EDUCATION
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ORIGINAL ARTICLE

Establishing force and speed training targets for lumbar spine high-velocity, low-amplitude chiropractic adjustments*

Edward F. Owens, Jr., MS, DC, Ronald S. Hosek, PhD, DC, MPH, Stephanie G.B. Sullivan, DC, Brent S. Russell, MS, DC, Linda E. Mullin, DC, and Lydia L. Dever, DC

Objective: We developed an adjusting bench with a force plate supporting the lumbar portion to measure loads transmitted during lumbar manual adjustment. It will be used to provide force-feedback to enhance student learning in technique labs. The study goal is to define the learning target loads and speeds, with instructors as expert models.
Methods: A total of 11 faculty members experienced in teaching Gonstead technique methods performed 81 simulated adjustments on a mannequin on the force plate. Adjustments were along 9 lumbopelvic "listings" at 3 load levels: light, normal, and heavy. We analyzed the thrusts to find preload, peak load, duration, and thrust rate.
Results: Analysis of 891 thrusts showed wide variations between doctors. Peak loads ranged from 100 to 1400 N. All doctors showed clear distinctions between peak load levels, but there was overlap between high and low loads. Thrust rates were more uniform across doctors, averaging 3 N/ms.
Conclusion: These faculty members delivered a range of thrusts, not unlike those seen in the literature for high velocity, low amplitude manipulation. We have established at least minimum force and speed targets for student performance, but more work must be done to create a normative adjustment to guide refinement of student learning.

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

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INTRODUCTION

Art might be considered as "the skillful application of science."[1] This perhaps is becoming truer for the healing art of chiropractic adjustments or manipulation. In recent years, many efforts have gone toward using technology to describe the loads applied to tissues during chiropractic adjustments, and then use this science to improve the adjusting art. Pressure-sensing pads and force plates have been used extensively to describe contact pressures and transmitted loads during real and simulated adjustments. The magnitude and speed of high-velocity, low amplitude (HVLA) adjustments have received the most attention, and we know the general load magnitude and rate of application by practitioners.[2–11]

It also is recognized that there is quite a bit of variability in these factors between different chiropractic techniques and even between different practitioners of the same technique.[3,6] Some work has been done to describe how loads differ when applied to various regions of the spine.[11]

Efforts are now underway to use force feedback in training to help standardize the delivery of adjustments in clinical trials[12,13] and in education. Early chiropractic education, where students are taught first to deliver manual thrusts, has been revolutionized by the addition of force and speed feedback and training devices.[14–20] Such devices can be used to enhance training by giving students more specific feedback than simple visual observation by teachers. It also has been recognized that students, typically practicing on each other in the teaching lab or clinic, sometime cause injury to each other.[21–23] Using devices and simulators early in student training may decrease the frequency of such injuries. Injuries due to tissue overload, for instance, may be avoided when training begins on a simulator.

Our college is engaged in the development of force-feedback systems for use in technique labs. The first device is an adjusting bench with a force plate supporting the lumbar portion. It will be used in the teaching lab to provide feedback to students on the loads they transmit

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Figure 1 - A photograph of the force plate in the lumbar section of the adjusting table. The force plate is mounted on rails attached to the table sides and isolated from other sections of the table. Table padding is removable.

during adjustments. The goal of this study is to define the target loads and speeds for students to aim toward, using their instructors as expert models. This first report will describe the equipment being used, methods for assessing the faculty, and ranges of loads and speeds measured for the specific techniques being taught for application in the lumbar spine and pelvis.

METHODS

Adjusting Bench

We built a special flat adjusting bench with rails in the side supports to securely mount an 18 × 20-inch force plate (Bertec model FP450-08; Bertec Corp, Columbus, OH) in 1 of 3 positions to measure loads on the cervical, thoracic, or lumbar regions. The force plate was isolated from the side rails and other sections of the table. For this study, the force plate was placed in the lumbar section of the table.

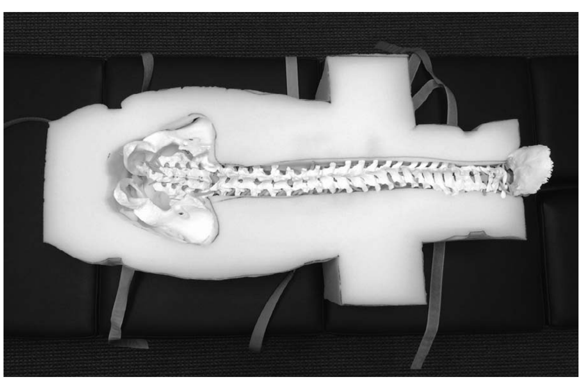

Figure 2 - The mannequin used in this study consisted of a block of 8-inch foam, roughly shaped like a human torso and hollowed out for placement of a plastic model spine. During use, the spine was covered with an additional layer of 2-inch foam, shaped identically to the base layer.

Foam pads were mounted to the individual sections to provide comfort (Fig. 1).

Target Mannequin

For this study we used a mannequin to simulate the human to be adjusted. The mannequin was a plastic spine and pelvis model enclosed in a sheath of high-density foam padding shaped roughly like a human torso (Fig. 2). Plastic landmarks, such as the posterior-superior iliac spine and spinous processes, were palpable through the foam and it could be placed in the prone or side-lying position. The mannequin allowed us to thrust many times on the same segment, by several adjustors, without concern for the effects of overadjustment. We measured the compliance of the mannequin to be approximately 0.028 cm/N.

When used for prone adjustments, the mannequin was placed in the center of the force plate in a prone position. All contact between the adjuster and mannequin was through the contacting hand, either a pisiform or palmar contact, and directed into the force-plate. For side posture adjustments, each adjustor started with the mannequin on its left or right side, depending on the side from which it would be adjusted. It also was placed closer to the table edge on which the adjustor stood. The adjustor could roll the mannequin forward using 1 hand on the upper portion of the mannequin (what would be a human's shoulder), and the other hand on the contact point on the spine or pelvis. The adjustor's upper thigh was allowed to provide a brace to control forward roll of the mannequin during the thrust. The adjustor's thigh also contacted the side-rail of the adjusting bench. Since the force plate was isolated from the side rail, some of the thigh force went into the table frame, but some also may have been applied to the force plate, through the mannequin. The stabilizing hand at the "shoulder" was not used in the thrust, and any load it contributed would have been over the solid portion of the adjusting bench and not in contact with the force plate. Hence, while the main force being measured during the side-posture adjustment was that produced by the adjusting hand on the lower part of the mannequin, we cannot rule out loads coming from the adjustor's stabilizing thigh contact.

Ethics Considerations

The institutional review board of Life University approved the study proposal and consent form. While no actual treatments were delivered, there was concern that individual faculty members might be judged by their performance on the system. Hence, we needed to provide for anonymity in the study design and avoid any association of individual adjustors with their data. We provided confidential reports to each doctor describing their adjustment factors in comparison with the mean of the group. The target population for the study was the classroom and lab teaching faculty members for the full-spine adjusting class. Those 16 faculty members were invited to attend an initial presentation of the study methods and equipment. Following the meeting, we scheduled those that volunteered to participate for a 30-minute data-recording session.

Data Collection

At each data collection session, the participant was shown the equipment and given a copy of the study consent form, which described the study aims, protocol, and risks. After any questions were answered, the consent form was signed. The participant also filled out a brief demographic survey with items for body morphology and practice experience.

To begin the recording, the experimenter calibrated the force plate to zero with the mannequin in place on the table so the weight of the mannequin did not contribute to measurement. Next, the experimenter set up the recording software (Bertec Acquire; Bertec Corp) to record continuously at 1000 points/s. The participant provided a series of 9 thrusts into the mannequin at a predetermined location and along a specific vector.

Vectors and contact points were derived by a "listing" drawn from the course materials and in the style of the Gonstead chiropractic adjustment technique.[24] Each "listing" is a shorthand representation of the direction of misalignment or fixation of the vertebral segment or pelvic structure that was the target of the adjustive thrust. The "adjustment" is a force with direction and location designed to counter the misalignment or reduce the fixation. For example, the Gonstead listing "PRI" describes a malposition of a vertebra from a theoretical ideal, relative to the bone below. The vertebra has undergone sagittal plane extension (P indicates "posterior-inferior"), transverse plane rotation (counterclockwise, if viewed from above, with "R" indicating the position of the spinous rotated to the right), and lateral bending to the right ("I" indicates that the right side of the vertebra is inferior, with respect to its left). The listing informs the doctor to provide a thrust in the opposite direction, presumably the optimal route to correct a restricted motion pattern (fixation). Likewise, a "PIEX" pelvic listing would indicate a malposition of an innominate bone, such that the posterior-superior iliac spine (a commonly used anatomical landmark) is relatively posterior, inferior, and externally flared from a theoretically neutral position relative to the sacrum and opposite innominate. The technique department faculty members use these listings daily in their teaching and are very familiar with them. These listings also are used to describe vertebral malposition on chiropractic national board exams. We chose a limited subset of lumbar and pelvic listings for the study.

There were 9 listings in all specifying a mannequin position (prone or side-lying), a segmental contact point on the spine or pelvis, the side to be adjusted, and the doctor's contact hand (right, left, or double hands and pisiform or thenar contact). To minimize the systematic effects of fatigue on the data collection, listings were presented to doctors in a random order. For each listing, the doctor was instructed first to thrust 3 times with what he or she considered a normal thrust, then 3 thrusts that would be considered "heavy" as might be applied to a large muscular patient, and then 3 "light" or low force thrusts as might be applied for a small or frail patient. We included these 3 load levels as a way to test the participants' abilities to control the force of their thrusts, anticipating that such control would be an important student training goal. Participants were allowed to move at their own pace through the thrusts and allowed to rest between listings as needed. All 9 thrusts for each listing were recorded in the same data file. In all then, with 9 listings performed, we recorded 81 thrusts per participant. Each recording session took less than 30 minutes.

As a follow-up to the recording session, we asked each participant to fill out an anonymous web-based survey to detect any adverse events and gauge the general acceptability of the simulated adjustment task. There were 5 questions on the survey: (1) How similar was adjusting the mannequin to adjusting a human? (2) How would you describe the compliance of the mannequin compared to a human spine? (3) Please describe any pain or discomfort you experienced during or after the simulated adjustments performed in the prone position. (4) Please describe any pain or discomfort you experienced during or after the simulated adjustments performed in the side posture position. (5) Do you have suggestions for ways to improve the mannequin or study design?

Data Reduction and Analysis

The force plate outputs forces and moments in 3 dimensions. We used a custom-designed and programmed software tool written in Microsoft Visual BASIC (Microsoft Corp, Redmond, WA) to first calculate a resultant force profile for each set of 9 thrusts from the x, y, and z force components. The software was written to detect the time of the relative maxima represented by each thrust peak, then locate relative minima that indicated other features of the thrust. The software took an initial guess at the locations of the peaks, but also allowed the user to tune the search for peaks to find all 9. We found the force and time for each of these events: the onset of preload, onset of thrust, peak load, and end of the thrust. We tabulated the software output in Microsoft Excel 2013 (Microsoft Corp) and used it to calculate the following thrust parameters: magnitude of preload, time from thrust onset to peak force, magnitude of peak thrust, rate of loading for middle one third of thrust, and time from peak load to resolution of thrust. We performed descriptive statistical analyses on these calculated factors to determine means and standard deviation of each participant at each listing and thrust level.

RESULTS

Of the 16 available faculty members, 11 consented to participate. Each recording session took less than 30 minutes and all collection was accomplished over a 2-week period. Table 1 summarizes the findings of the demographic survey. There were 4 female and 7 male participants, with a wide range of teaching experience (1–30 years) and practice experience (2–30 years).

Table 1 - Participant Demographics

	Females	Males
Count	4	7
Height, mean inches	63.5	71.8
Weight, mean pounds	183	194
Years in practice, mean (range)	10 (2–22)	21 (10–30)
Years teaching, mean (range)	7.5 (1–20)	11.8 (1–30)

All 891 thrusts were captured and subjected to analysis. Table 2 lists the specifics of the listings and shows the mean preloads, peak loads, and thrust rates for each listing with standard deviations. Mean peak loads ranged from as little as 339 N for "light" force side posture thrusts to 744 N for prone thrusts. The mean thrust rates ranged from approximately 2.3 to 5 N/ms.

Figures 3 and 4 show the mean and standard deviation of thrust magnitude and speed, respectively, for each doctor. The values were sorted by force of the normal thrust, from lower force on the left, to greater force on the right.

Only 6 of the 11 participants filled out the post-study survey. Four of 6 thought that adjusting the mannequin was somewhat similar to adjusting a human. When asked specifically about the mannequin's compliance, 3 thought the compliance of the mannequin was somewhat similar to human tissue, 1 thought it was more rigid, and 2 thought it was softer. Two participants noted hand and arm soreness or fatigue toward the end of the testing session. One participant verbally reported shoulder pain to 1 of the investigators a few days after a recording session, but no participants reported shoulder pain in the post-study surveys.

DISCUSSION

Our school has developed a hardware and software system capable of measuring transmitted loads during adjustments in the lumbar spine. In this initial study, we are using it to assess the loads delivered by teaching faculty in a simulated adjustment of a mannequin. The forces we recorded, on the average, were comparable to those reported in the lumbar spine by previous investigators. Downie et al[11] reviewed manipulative thrust forces and showed average transmitted lumbar forces across studies with similar measurement systems to range between 321 and 515 N for experienced practitioners. Our average light and normal thrusts (Table 2; prone, 379 N and 475 N, respectively; side-posture, 356 N and 433 N, respectively) were within this range, while the heavy thrusts were somewhat beyond. Similar to Forand et al,[6] we see a wide range of peak forces. While Forand et al[6] measured forces in the thoracic spine and saw peak loads between 200 and 800 N, we saw forces as high as 1400 N for Gonstead lumbar adjustments (Fig. 3); even that seemingly extreme value is not completely unprecedented, as Kirstukas and Backman[5] recorded a number of thrusts above 1200 N, and a few above 1300 N, in thoracic manipulation on human participants.

Table 2 - Measured Adjustment Force Parameters

Posn	Listing	SCP	Hand	Preload (N)			Peak Load (N)			Thrust Rate (N/ms)		
				Light	Normal	Heavy	Light	Normal	Heavy	Light	Normal	Heavy
Prone	PRI	L5 Mam	Both	148.2 (79.1)	175.8 (81.4)	175.7 (86.4)	381.9 (113.2)	528.8 (183.1)	744.1 (297.6)	2.46 (0.89)	2.92 (1.26)	4.31 (1.52)
	PLI	L5 Mam	Both	153.2 (76.6)	175.3 (64.3)	179.3 (82.7)	381.8 (125.8)	485.2 (152.0)	672.2 (253.0)	2.55 (1.03)	2.85 (1.16)	3.99 (1.31)
	P	Spinous	Rt	124.7 (72.7)	141.4 (76.6)	142.7 (80.1)	362.7 (183.0)	431.6 (179.5)	653.1 (299.3)	2.96 (1.78)	2.79 (1.17)	4.76 (3.27)
	PRS	Spinous	Lt	144.0 (75.6)	157.0 (74.4)	161.8 (90.9)	412.9 (270.3)	453.4 (158.8)	713.6 (319.8)	3.29 (3.05)	3.11 (1.08)	4.94 (3.38)
	PLS	Spinous	Rt	122.1 (85.9)	155.4 (83.7)	157.5 (95.5)	357.2 (130.2)	476.4 (165.6)	687.0 (291.7)	2.74 (1.12)	3.04 (1.22)	5.07 (2.70)
Average Prone				138.4 (78.2)	161.0 (76.6)	163.4 (87.3)	379.3 (173.4)	475.1 (169.4)	694.0 (291.3)	2.80 (1.79)	2.94 (1.19)	4.61 (2.62)
Side posture	PI-EX L	PSIS	Rt	91.5 (70.7)	101.2 (56.0)	98.4 (69.7)	357.7 (165.0)	429.1 (157.0)	594.6 (232.8)	2.29 (1.34)	2.69 (1.49)	4.65 (2.05)
	PI-EX R	PSIS	Lt	84.6 (61.1)	100.0 (55.7)	91.2 (63.4)	339.3 (159.9)	398.2 (118.9)	519.5 (165.7)	2.53 (2.30)	2.68 (1.02)	4.14 (1.63)
	AS-EX L	PostAcet	Rt	105.8 (51.5)	125.7 (59.8)	114.9 (62.4)	376.3 (156.5)	464.1 (188.8)	638.8 (215.4)	2.46 (1.32)	2.92 (1.37)	4.90 (2.10)
	AS-EX R	PostAcet	Lt	96.9 (67.4)	118.4 (76.3)	108.1 (71.7)	354.0 (119.3)	443.1 (149.8)	568.2 (178.6)	2.53 (1.43)	3.24 (1.89)	4.86 (2.36)
Average Side Posture				94.7 (62.9)	111.3 (62.8)	103.1 (66.8)	356.8 (150.1)	433.6 (155.7)	580.3 (202.4)	2.45 (1.65)	2.88 (1.49)	4.64 (2.07)

Preload and Peak load are in Newton (±SD). Thrust Rate is measured in Newtons/ms. Each cell represents the average of 33 data points, since each of 11 doctors provided 3 thrusts for each listing at each load level. Posn, mannequin position; PRI, posterior right and inferior; PLI, posterior left and inferior; P, posterior; PRS, posterior right and superior; PLS, posterior left and superior; PI-EX, posterior inferior and exterior rotation of ilium on left or right; AS-EX, anterior superior and external rotation of ilium on left or right; SCP, segmental contact point: L5 Mam, 5th lumbar mammillary process; PSIS, posterior inferior iliac spine; PostAcet, posterior acetabular ridge.

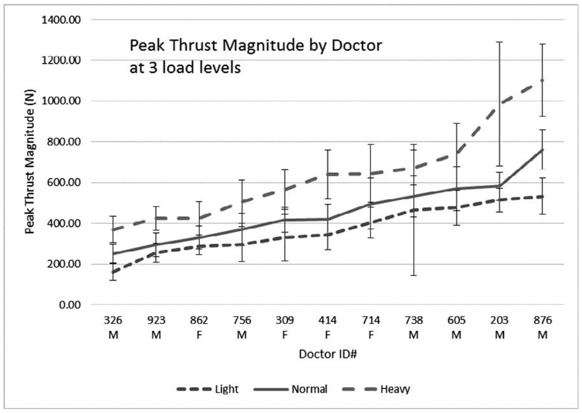

Figure 3 - Peak thrust magnitude by doctor, showing interdoctor variability. Peak thrust is shown in Newtons. Each data point represents the mean of 27 thrusts (3 thrusts of the same load at each of 9 listings). Error bars are 1 standard deviation. Sex is indicated by "F" or "M" beneath Doctor ID#.

Our results might be compared to those of Descarreaux and colleagues,[10] with means in the range of 500 to 600 N, but derived from very different methods. Those investigators also used a mannequin, but it was itself instrumented, with an internal strain gauge and a release mechanism based on force, in contrast to our table-mounted force plate, and the thrusts were meant to mimic thoracic spine manipulation. Recent work by Gudavalli and Rowell[13] should be noted, at least for their investigation of side posture manipulation. Their forces were mostly in the range of 300 to 400 N. Comparisons with our study should take into account that only 2 chiropractors were delivering thrusts to human participants, and that measurements were made with a force transducer placed between the chiropractor's hand and the patient's back. The measures of contact forces during HVLA thrusts reported by Van Zoest et al[7] were quite a bit lower in magnitude than those we measured, or those of other investigators.

There are clear differences in peak loads and thrust rates between the light, normal, and heavy loads (2-way analysis of variance [ANOVA] shows $p < .0001$ for both comparisons) in our sample. Thrust rates for light and normal thrusts are similar to each other, but heavy thrusts show larger thrust rates. It is interesting to note that the peak forces and speeds we measured for prone and side posture adjustments were similar to each other. Indeed, the profiles looked quite similar, even though, as mentioned, loads may have been transmitted to the force plate from the doctors' hips during the side posture adjustment. Preloads tend to be lighter in side posture and loads heavier in the prone (by as much as 100 N overall). It also was noticed that the standard deviations of the peak load and thrust rates are quite high. This is an indication of high variability between doctors.

It is clear from Figure 3 that doctors could control their thrusts to create distinctions between light, normal, and heavy loads. It also is clear that, while doctors were relatively consistent between listings (considering the relatively short error bars), they varied widely between doctors. For instance, the light thrusts by the 3 doctors that thrusted with the greatest peak load (lower trace, right-most points) is greater than the heavy thrusts generated by the 3 doctors that generally delivered lighter thrusts (upper trace, left-most points).

Sex may be a contributing factor to peak force. All 4 doctors with the highest loads were male; however, the 2 doctors with the lowest loads also were male. The female doctors tended to clump in the mid-range.

A similar analysis and charts of thrust rate with respect to individual doctors (Fig. 4) shows less variation between doctors. Within each doctor, light and normal thrusts have very similar rates, while heavy thrusts generally are faster. There is only a slight tendency for heavy adjusters (on the

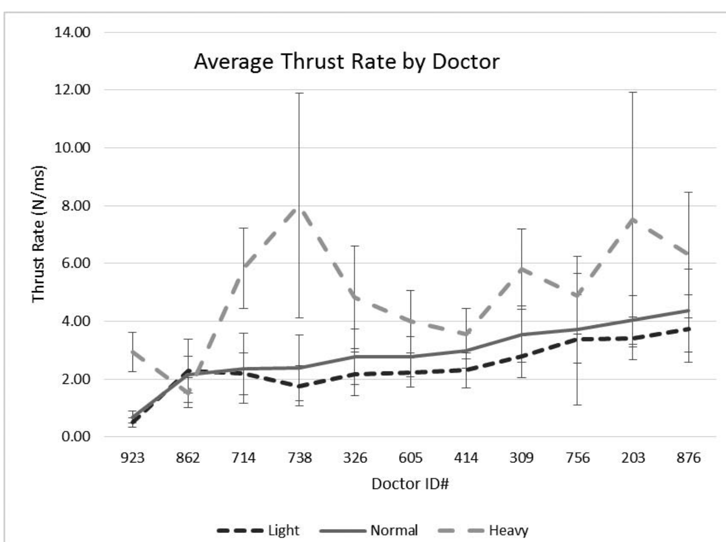

Figure 4 - Thrust rate by doctor, showing interdoctor variability. Thrust rate is shown in N/ms. Each data point represents the mean of 27 thrusts (3 thrusts of the same load at each of 9 listings). Error bars are 1 standard deviation.

right side of Figure 4) also to have faster thrusts. We have used rate of thrust, rather than thrust duration, as our primary measure of speed. It is important to distinguish this measure from thrust time, which will tend to be greater for heavier thrusts, simply because heavy thrusts cover more ground and would take longer.

Our intention was to use these results to help identify targets for student performance in technique labs. We could at least specify a minimum load: all doctors produced at least 100 N at the light load thrust and nearly 200 N at the normal load. We also could specify that students should be able to control their thrusts in such a way as to generate clear distinctions between light, normal, and heavy thrusts. The interdoctor variation makes it difficult at this time to specify what a maximum load should be. Thrust rate was more consistent between doctors with a mean of nearly 3 N/ms for the light and normal thrusts. This speed would be a good target for students to achieve.

There are several limitations to this study. This report only discusses the analysis of thrust magnitude and speed, without attention to the force vector. While our adjusting table is able to record the directional components of force and moment transmitted to it during a thrust, we did not analyze those components for this study. It will be presented later. Our next step will be to use the force and speed data and the equipment that generated it to develop more specific student goals in a consensus process among the teaching faculty.

The forces recorded with the mannequin in a prone position appear to have been generated solely by the adjustors' hands, but that is not the case for the side posture trials. Side posture adjustments typically involve multiple points of contact between the doctor's body and the patient's body; in our study, it appears that some of the adjustors' hips may have contacted the mannequin's pelvic region enough to have transferred some force to the force plate. We have not yet determined what percentage of the resultant thrust the hip movements might typically contribute. That there are dual sources does present an uncertainty for the goal of using force feedback in the teaching of side posture adjustments and deserves further investigation in the future.

A session of 81 thrusts over 30 minutes produced some fatigue and soreness in some of the practitioners. Since those sessions the adjustment table has been modified to add additional cushioning. Also, we should take care in the future in studies like this to allow more time between thrusts, or decrease the number and frequency of thrusts.

Finally, we assessed loads delivered into a mannequin, which has few characteristics in common with a live human. Even so, the participants generally felt that the adjusting experience was similar and that the mannequin compliance was acceptable. Although we cannot be certain that the loads truly represent what would be delivered in practice, our findings were similar to other reported measures of HVLA thrusts on humans. It would be infeasible to perform this study with so many thrusts on humans. The mannequin was asked to undergo 891 thrusts over a 2-week period. The table is suitable, however, for use with a human as long as the adjustments are limited in number or frequency.

CONCLUSION

The adjusting force measurement table developed at our school is a tool that can be used to assess transmitted adjustment loads in simulated tasks. It shows that the faculty teaching the chiropractic technique courses deliver a range of thrusts, not unlike those seen in the literature for other HVLA manipulations. We have established at least minimum force and speed targets for student performance, but more work must be done to create a normative adjustment to guide refinement of student learning.

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About the Authors

Edward Owens is an adjunct professor at the Dr. Sid E. Williams Center for Chiropractic Research of Life University (1269 Barclay Circle, Marietta, GA 30060; edward.owens@life.edu). Ronald Hosek is a staff research associate at the Dr. Sid E. Williams Center for Chiropractic Research of Life University (1269 Barclay Circle, Marietta, GA 30060; ronald.hosek@life.edu). Stephanie Sullivan is the director of the Dr. Sid E. Williams Center for Chiropractic Research of Life University (1269 Barclay Circle, Marietta, GA 30060; stephanie.sullivan@life.edu). Brent Russell is a professor at the Dr. Sid E. Williams Center for Chiropractic Research of Life University (1269 Barclay Circle, Marietta, GA 30060; brent.russell@life.edu). Linda Mullin is a professor in the chiropractic sciences division of Life University (1269 Barclay Circle, Marietta, GA 30060; mullin@life.edu). Lydia Dever is an associate professor and chair of the chiropractic sciences division of Life University (1269 Barclay Circle, Marietta, GA 30060; ldever@life.edu). Address correspondence to Edward Owens, 1269 Barclay Circle, Marietta, GA 30060; edward.owens@life.edu.

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Author Contributions

Concept development: EO, RH, SS, BR, LM, LD. Design: EO, RH, SS, BR, LM, LD. Supervision: EO, SS. Data collection/processing: RH, SS, BR, LM, LD. Analysis/interpretation: EO, RH. Literature search: EO, BR. Writing: EO, RH, SS, BR, LM, LD. Critical review: EO, RH, SS, BR, LM, LD.

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