torso.

data provided by Descarreaux and Dugas,[6] a minimum sample size of 7 participants per group was estimated to be necessary to detect significant differences in the force-time characteristics between interns and clinicians (G*Power[23], $\beta = 0.80$, $\alpha = 0.05$). However, given that we did not anticipate significant differences, the sample size was aimed to be a minimum of 10 participants per group. All participants provided a written informed consent prior to participating in the study.

Study Protocol Summary

Participants took part in a 45-minute session at the research laboratory located in the Chiropractic Department at UQTR. Once they provided their written informed consent, participants completed a general demographics questionnaire (height, weight, age, sex, hand dominance, number of years in clinical practice, and institution of chiropractic degree for licensed chiropractors). The SMT technique was then demonstrated to the participants, and they were allowed to practice until feeling comfortable with the experimental setup. Immediately after the practice trials, participants had to perform a total of 9 trials per manikin side (left and right) with 3 trials using their typical force, 3 using a lower force, and 3 using a higher force. An auditory signal was used to inform participants when they could begin their SMT, with a 10-second window after the signal to perform their trial. The order of the manikin side and of the force level was randomized using an online scheme generator (randomization.com). The experimental setup can be visualized on Figure 1.

Cervicothoracic SMT Technique

Participants were asked to perform a series of posterior-to-anterior SMTs at the cervicothoracic junction, using the technique referred to as the hypothenar/transverse push with

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combination move, as described by Bergmann and Peterson.[24] More specifically, participants were instructed to position themselves at the side of the table headpiece on the same side as their contact with the manikin (left side of the table if they were contacting the left side of the manikin). They were instructed to contact the cervicothoracic spine of the manikin using the hypothenar region of their contact hand (the right hand if they were contacting the left side of the manikin) and stabilize the manikin's head with their other hand. Upon hearing an auditory signal ensuring that the force-sensing table technology (FSTT, Canadian Memorial Chiropractic College) system was calibrated and reset to initial parameters, participants were given 10 seconds to execute the manipulative thrust as if they were performing it on a living human with the desired force level (low, typical, high). They were instructed to administer the thrust in a posterior-to-anterior direction (Fz vector), which corresponds to a force directed towards the treatment table. This technique is a common procedure taught in the UQTR chiropractic program. If participants were not satisfied with their performance, they had the option to repeat the trial. In such cases, the previous attempt was discarded. Only the 3 trials judged as successful for each specific force level were used for analysis.

Instrumentation

SMT were executed on a human analog manikin (HAM, CMCC, Toronto, ON, Canada) designed to replicate the size and shape of an adult torso. The manikin was positioned on a treatment table equipped with a force plate and was securely fastened with straps to the thoracic section of the table, which was fitted with the force plate. This setup prevented the dispersion of force to other parts of the table. The manikin's head was positioned on the table's headpiece and was not attached to the manikin to prevent any force generated by the stabilizing hand on the manikin's head from being recorded by the force plate.

The FSTT was used to measure the forces at the manikin-table interface. The FSTT is composed of a regular chiropractic treatment table with an embedded AMTI force plate (OR6–7, Advanced Mechanical Technology Inc) at its thoracic portion. To ensure that the force plate only recorded the interaction between the manikin and the thoracic portion of the treatment table, this latter is mechanically independent from the remainder of the treatment plinth. Previous research has demonstrated excellent reliability and validity of the FSTT in measuring forces at the participant-table interface during SMT.[25] Although the FSTT is typically employed to offer immediate post-trial feedback, participants in this study were not permitted to view their SMT force-time characteristics, and the researcher refrained from providing any verbal feedback. The 3-dimensional force plate measured voltages in *3* axes: Fx (left to right), Fy (cephalad to caudal), and Fz (posterior-anterior through the thorax). These measurements were recorded at a frequency of 1000 Hz using a 12-bit analog-to-digital (A/D) converter.

Data Processing

The data recorded by the FSTT were imported into a custom MATLAB (MathWorks Inc) script developed by the research team for this study. The MATLAB code was designed to display the force-time curve using the force data in the Z-direction and the corresponding time data from the table. Subsequently, a member of the research team (FP) manually identified and marked 3 significant points on the force-time curve, denoting the preload force, the thrust initiation, and the peak force attained. To ensure precise marking, the senior investigator (IP), who has extensive experience in marking SMT force-time curves, trained FP to ensure consistency in marking the same points on the force-time curves of a randomly selected set of 10 trials. After this initial training, FP continued with the marking process independently. The force-time characteristics are depicted in Figure 2 and were defined according to Gyer et al.[26] Specifically, the preload force (Newtons, N) was defined as the maximum force observed just before the thrust that is before an inflection in the force-time curve occurred. The thrust initiation force (N) was determined as the force at which there was an inflection point in the force curve, indicating the initiation of the thrust. If no decrease in force was observed before thrust initiation, the preload force and the thrust initiation force were considered equal. The peak force (N) was defined as the maximum force reached before a subsequent decrease in force occurred after the thrust initiation force. For each marked force-time plot, the MATLAB code calculated 3 additional force-time characteristics using the coordinates of the 3 marked points. The thrust duration (ms) was calculated by subtracting the time point of the peak force from the time point of the thrust initiation force. The downward incisural point (DIP, N), which referred to the force loss just before initiating the thrust, was obtained by subtracting the thrust initiation force from the preload force. Lastly, the rate of force application (N/ms) was obtained by dividing the force delta by the thrust duration. The average of the 3 trials of each force-time characteristic was used for further analysis.

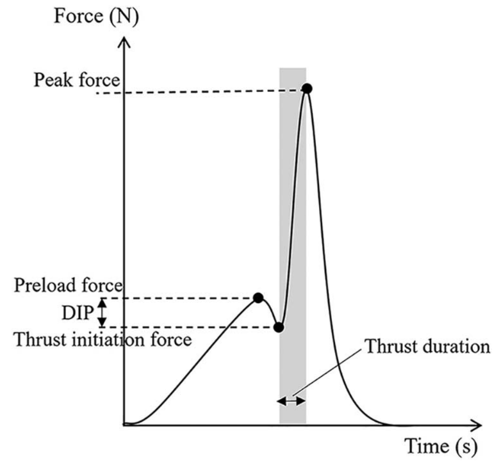

Figure 2 - Typical force-time curve with visualization of the force-time characteristics. The 3 marked points are indicated by black circles. DIP, downward incisural point.

Statistical Analysis

Normality of the data was determined by visual inspection of the data distribution, the Shapiro–Wilk normality test and the Kolmogorov–Smirnov test. Participants' characteristics

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Table 1 - Participants' Demographic Characteristics

Characteristics	Interns ($n = 15$)	Clinicians ($n = 10$)	p Value
Females : Males[a]	9 : 6	5 : 5	$p = .70$
Age (y, median, IQR)[b]	24 (2)	49.5 (18)	$p < .001$*
Height (m, mean ± SD)[c]	1.7 ± 0.1	1.7 ± 0.1	$p = .46$
Weight (kg, median ± IQR)[b]	68.0 ± 24.9	85.0 ± 36.9	$p = .15$
BMI (m/kg^2, mean ± SD)[c]	24.4 ± 2.7	26.9 ± 6.1	$p = .17$
Dominant hand for delivering spinal manipulations (right : left : either)[a]	12 : 1 : 2	8 : 0 : 2	$p = 1.00$
Years in practice (y, mean ± SD)	—	21.8 ± 9.05	—
Institution of graduation	—	UQTR, $n = 6$; CMCC, $n = 2$; Palmer Davenport, $n = 2$	—

* Statistically significant.
[a] Fisher's exact test was used to compare the variable between groups.
[b] Mann–Whitney U test was used to compare the variable between groups.
[c] *t* test for independent samples was used to compare the variable between groups.

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were first described using descriptive statistics. Mean and standard deviation (SD) were reported for parametric variable (height and BMI) and median with interquartile range (IQR) for nonparametric variable (weight and age). Age, weight, height, and BMI were compared between interns and clinicians using *t* test for independent samples (for parametric variable) or Mann–Whitney U test (for nonparametric variable). Means and SDs of the 3 trials for each force-time characteristic were calculated for each force level (low, typical, high) or each group (clinicians and interns) and plotted using line plots. Sex and hand dominance were compared between groups using Fisher's exact test. Three-level analysis of variance (ANOVA) was conducted for each force-time characteristic to evaluate the main effects of Groups, Contact side, and Force level, as well as to examine the interaction effects among these factors. If a main effect of force was observed on the peak force, planned comparison was computed to test for a priori hypothesis that all force-time characteristics would increase in a linear manner between the low, typical, and high force trials.[19–21] For any other significant interaction or main effects, Tukey post hoc tests were computed.

To compare the intra-individual consistency between groups and whether the contact side and the level of force influence this variable, the variable error was calculated. The variable error was defined as the absolute value of the difference between each trial's force-time characteristics and the average of the concerned trials for a participant: $VE_i = \left|V_i - \bar{V}\right|$ where VE_i represents the variable error for a specific trial, V_i is the value of that trial, and $\bar{V}$ is the average value of the set of trials for that particular participant. The mean variable error of each of the 3 trials was then averaged. A low variable error therefore signifies high consistency for that force-time characteristics. Three-level ANOVA was used to evaluate the effect of Group, Contact side, and Force level on the variable error of each force-time characteristics or any interaction effect between these variables. Tukey post hoc tests were computed if any significant effect or interaction effect was observed. Considering that the data distribution of the thrust duration variable error was not normally distributed, Mann–Whitney U test was used to compare the variable error between groups for each force level (error values of both hands were averaged). All statistical analysis was performed using STATISTICA data analysis software system version 10 (StatSoft, Inc, 2011) and significance was set at $p < .05$ for all analyses.

RESULTS

Participants

Table 1 presents the demographic characteristics of the participants. Overall, 15 interns in chiropractic (60% female) and 10 clinicians (50% females) participated in the study. Participants only differed in terms of their age with interns being younger than clinicians (mean difference = 22.1 years, U = 0.00, $p < .001$).

Differences in SMT Force-Time Characteristics

No data was missing, and all force-time characteristics showed a normal distribution. Table 2 presents the mean values of the force-time characteristics measured by the FSTT for each participant group. Three-level ANOVAs revealed no significant interaction effects between Group, Contact side, and Force level for any of the force-time characteristics (all p values $> .05$). Similarly, no significant main effects of Group or Contact side were observed (all p values $> .05$). A main effect of Force level was observed for peak force ($F_{2,46} = 129.86$, $p < .001$), preload force ($F_{2,46} = 19.12$, $p < .001$), force at thrust initiation ($F_{2,46} = 3.27$, $p = .047$), rate of force application ($F_{2,46} = 55.11$, $p < .001$), and the DIP ($F_{2,46} = 21.29$, $p < .001$). Planned contrasts indicated that all force-time characteristics increased from the low level of force to the high level of force ($p < .001$) with exception of the impulse duration for which no difference between force levels was observed ($p > .05$). Figure 3 presents, for each group, the variation in the force-time characteristics depending on the force level.

Participants' Consistency

Table 3 shows the variable errors of the interns and clinicians for each force-time characteristic. Three-level ANOVAs revealed no significant interaction effect between Group, Force

Table 2 - Force-Time Characteristics Measured by the FSTT During Cervicothoracic SMT Delivered by the Interns ($n = 15$) and Clinicians ($n = 10$). All Data are Expressed as Mean ± SD

		Left Hand		Right Hand	
Force-Time Characteristics	**Force**	**Interns**	**Clinicians**	**Interns**	**Clinicians**
Preload force (N)	Low	338.1 ± 121.3	277.4 ± 100.8	318.9 ± 93.3	283.1 ± 98.6
	Typical	381.9 ± 133.0	321.4 ± 104.9	380.0 ± 100.6	314.4 ± 128.8
	High	422.9 ± 159.6	358.9 ± 126.7	399.4 ± 134.0	312.5 ± 122.3
Thrust initiation force (N)	Low	299.7 ± 91.6	247.4 ± 78.0	279.4 ± 77.7	249.4 ± 85.8
	Typical	325.5 ± 95.2	272.0 ± 71.8	325.0 ± 88.9	249.6 ± 94.5
	High	320.6 ± 116.9	268.9 ± 90.2	308.0 ± 105.5	230.9 ± 110.8
Downward incisural point (N)	Low	38.4 ± 51.2	30.0 ± 38.3	39.5 ± 53.8	39.7 ± 42.4
	Typical	56.4 ± 73.3	49.5 ± 62.8	55.0 ± 73.3	64.8 ± 74.0
	High	102.3 ± 112.6	90.0 ± 78.8	91.4 ± 95.6	81.7 ± 78.4
Peak force (N)	Low	681.4 ± 136.6	697.7 ± 190.6	685.2 ± 121.7	668.6 ± 167.3
	Typical	798.6 ± 151.3	811.9 ± 164.4	804.6 ± 129.8	809.2 ± 190.8
	High	888.1 ± 166.0	932.3 ± 173.5	889.2 ± 157.3	935.9 ± 196.9
Thrust duration (ms)	Low	160.8 ± 60.0	169.8 ± 46.5	154.6 ± 55.2	168.4 ± 46.2
	Typical	159.7 ± 59.0	167.4 ± 37.2	143.7 ± 30.8	157.9 ± 30.1
	High	159.1 ± 81.3	162.6 ± 28.4	142.7 ± 35.5	157.6 ± 23.8
Rate of force application (N/ms)	Low	2.7 ± 1.2	2.8 ± 1.0	3.0 ± 1.3	2.7 ± 1.2
	Typical	3.4 ± 1.2	3.3 ± 0.9	3.7 ± 1.5	3.7 ± 1.3
	High	4.4 ± 2.0	4.2 ± 1.1	4.5 ± 1.5	4.6 ± 1.4

level, and Contact side or main effect of Contact side for any of the force-time characteristics variable error (all p values $> .05$). A significant main effect of Group was observed for the force at the thrust initiation ($F_{1,23} = 6.64$, $p = .017$) with interns having greater variability (mean ± SD = 35.7 ± 7.7N) than clinicians (25.8 ± 11.5N). A main effect of Force level was observed for the DIP variable error ($F_{2,46} = 14.75$, $p < .001$), and of the rate of force application variable error ($F_{2,46} = 4.98$, $p = .011$). Post hoc tests revealed that, regardless of groups, the rate of force application variable error was lower at the low force (0.39 ± 0.14 N/s) than at the high force (0.61 ± 0.39 N/s) ($p = .003$). Regarding the DIP, lower variable error was observed at both

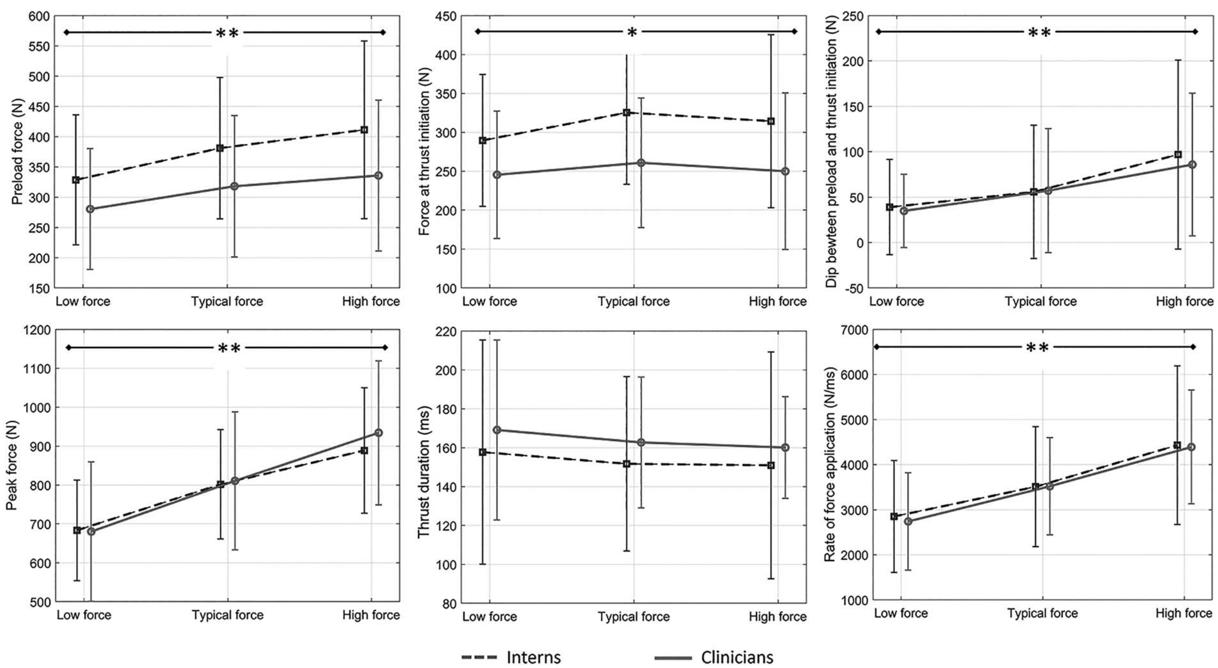

Figure 3 - Mean (with SD) value of the force-time characteristics of the SMT delivered by the interns (dashed lines) and clinicians (full lines) for the low, typical, and high force levels. Values are expressed as the mean of the 3 trials delivered on the left and right sides of the manikin. A significant increase in the value from low force to high force is denoted with * for a p value $< .05$ and ** for a p value $< .001$.

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Table 3 - Variable Error for Each SMT Force-Time Characteristic for the Interns (n = 15) and Clinicians (n = 10). All Data are Expressed as Mean ± SD Except Thrust Duration Data for which the Median and Interquartile Range are Reported

		Left Hand		Right Hand	
Force-Time Characteristics	Force	Interns	Clinicians	Interns	Clinicians
Preload force (N)	Low	23.0 ± 20.0	26.9 ± 13.1	31.3 ± 22.2	31.8 ± 16.4
	Typical	31.4 ± 23.7	37.8 ± 22.7	37.1 ± 20.3	39.1 ± 28.3
	High	30.6 ± 26.7	40.8 ± 15.4	30.8 ± 22.5	41.7 ± 32.0
Thrust initiation force (N)	Low	29.0 ± 19.8	21.6 ± 12.5	33.8 ± 21.4	26.0 ± 14.8
	Typical	39.1 ± 24.3	32.4 ± 22.7	37.6 ± 26.3	17.2 ± 9.4
	High	41.7 ± 21.5	26.6 ± 13.0	32.8 ± 18.5	30.9 ± 17.2
Downward incisural point (N)	Low	15.2 ± 16.3	15.8 ± 14.6	17.0 ± 13.2	14.6 ± 12.3
	Typical	15.9 ± 16.7	17.0 ± 24.6	15.6 ± 16.1	26.7 ± 22.0
	High	28.8 ± 27.5	31.0 ± 19.6	27.0 ± 23.7	38.6 ± 33.6
Peak force (N)	Low	27.1 ± 12.8	45.2 ± 42.0	38.1 ± 23.8	38.0 ± 14.5
	Typical	29.6 ± 21.2	52.5 ± 26.9	40.3 ± 23.3	44.6 ± 26.5
	High	41.4 ± 19.8	47.3 ± 48.7	34.1 ± 22.4	42.6 ± 29.8
Thrust duration (ms)*	Low	13.7 ± 18.6	12.3 ± 13.6	11.0 ± 28.1	12.4 ± 14.0
	Typical	14.3 ± 40.9	14.6 ± 14.2	11.6 ± 21.6	10.6 ± 9.4
	High	6.4 ± 18.9	9.9 ± 11.1	13.8 ± 8.2	11.8 ± 8.2
Rate of force application (N/ms)	Low	0.42 ± 0.21	0.44 ± 0.25	0.38 ± 0.18	0.31 ± 0.13
	Typical	0.53 ± 0.26	0.31 ± 0.19	0.58 ± 0.52	0.47 ± 0.34
	High	0.66 ± 0.43	0.48 ± 0.35	0.77 ± 0.61	0.54 ± 0.48

* Nonparametric, median IQR.

the low force (15.6 ± 13.1N, $p < .001$) and the typical force (18.8 ± 16.3N, $p < .001$) compared to the high force (31.3 ± 24.3N). Finally, the thrust duration for which Mann–Whitney U test was used, no difference between groups was observed at any force levels (all *p values* > .05).

DISCUSSION

This study was conducted to investigate whether last-year chiropractic students deliver cervicothoracic SMT with similar force-time characteristics than experienced chiropractors. Overall, results confirmed our initial hypothesis since no significant difference was observed between groups. However, students showed greater variability than experienced chiropractors, but only for the force just before initiating their thrust. The implications of these results are discussed below.

The cervicothoracic junction is commonly defined as the region spanning from C6 to T3.[24] As such, SMT targeting this area often involves techniques specific to the cervicothoracic region, as well as those that address the midcervical and upper-to-mid thoracic vertebrae. Recently, Gorell et al[8] published a scoping review detailing the force-time characteristics of SMT applied to the cervical, thoracic, lumbar, and lumbopelvic spine. This review highlights that although previous studies have explored the force-time characteristics of SMT applied to the C6–T3 region, the specific bimanual cervicothoracic SMT technique used in this study has only been evaluated once before.[7] Except for peak force, the force-time characteristics observed in our study are consistent with the ranges reported by Triano et al.[7] The higher peak forces observed in our study may be due to methodological differences. Although Triano et al[7] also measured SMT forces using a force-sensing table, their participants performed SMT on live human subjects, whereas our study utilized a manikin. Studies using live subjects and instrumented tables may introduce variability in force accuracy compared to using manikins.[8,27] When comparing the peak forces observed in our study (exceeding 700 N for interns and chiropractors) to those reported in studies of SMT applied to the thoracic spine, including the upper thoracic region, using manikins and force platforms, our values exceeded the reported range of 337–536 N found in Gorrell et al.[8] Whether these differences are due to the measurement devices or variation in peak forces between SMT techniques or between spine regions remains uncertain. Therefore, caution should be exercised when comparing force values across studies with differing methodologies.

The learning of SMT motor skill has been shown to follow different stages[11] that are consistent with common understanding of a motor skill learning.[10] Because the technique investigated in the current study involved the proper coordination of both hands, on 2 different parts of the patient's body (i.e., the head and cervicothoracic spine), it is believed to be a complex procedure that students often report as one of the most difficult to feel competent with its delivery. Understanding the maturation of this technique is therefore crucial to inform the need of learning aids and the proper moment of their inclusion into the student curriculum. Nevertheless, the learning maturation of this specific technique had only been previously investigated by Triano et al[7] who compared the force-time characteristics of this SMT technique between experienced chiropractors and chiropractic students from the first year up to the fourth year. In both studies, final-year students (5th year in the current study and 4th year in Triano et al study) showed similar preload force, peak force, thrust duration, and rate of force application as experienced chiropractors.

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These results are also in line with Descarreaux et al[5] who investigated the maturation of postero-anterior prone unilateral hypothenar transverse push SMT using an instrumented cardiopulmonary reanimation manikin. Their results revealed that last-year students deliver SMT of similar force-time characteristics to experienced chiropractors. Interestingly, these authors only observed a maturation of force-time characteristics when participants were grouped by their clinical experience (students of year 2 and 4 vs last-year students and clinicians) suggesting that the clinical experience gained during internships support further maturation in SMT motor skill.

Although final-year students provided SMT with similar force-time characteristics as experienced chiropractors, the results of this study revealed that students were more variable in their force just before they initiated their thrust compared to chiropractors. Variability is a common indicator of the stage of learning.[28] In the early stages, learners are typically highly variable in their motor skill as they learn through trials and errors. With practice, learners develop their ability to perform the task in a more rigid manner, resulting in reduced variability. However, when reaching expertise, variability increases again as individuals gain the capacity to adapt their motor skills to new situations.[28] Within the context of SMT, research has shown that variability in force-time characteristics follows a similar pattern: students are highly variable in their early stages of learning and become more consistent as they progress toward their final year.[6,13] For example, Pasquier et al[13] measured the consistency of SMT delivered to the thoracic spine by fourth- and fifth-year chiropractic students using the HAM and FSTT system. Although their findings indicated that greater expertise correlates with improved consistency, they did not observe significant differences in the variable error between the two student groups. Specifically, the mean variable error for peak force among fourth-year students was 24.1N (SD = ±12.0N) for females and 37.7N (±28.4N) for males, compared to 28.9N (±16.6N) and 36.1N (±16.4N) for fifth-year students. These results align with our study, where the interns' variable error for peak force ranged between 27.1N and 41.4N. Unfortunately, research on variability in force-time characteristics among clinicians is very limited to date. Descarreaux et al[5] evaluated the variability of SMT force-time characteristics among chiropractic students, interns, and experienced clinicians (with at least 5 years of practice). Their results showed nonsignificant differences in variability between interns and clinicians, with average peak force standard deviations of 45N for interns and 44N for clinicians, and with average rate of force application standard deviations of 8N/s for both groups. In line with these findings, our study did not observe significant differences in variable error for peak force or rate of force application between interns and clinicians. In the current study, a significant difference between students and clinicians for the variable error was only observed for the force before initiating the thrust. Interestingly, to our knowledge, no other studies have reported variability in force during thrust. During the thrust phase, students must generate a high-velocity controlled impulse using various potential motor strategies, such as a rapid concentric contraction of their triceps, a shoulder drop or a body drop.[29] The higher variability in their force at this moment may imply that they have not yet determined the most effective way to execute their SMT to modulate their peak force. The results of this study suggest the possibility that variability in force-time characteristics could be used as an indicator that a student has reached the final stage of SMT learning. In other words, although students in their final year may deliver, on average, SMT with force-time characteristics similar to those of experienced clinicians, they may still struggle to achieve consistent force-time characteristics between trials, suggesting that they may still be in their learning process.

Teaching Implications

The results of this study carry important implications for chiropractic education, particularly in the teaching of SMT techniques. The observed variability in force just before initiating the thrust among final-year students suggests that, despite their ability to deliver thrusts with force-time characteristics comparable to experienced clinicians, there remains a need for further refinement of their motor skills. This finding highlights the importance of incorporating targeted training interventions that focus on reducing variability during the preparatory phase of the thrust. Integrating force-sensing technology, such as the FSTT system, into the curriculum may provide students with real-time feedback and facilitate enhancing their consistency in force delivery. Additionally, considering the complexity of delivering a SMT to the cervicothoracic junction, more practice opportunities and guided instruction may be required earlier in the program to help students achieve proficiency before reaching their final clinical internships. These strategies could facilitate a smoother transition from student to clinician and contribute to the development of more consistent, skilled practitioners.

Strengths and Limitations

The primary strength of this study lies in the utilization of a standardized experimental model involving a human-like shaped manikin secured on a validated instrumented table. This model enables the delivery of repetitive SMT by participants, a feature typically constrained in manual therapy studies involving human participants as recipients. Moreover, the use of a manikin also provides a more accurate measurement of force-time characteristics by a force plate positioned under it than when SMT are delivered on living humans.[27] A limitation of the study is that the sample size was determined based on our primary objective, and it may be insufficient for addressing our secondary objective (consistency of forces), and that all participants were drawn from a single chiropractic program. This limitation affects the generalizability of our findings to other interns and clinicians. Additionally, since students were assessed only at the start of their 5th year, it remains unknown whether students graduate with consistency similar to the one of experienced clinicians due to the extensive clinical experience gained during their internship. It is important to note that although the researcher did not intentionally provide feedback to the participants, they visualized the SMT force-time curves after each trial to confirm data quality. As a result, it is possible that unintentional nonverbal feedback was given to the participants. Finally, it should also be noted that the marking of the force-time curves was conducted by a single researcher, which could introduce bias.

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CONCLUSION

This study shows that chiropractic interns and experienced clinicians deliver SMT to the cervicothoracic junction with similar force-time characteristics. However, final-year students exhibited greater variability in controlling their force just before initiating the thrust, potentially suggesting that some aspects of their motor control are still developing. Future studies should include longitudinal assessments to better track SMT skill development throughout chiropractic education. Additionally, larger sample sizes and further exploration of variability in SMT performance are necessary to draw stronger conclusions regarding learning maturation and clinical competency.

FUNDING AND CONFLICTS OF INTEREST

No funding was received for this study. The authors declare that they have no competing interests.

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Author Contributions

Concept development: IP, MF, JLG, FP. Design: IP, MF, JLG. Supervision: IP. Data collection/processing: FP. Analysis/interpretation: IP, MF, JLG, FP. Literature search: FP, JLG. Writing: IP, MF, FP. Critical review: JLG. During the preparation of this work the author(s) used the language model ChatGPT (version 3.5) developed by OpenAI in order to improve readability and language. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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