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ORIGINAL ARTICLE

Chiropractic students' force-time parameters for chiropractic adjustments at the beginning and end of an academic term

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ABSTRACT

Objective: To evaluate changes in chiropractic students' spinal manipulation force-time parameters from the beginning to end of an academic term and compare pre-post differences by students' level of self-reported training outside of required class time.
Methods: Students were recruited using campus-wide flyers and club announcements. Participants performed 12 mannequin adjustments and total peak force, impulse peak force, and time to peak force were measured using force sensing table technology. Changes in pre and post data were assessed with paired *t*-test and signed-rank tests. The rank-sum test was used to test the association between out of class practice time and changes in adjustment parameters. Alpha was set at $p \leq .001$.
Results: Twenty students agreed to participate and pre-post data were collected for 17 students. Average time to peak force decreased and impulse peak and total peak forces increased over the academic term. Statistically significant changes were observed for cervical adjustment time to peak (mean decrease of 38 ms, SD = 59 ms) and thoracic adjustment total peak force (mean increase of 86 N, SD 113 N). No statistically significant differences were observed between students based on practice time.
Conclusion: Using force sensing table technology in this doctor of chiropractic program, student changes in adjusting force-time parameters were documented. Future research, with a larger sample size, is needed to evaluate student characteristics associated with changes in student adjustment parameters.

Key Indexing Terms: Chiropractic, Manipulation; Education, Professional; Kinetics; Motor Skills

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INTRODUCTION

A large body of research in the chiropractic field is focused on high-velocity, low amplitude (HVLA) thrusts to the spine, also known as chiropractic adjustments or chiropractic spinal manipulation therapy (SMT). Many chiropractors provide HVLA thrusts to their patients and previous research has observed that this intervention creates improved neuromuscular function,[1] decreased reaction time,[2] changes in brain integration for sensory and motor information,[3–5] reduced joint position sense error,[1,6] and improved altered visual acuity and visual field size.[7,8] New technology can measure the general load magnitude and rate of HVLA application by chiropractors, for example, using pressure sensing pads and force plates that record and analyze load, speed, and direction of simulated adjustments.[9,10]

More research is needed to identify the optimal combination of HVLA thrust force, speed, and dosage for vertebral displacements and clinical responses.[11] A 2023 scoping review summarizes thrust parameters from previous studies.[12] The range of peak force for cervical HVLA measured at the clinician patient interface was 41–407 N; whereas the reported range for thoracic and lumbar HVLA thrusts measured at the patient table interface were 290–878 N and 128–516 N, respectfully.[12] There is some evidence suggesting larger thrust forces are associated with greater muscular response amplitudes and vertebral displacements than lighter thrusts.[11]

It takes time for students to develop the psychomotor skills for performing chiropractic adjustments as noted by studies comparing students' HVLA thrust parameters to instructors or practicing doctors of chiropractic.[13,14] It has been demonstrated that in the early stages of motor learning, learners focus on mastering force production and reducing time to peak force, but stabilization of these skills takes longer.[14] Over time, learners reduce variability and improve coordination, though complete mastery often continues beyond initial training and into clinical practice.[14] One study showed that as students learned to improve their control over the thrust force, their speed in applying force decreased.[13]

Students learning and refining their skills utilizing HVLA thrusts may injure themselves while practicing[15] or experience an injury from another student who is also learning.[16] Certain research suggests the utilization of mannequins can be just as effective for students learning as practicing on classmates[17] and that gains in HVLA performance can be increased with short training periods less than 2 hours with mannequins and other augmented devices.[18] De Kock et al did a review of several studies that used the Human Analogue Mannequins (HAM) FSTT, finding that the available evidence supports the use of these types of feedback devices for improving spinal manipulation delivery.[18] With the new technology being developed for measuring force and speed of manual thrusts in humans in simulated settings and in a variety of techniques,[19] there is opportunity to use this technology in a chiropractic students' education.

The purpose of this study was to evaluate changes in students' adjustment force and time to peak force between the beginning and end of an academic quarter and to evaluate if these changes vary depending on the amount of time students spent outside of assigned curriculum classroom training. A secondary aim was to compare students' force and time to peak force for adjustments that they consider "light," "medium," and "heavy."

METHODS

Participants

To be included in this study, students had to be enrolled in the doctor of chiropractic program (DCP) at Life Chiropractic College West. A student could be in any quarter of the program, ranging from 1 to 14. However, they could not have had any prior manipulative therapy training, such as an osteopathic or physical therapy degree.

The institutional review board of Life Chiropractic College West determined this educational research study was exempt from institutional review board review (IRB PIDN # 2023-002.irb). Risks for this study were minimal since no interventions were delivered to participants. Consideration was taken to protect participants' anonymity and to prevent people from being judged on their performance.

Sample size was determined a priori, noting that effect sizes calculated from data in related studies vary.[20–22] Forty-five participants were needed to detect pre-post differences with an effect size of .5, alpha .05, and Power .95 according to G*Power 3.[23]

Participants were recruited by hanging flyers with information about the study around campus and posting a copy of the flyer in all-campus weekly newsletters. The study was also announced at Kairos Training Culture (KTC) club meetings and in some classes to increase representation from students across the curriculum. The flyer had a QR code that students scanned to access an online recruitment questionnaire in Qualtrics (Provo, UT). The questionnaire had 7 questions for name, email, past osteopathic or physical therapy training, plans for enrolling at the school during the time of data collection, level of completion of the DCP, history of KTC participation, and interest in KTC participation.

Data Collection

No interventions were assigned to the students to influence their adjustment force-time parameters. This observational study collected data about students' self-reported out-of-class adjusting practice. The institution's adjusting policy is that no student may adjust any person outside of classroom or clinic supervision; all "practice" is practice that does not include delivering physical adjustments. Time spent out of the classroom practicing includes on-campus clubs, off-campus palpation groups, seminars, or time spent in the school's Technology Training Center, a room located in the school where students have access to all the technology used in this study under the supervision of staff trained on the use of this equipment and available to help students modify their mannequin adjusting and interpret results. Most students do not have access to the mannequins used in this study unless they had practice time in the Technology Training Center. Therefore "practicing adjusting" may include palpation, using drop tables to mimic thrusts with resistance, or practicing HVLA thrust line of drives in the air. One of the student-led on-campus clubs (KTC Club) includes training time in the Technology Training Center. Students participating in KTC meet twice a week for 1 hour in the mornings before classes and go over ergonomic movement for chiropractors, breathwork, and lessons centered on learning how to perform chiropractic adjusting.

The parameters included in this study were Impulse Peak Force (N) and Time to Peak Force (ms) as these have been suggested as important in the successful delivery of a chiropractic adjustment.[24] Time to Peak (aka thrust duration[25]) is defined as the elapsed time between the initiation of the HVLA thrust and the moment the force is at its greatest amount (Impulse Peak Force). When chiropractors deliver an HVLA thrust adjustment, they typically apply a tissue pull and preload force. This may be followed by an unloading/decrease in force before the HVLA thrust, especially in novice adjusters. Therefore, this study also included Total Peak Force (N), which captures both the Impulse Peak Force and the Pre-Load force (Fig. 1). It was hypothesized that students who report practicing adjusting outside of required technique classes and labs will have greater increases in adjustment Impulse Peak and Total Peak forces and larger decreases in Time to Peak than students who do not report out of class adjusting practice (over the course of a 11-week quarter).

Students' adjusting Impulse Peak Force, Total Peak Force and Time to Peak Force were measured as close to the beginning and end of an academic quarter as possible, allowing for approximately 7 weeks in between pre and post data collection. Prior to data collection, each participant received a copy of the informed consent and a video briefly explaining where to come for their data collection appointment and what to expect. At the initial data collection date, students arrived and investigators reviewed the informed consent form with them, answered any questions, then gave an explanation of the equipment they would be using and the adjustments they would be performing (details below). After the second session, students were asked 3 questions about the out-of-classroom training they participated in during the Spring 2023 11-week quarter (KTC participation, Yes or No; Number of 1-hour KTC sessions attended during the 11 week quarter (0-18); and approximate number of hours practicing adjusting skills outside of the classroom, excluding KTC). Students were also asked to provide details on their level of DCP completion, gender, height, weight, and if they are left- or right handed.

Apparatus

This study used Force Sensing Table Technology (FSTT) version 1.9 (Canadian Memorial Chiropractic College, Toronto

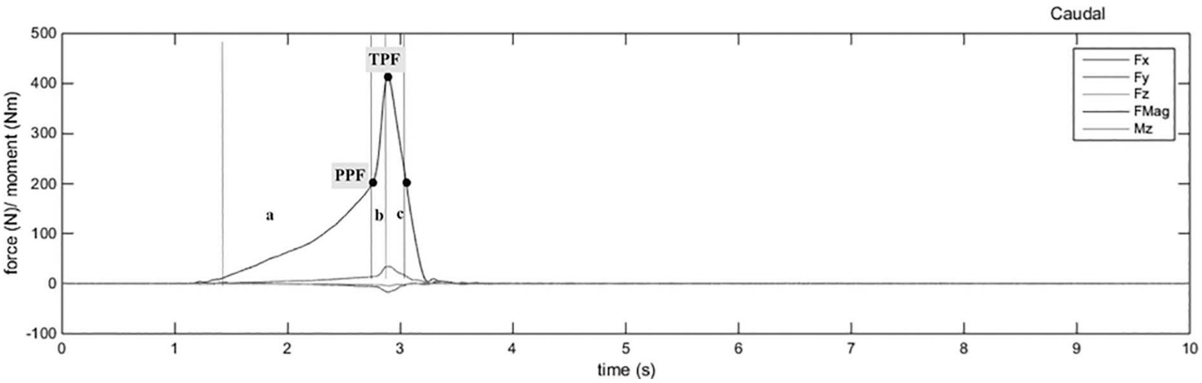

Figure 1 - Screenshot of force-time curve and parameters automatically calculated by Force Sensing Table Technology (FSTT). a = preload phase, b = thrust phase, c = resolution phase. Total Peak Force (TPF) = highest point in thrust phase. Time to Peak automatically calculated as milliseconds between Peak Preload Force (PPF) and Total Peak Force (TPF). Impulse Peak Force automatically calculated as difference in force between PPF and TPF.

Canada) for recording adjustment speed and force. A chiropractic adjusting bench with an AMTI force plate (Netforce, AMTI, Watertown, MA, USA) inside was used for detecting thoracic adjustment force and speed at the patient-table interface (Fig. 2), and a smaller puck force plate called a Handheld Tri-Axial Load Cell by ATI Industrial Automation (model number FTIFPS1) was used for detecting cervical adjustment force and speed (at the clinician-patient interface) (Fig. 3).

Adjusting Procedures

At each station (cervical and then thoracic), participants were allowed a few practice thrusts on a mannequin before delivering their adjustments for data collection. This allowed all students to have a chance to become familiar with the feeling of how to deliver the adjustment on these mannequins. The Human Analogue Mannequins (HAM) were used to simulate adjusting for the cervical and thoracic spinal regions.[26] For thoracic adjustments, the mannequin was placed prone over the force plate and strapped in with a seatbelt to provide a counterforce so the mannequin would not move on the table with delivery of the adjustments (Fig. 2). For the cervical adjustments, the Handheld Tri-Axial Load Cell was placed on the neck of the mannequin (Fig. 3), which was secured by a seat belt in the supine position to simulate the adjustment (Fig. 4). The mannequin heads are able to rotate and laterally bend to simulate the delivery of an actual adjustment. Students were instructed to adjust perpendicular into the Handheld Tri-Axial Load Cell after they positioned the mannequin's head.

Each student started with their cervical adjustments and were asked to perform a Body Right (BR) Diversified listing at the level of C4[27] and deliver 1 light, 1 medium, and 1 heavy adjustment. To describe this, participants were asked to think of the normal force they would deliver with an adjustment; this would represent their medium force.[28] Then they were asked to think of a 200-pound linebacker, and a 12-year-old child; those would be the heavy and light adjustments. This was then repeated with a Body Left (BL) Diversified listing at the 4th cervical vertebra (C4).[27] The only instruction that participants were given for their stance was demonstration by the primary investigator and the cues of what adjustment they

Figure 2 - Human Analogue Mannequin (HAM) secured on Force Sensing Table Technology (FSTT) version 1.9 (Canadian Memorial Chiropractic College, Toronto Canada) adjusting table with a seatbelt to minimize movement during adjustments.

Figure 3 - Handheld Tri-Axial Load Cell by ATI Industrial Automation (model number FTIFPS1).

Figure 4 - Supine cervical adjustment on Human Analogue Mannequin (HAM™) with the Handheld Tri-Axial Load Cell at the doctor/patient interface to measure adjustment time parameters.

would be giving. This totaled 6 cervical adjustments for each participant. At the thoracic tables, students had the chance to choose between 2 tables that they felt would best fit their height. Once they selected their table, they were set up to deliver a Posterior Left Inferior Thoracic (PLI-t) Diversified Double Thenar listing at the 5th thoracic vertebra (T5).[27] They were asked again to deliver 1 of each light, medium, and heavy adjustments. This was repeated with a Posterior Right Inferior Thoracic (PRI-t) Diversified Double Thenar listing.[27] This totaled 6 thoracic adjustments for each participant.

Three levels of adjustment force were included, "light, medium, and heavy," as a way to observe participants' abilities to modulate the force of their thrusts, anticipating that such control would be an important student training goal to adapt their adjustments for different patients. In total each student delivered 12 adjusting forces. In week 9 (the last week of classroom instruction) of the Spring 2023 school quarter, students were invited to return to the Technology Training Center and repeat the above procedures. During the practice times for both sessions before delivering adjustments for data collection, participants were not able to view the computer screen and visualize their adjustment force and speed.

Data Analysis

The FSTT system installed in this institution includes its own data collection software (developed by FSTT using MATLAB, by MathWorks, Natick, MA). The FSTT software system was used to automatically calculate the participants' adjustment forces (Impulse Peak Force (IPF) and Total Peak Force (TPF)) and Time to Peak Force (T2P). In some instances, the FSTT system captured the raw thrust data but did not automatically calculate the derived measures; therefore, requiring analytic measures to be calculated by hand. When the threshold was not reached, the first author used the FSTT plot function to manually select 2 points on the force-time curve (the intersection between the preload and thrust phases (Peak Preload Force PPF Fig. 1) and the highest point of the thrust phase (Total Peak Force TPF, Fig. 1). To calculate IPF, the y-axis for TPF was subtracted from the y-axis of PPF (IPF = yTPF - yPPF). To calculate T2P, the x-axis of TPF was subtracted from the x-axis of PF (T2P = xTPF - xPPF). These equations were provided to the authors by the developers of the FSTT software. When performing manual calculations, the investigator was blinded to student identity and their out-of-classroom practice time.

Data were organized in a Google Sheet (Google LLC Mountain View, CA) and then exported to Microsoft Excel (Version 16.79.1). To create a variable for total out-of-class time practice, the number of hours students attended KTC and the number of hours they reported for additional practice were added together. This variable was not normally distributed and a dichotomous variable was created for 10 or less hours and 11 or more hours. To reduce the number of statistical tests and possibility of a Type 1 error, the pre-data for BR and BL Medium-thrust adjustments were averaged for each student as were the pre-data for the PLI-t and PRI-t Medium-thrust adjustments. This was repeated for the post data. New variables were then created for (1) the difference between the post- and pre-averaged BR and BL Medium-thrust data and (2) the difference between the post- and pre-averaged PRI-t and PLI-t Medium-thrust data. After the new variables were created, they were imported into STATA 17 for descriptive and inferential statistics.

Chi-square and Wilcoxon rank-sum tests were used to assess differences in survey data and baseline medium thrust characteristics between the 2 independent student groups (Students reporting 11 or more hours of out of class practice and students reporting 0–10 hours of out-of-class practice) (Table 1). To assess the average changes in student adjustment characteristics between beginning and end of the quarter, the paired *t*-test was used when the data was normally distributed and the Wilcoxon signed-ranks test was used when assumptions were not met for the paired *t*-test (Table 2).[29] Pre and post differences of Medium-thrust T2P, IPF, and TPF were not normally distributed. Therefore, the Mann-Whitney-Wilcoxon (rank-sum) test was used to assess whether pre-post changes in thrust parameters differed between the two independent student groups (Table 3).[30] To minimize the chance of finding a spurious difference between pre and post data or between out of class practice and changes in force time parameters, the alpha level was set to $p \leq .001$ using Bonferroni correction.

For the secondary aim of comparing students' light, medium, and heavy adjustments force-time parameters, data were summarized for the light and heavy thrusts as they were for the medium thrusts described above.

RESULTS

A total of 36 students responded to study recruitment efforts by scanning the QR code on the flyer and answering the recruitment questionnaire. All 36 of these students met the study inclusion criteria and were emailed an invitation to participate in the study. Of the 36 students who were emailed, 22 responded and scheduled a data collection appointment in week 2 or 3 of the quarter. Twenty of these students showed up for their time slot, completed the informed consent, and agreed to participate. The informed consent process and first data collection appointment took 10–15 minutes per person. Out of the 20 original participants, 17 returned week 9 for

Table 1 - Characteristics of Students Who Reported 11 or More Hours of Out-of-Class-Time Practice Compared to Those Who Reported 10 or Less Hours During an Academic Quarter

	All Students (n = 17)	Students With 0–10 hr/wk (n = 8)	Students With 11 or more hr/wk (n = 9)	*p* Value
Male (%)	8 (47.06%)	4 (50.00%)	4 (50.00%)	.82
Female (%)	9 (52.94%)	4 (44.40%)	5 (55.56%)	
Left-handedness (%)	2 (11.76%)	1 (50%)	1 (50%)	.93
Right-handedness (%)	15 (88.24%)	7 (46.67%)	8 (53.30%)	
KTC - No (%)	4 (23.53%)	4 (100%)	0 (0.00%)	.015
KTC - Yes (%)	13 (76.47%)	4 (30.77%)	9 (69.23 %)	
Height mean (SD)	66.57 (4.04)	67.75 (3.69)	65.53 (4.26)	.29
Weight mean (SD)	171.18 (37.15)	165 (26.32)	176.67 (45.62)	.99
QTR mean (SD)	4.88 (2.42)	4.25 (3.15)	5.44 (1.51)	.12
Time to peak mean baseline for medium thrust BL&BR (SD)	154.24 (71.25)	171.06 (99.62)	139.28 (30.59)	.96
Time to peak mean baseline for medium thrust PLI-t & PRI-t (SD)	143.38 (32.50)	155.13 (39.60)	132.94 (21.91)	.32
Impulse Peak Force mean baseline for medium thrust BL&BR (SD)	73.82 (19.31)	73.48 (19.14)	74.11 (20.62)	.81
Impulse Peak Force mean baseline for medium thrust PLI-t & PRI-t (SD)	340.97 (122.62)	314.94 (88.44)	364.11 (148.15)	.67
Total Peak Force mean baseline for medium thrust BL&BR (SD)	85.19 (22.38)	83.80 (25.66)	85.42 (20.54)	.50
Total Peak Force mean baseline for medium thrust PLI-t & PRI-t (SD)	480.50 (154.36)	451.13 (127.66)	506.61 (178.23)	.67

[a] KTC, Attended at least one Kairos Training Culture Club meeting; QTR, Academic quarter in which students are enrolled. SD, standard deviation. P, posterior; I, inferior; t, transverse process: B, (cervical vertebral body); L, left; R, right.
* Chi2 for association between 11 or more hours of out-of-class time practice and gender, hand dominance, and KTC participation. Wilcoxon rank-sum test for association between Height, Weight, Quarter, and baseline Force Time variables.

completing the second set of testing, which took 15–20 minutes per person.

The final study dataset for 17 participants who completed the study included 612 data points for each session (T2P, IPF, and TPF for 17 participants delivering 12 total thrusts). Of the 612 session 1 "Pre" data points, 189 were manually calculated for the cervical thrusts and 6 were manually calculated for the thoracic thrusts due to the FSTT system not automatically calculating T2P, IPF, and TPF. Of the session 2 "Post" data points, there were 99 manual calculations for the cervical data and 1 manual calculation for the thoracic data. This was the only instance where the FSTT system only calculated 2 of our 3 values and the cause is unknown.

Table 1 shows that the majority of the participants were female and were right handed. Fourteen of the students were in the first 2 years of the DCP and had not yet started outpatient clinical care (specifically, 3 students were in quarter 2, 4 quarter 3, 1 in quarter 4, 6 in quarter 6, 2 in quarter 7 and one in quarter 11). Out of the 17 participants, 13 (76.47%) went to at least one KTC session and 9 students (69.23%) reported at least 11 hours of out of class-time practice. Students who reported 11 or more out of class time practice were more likely to report KTC participation ($p = .015$). The median number of quarters completed by students reporting 11 or more hours of out of class time practice was 6 (~18 months), compared to 3 quarters (~9 months) for students reporting 10 or less hours ($p = .12$) There were no statistically significant differences between students reporting 11 or more hours of out of class time practice and their peers by gender, handedness, height, weight, and baseline medium thrust characteristics (Table 1). There was also no statistically significant differences between the changes in students' Total Peak Force, Impulse Peak Force, and Total Peak Force from the beginning to the end of the quarter based on whether or not they reported 11 or more hours of out-of-class time practice (Table 3).

Table 2 shows the mean force-time characteristics of both cervical and thoracic adjustments at the beginning and end of the academic quarter. Changes that were statistically significant at $p \leq .001$ were decreases in Time to Peak Force for cervical medium thrust adjustments and light thoracic adjustments as well as increases in Total Peak Force for light and medium thrust thoracic adjustments. The results for the thoracic data are highlighted in Figures 5 and 6.

DISCUSSION

The current understanding of spinal manipulation force-time characteristics suggests that these skills mature through distinct stages of motor skill learning, progressing from cognitive to associative, and ultimately to autonomous phases.[31] Statistically significant changes were observed in this study for students' Total Peak Force and Time to Peak Force. An additional indication that students improved over the course of the academic quarter is that 31.86% of the pre data had to be manually calculated because the thrusts did not meet the minimum threshold of the FSTT system for automatic calculations, compared to 16.34% of the post data. This maturation

Table 2 - Mean Force-Time Characteristics of Cervical and Thoracic Adjustments at the Beginning (pre) and End (Post) of an Academic Quarter for 17 Doctor of Chiropractic Students

	Pre/ Post	Mean Total Peak Force in Newton (±SD)			Mean Total Peak Force in Newton (±SD)			Mean Time to Peak in Milliseconds (±SD)		
		Light	Med	Heavy	Light	Med	Heavy	Light	Med	Heavy
BL & BR	Avg Pre	54.74 (17.18)	73.82 (19.31)	87.81 (22.98)	71.25 (24.55)	85.19 (22.38)	97.97 (25.84)	175.35 (94.50)	154.24 (71.25)	131.47 (57.27)
BL & BR	Avg Post	65.61 (15.77)	87.28 (25.97)	94.47 (31.30)	83.33 (22.12)	103.84 (25.59)	112.02 (31.00)	123.78 (40.82)	116.12 (33.27)	118.50 (38.42)
	Diff (Post -Pre)	10.87 (16.42)*	13.46 (17.75)**	6.66 (22.12)	12.08 (26.71)*	18.66 (26.02)**	14.05 (22.90)* +	−51.57 (78.47)**+	−38.12 (58.99)***+	−12.97 (48.56)
PLI-t & PRI-t	Avg Pre	229.10 (105.55)	340.97 (122.62)	442.41 (152.05)	374.20 (125.70)	480.50 (154.36)	567.76 (200.79)	143.32 (28.65)	143.38 (32.50)	146.06 (28.08)
PLI-t & PRI-t	Avg Post	304.00 (123.43)	399.94 (126.81)	515.26 (187.00)	478.00 (164.98)	566.26 (168.27)	685.74 (241.83)	127.24 (21.63)	130.71 (21.14)	128.53 (27.55)
	Diff (Post -Pre)	74.90 (99.62)**	58.97 (87.03)**	72.85 (106.69)**	103.80 (107.68)***	85.76 (112.90)***+	117.97 (153.30)**+	−16.09 (18.83)***	−12.68 (29.51)*	−17.53 (37.78)*

[a] Avg, Average; Pre, Initial measurements near the beginning of the academic quarter; Post, Second measurements near the end of the academic quarter; Diff, Difference between pre and post; SD, standard deviation; P, posterior; I, inferior; t, transverse process: B (cervical vertebral body); L, left; R, right.
Statistical tests for post-pre difference = paired t-test unless noted with a "+" for sign-test.
*p ≤ 05;**p ≤ .01;***p ≤ .001.

process is critical to chiropractic practice, where SMT techniques are complex psychomotor tasks. The current study results align with this understanding, demonstrating that over time learners improve their SMT technique, becoming more efficient in force application and timing.[21,22,31]

Although it is difficult to compare HVLA biomechanical parameters across studies due to different tools for measuring force, the Impulse Peak Force and Time to Peak Force observed by students in this study were similar to those previously reported among chiropractic students and practicing chiropractors.[12] In a study of 16 second-year chiropractic students, Owens et al (2017) observed an average peak force of 314 N (SD: 107 N) for their medium lumbar prone adjustments at the beginning of an academic quarter that increased to 327 N (SD: 106 N) at the end of the quarter.[21] This is similar to the pre/post medium-thrust prone thoracic adjustment Impulse Peak Force findings of 341 N (SD: 123 N) and 399N (SD: 12 7N) in the current study, respectively. Forand et al evaluated upper thoracic adjustment forces of chiropractors with an average of 6 years of practice experience.[32] They measured average peak forces of 462 N (SD: 194 N) to 482 N (SD: 130 N) which are similar to the average Impulse Peak Forces observed for students in the current study performing "heavy" force thoracic thrusts (442.41 N (SD: 152.05 N) to 515.26 N (SD: 187.00 N)). The average Time to Peak Force (ms) observed in the Forand et al study was 120 ms (SD: 28 ms) and 132 ms (SD: 29 ms) for upper thoracic adjustments.[32] This is less time than the average reported Time to Peak Force for medium-thrust thoracic adjustments at the beginning of the quarter (143.38 ms (SD: 32.50 ms)) but in line with what was observed at the end of the quarter (130.71 ms (SD: 21.14 ms)).

No statistical tests were performed to compare the force-time parameters between light, medium, and heavy thrusts since this was not the primary objective of the study. Table 3, however, highlights that the average Impulse Peak and Total Peak Forces were lowest for "Light" and highest for "Heavy" thrusts, suggesting that the students in this study were able to modulate their adjustment forces, as was observed in prior research.[21]

There are some strengths of this project. The investigators took several steps to deidentify study participant data and to prevent systemic errors in the data imputation and analysis. The investigator inputting the data and doing the manual calculations was blind to the student identification and was unaware of which students had more out-of-class practice. The investigator also calculated the pre- and post-data independently.

Despite the study finding statistically significant differences between pre and post measurements, no statistically significant differences were observed between students based on their reported out-of-class time practice. This may be due to the study not being sufficiently powered to detect differences between students based on their levels of out-of-class time practice, individual variations in practice methods, or the type of activities included in self-reported practice hours. Prior research highlights the importance of practice and feedback for changing HVLA thrust force-time profiles.[18,22,33–36] Clinical relevance of these changes still needs to be established[33,37,38]

Another limitation of this study is that some participants' adjustments did not meet the force threshold levels for the FSTT system to automatically record Impulse Peak Force, Time to Peak, and Total Peak Force. Therefore, it was necessary to manually plot Peak Preload Force and Total Peak Force. Manually

Table 3 - Mean Changes in Medium Thrust Force-Time Parameters for Cervical and Thoracic Adjustments at the Beginning (pre) and End (post) of an Academic Quarter by Level of Reported Out-of-Classroom Practice

	All Students (n = 17)	Students With 0–10 hr/wk (n = 8)	Students With 11 or More hr/wk (n = 9)	*p* Value
Time to peak mean post-pre difference for medium thrust BL&BR (SD)	−38.12(58.99)	−49.31 (75.07)	−28.17 (42.32)	.41
Time to peak mean post-pre difference for medium thrust PLI-t & PRI-t (SD)	−12.68(29.51)	−21.56 (38.20)	−4.78 (14.12)	.47
Impulse Peak Force mean post-pre difference for medium thrust BL&BR (SD) (SD)	13.46(17.75)	20.09 (18.56)	7.58 (15.68)	.11
Impulse Peak Force mean post-pre difference for medium thrust PLI-t & PRI-t (SD)	58.97(87.03)	47.94 (88.47)	68.78 (89.82)	1.0
Total Peak Force mean post-pre difference for medium thrust BL&BR (SD) (SD)	18.66(26.02)	20.66 (23.22)	16.88 (29.58)	.61
Total Peak Force mean post-pre difference for medium thrust PLI-t & PRI-t (SD)	85.76(112.90)	79.94 (146.17)	90.94 (82.05)	.74

Avg, Average; Pre, Initial measurements near the beginning of the academic quarter; Post, Second measurements near the end of the academic quarter; Diff, Difference between pre and post; SD, standard deviation; P, posterior; I, inferior; t, transverse process: B (cervical vertebral body); L, left; R, right.

plotting the Peak Preload Force leaves room for error by not having the exact point where the preload ends and the thrust initiation begins. Total Peak Force was not altered due to it being the highest point when observing the force-time curve.

At the chiropractic institution where this research took place, there were 3 FSTT tables of different heights. Participants were allowed to choose which table they wanted to use for data collection. It is possible they chose different tables for the post assessment than the pre-assessment. To the authors' knowledge, intertable reliability of FSTT tables has not been previously studied and if there is variability in the FSTT tables measurements, this may have introduced a bias in the study results. Additional bias may be recall bias from students' self-reported out of classroom practice time. Due to the small sample size of students from one doctor of chiropractic program, this study also has limited generalizability.

For future research, having participants complete 3 repetitions of each thrust would allow examination of participants' ability to maintain a consistent delivery of their force. For replication of this study, including particular markers on mannequins will allow for less error in hand placement. For example, labeling T5 on the thoracic mannequin exactly where the participant should place their thenar pads and placing a dot exactly where the Handheld Tri-Axial Load Cell should be placed. Another consideration for future research could be utilizing a program that has the ability to select a lower threshold level for automatically calculating force-time parameters so there is less need for manual calculations, reducing the possibility of human error. The FSTT system currently does not have this capacity.

Longitudinal studies tracking students' progress over multiple academic terms could provide further insight into the long-term development of adjusting skills. Identifying which aspects of supplemental training contribute most to skill

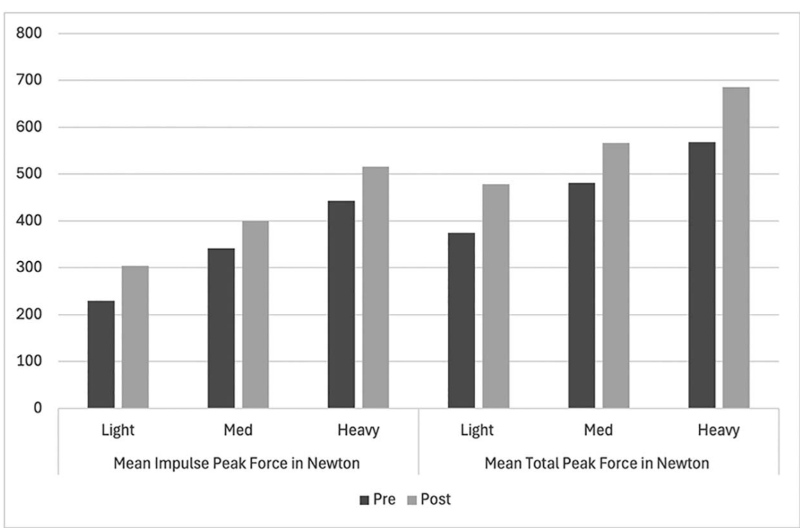

Figure 5 - Mean force characteristics of thoracic adjustments at the beginning (pre) and end (post) of an academic quarter (n = 17 students).

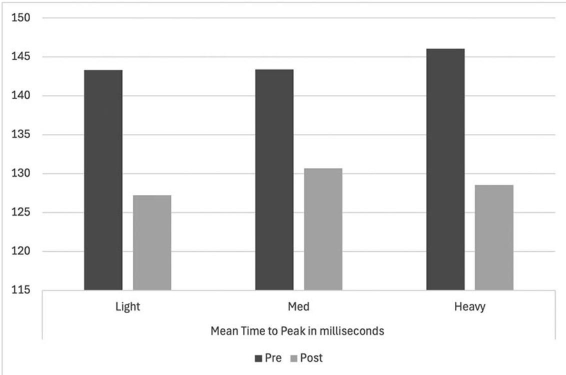

Figure 6 - Mean Time to Peak for thoracic adjustments at the beginning (pre) and end (post) of an academic quarter (n = 17 students).

improvement could help refine chiropractic education strategies and optimize student performance. Further investigation is also needed to determine whether different styles of practice yield distinct benefits. A more comprehensive understanding of the relationship between practice habits and skill acquisition may inform curriculum design and ensure students develop competency in delivering safe and effective chiropractic adjustments.

CONCLUSION

Using the FSTT in this doctor of chiropractic program, student changes in adjusting force-time parameters were documented over a single, 11-week academic term. Specifically, Time to Peak Force decreased for cervical medium thrust adjustments and thoracic light thrust adjustments, while Total Peak Force increased for light and medium thoracic thrusts. These observations are consistent with prior research. There was no statistically significant association between the amount of out-of-class practice and changes in force-time parameters. Future research with a larger sample size is needed to evaluate student characteristics associated with adjustment parameter changes.

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