ORIGINAL ARTICLE

Changes in adjustment force, speed, and direction factors in chiropractic students after 10 weeks undergoing standard technique training

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Objective: To assess the force profiles of high-velocity low-amplitude thrusts delivered to a mannequin on a force platform by novice students given only verbal instructions.
Methods: Student volunteers untrained in adjusting delivered a series of adjustments to a mannequin on a force platform. Participants performed 3 light, 3 normal, and 3 heavy thrusts on 5 listings specifying contact point, hand, and direction. Force profiles were analyzed for speed and amplitude, consistency, and force discrimination. Two recording sessions occurred 10 weeks apart.
Results: Sixteen participants (11 females, 5 male) completed the study. Peak forces ranged from 880 to 202 N for heavy thrusts and 322- to 66 N for light thrusts. Thrust rate was from 8.1 to 1.8 Newtons per millisecond. Average coefficients of variability (CV = STD/mean) at each load level (initial/final) were heavy: 17%/15%; normal: 16%/15%; and light: 20%/20%, with 0 as ideal. A force ratio measured students' abilities to distinguish thrust magnitude. The heavy/normal ratio (initial/final) was 1.35/1.39, and the light/normal ratio was 0.70/0.67.
Conclusions: At this point, without force feedback being used in the classroom, novice students can produce thrusts that look like those of their teachers and of experienced practitioners, but they may not produce similar speed and force values. They are consistent within and between sessions and can discriminate between light and heavy loads. A natural next step in our educational research will be to measure adjustment factors on more experienced cohorts of students with and without the presence of force-feedback training apparatus.

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

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INTRODUCTION

It is generally agreed that chiropractors, as well as therapists who practice manipulation, need highly developed skills in performing high-velocity low-amplitude (HVLA) manual thrusts.[1] A significant portion of the curriculum at our college is devoted to developing those skills.

Various tools have been developed for measuring force and speed of manual thrusts in humans and in simulated settings and in a variety of techniques.[2–14] More recently, those same tools are being used to augment the learning in chiropractic colleges in the United States and abroad,[11,15–24] and in physical therapy programs as well.[25]

Preload, peak loads, and speed have all been suggested as important performance factors. Loranger et al,[26] for example, found first-year students to produce lower preload forces, lower peak forces, and slower thrusts as compared to students later in a doctor of chiropractic program and to experienced chiropractors. Short-term effects of force feedback in training have been shown, including increasing force production and increasing speed.[27] Descarreaux et al[10] also looked at coordination, comparing the hand thrust to other kinematics of the body.[23,24] Directional control of the thrusts has seen less attention, although it is considered an important factor in HVLA adjusting.[1]

Comparisons between schools have shown longer-term effects that seem to accrue from differing educational programs.[25] The learning process has been shown to be complex, involving different rates of improvement for different adjustment factors. Descarreaux and Dugas[28] found that force production improved more rapidly than did speed. Automaticity—that is, the ability to deliver forces consistently as an automatic habit—takes even longer to acquire.[28] Sophisticated experimental studies have used table placement or support instability to show adaptability of the thrusting mechanisms.[23] The ability of learners to control thrust magnitude is considered important.[24] It is still not clear whether the introduction of force feedback improves overall manual skills or clinical success. We cannot say for certain how the force parameters of any manual therapy procedures determine clinical effects.

Our school developed a system to measure adjustment loads and is introducing force-feedback tools into early technique courses. We carried out 2 previous studies assessing faculty performance of HVLA adjustments on a mannequin as a way to develop training targets for student achievement.[29,30]

The conclusions from 2 previous studies were that faculty provide a wide range of adjustment loads, but there is a generally consistent thrust rate of over 3 Newtons per millisecond (N/ms). Faculty can clearly control their force application when asked to provide light or heavy thrusts.[29] They can control direction of thrust, demonstrating clear medial-to-lateral vectors for single-hand prone lumbar thrusts.[30]

For this current study, we used the same equipment as the 2 previous studies to assess the abilities of students at baseline, that is, under the current educational scheme. Later, these results will be compared to those found in cohorts of students that have used force-feedback training to determine if any benefit accrues.

METHODS

We built a special flat adjusting bench incorporating an 18×20-inch force plate (Bertec model FP4550-08; Bertec Corp, Columbus, OH) spanning the lumbar section. Forces transmitted to the bench can therefore be analyzed 3-dimensionally in an x-y-z coordinate system, with a vertical component (z), a left-right component (x), and an inferior-superior component (y). Bench height is adjustable to participant preference. The bench has upholstery similar in appearance to other benches of this common type, except that individual sections can be removed to access the force plate.

We used a mannequin composed of a plastic spine and pelvis model enclosed in high-density foam padding to simulate a human torso (Adjust-ease; AdJustWorld, Johnson City, TN). These mannequins are used in seminars for teaching chiropractic adjustment techniques. Skeletal landmarks are palpable through the foam. We measured the compliance of the mannequin to be 0.028 cm/N. The mannequin allows many thrusts on the same segment without concern for injury.

The college's institutional review board approved the study proposal and consent form. We provided for anonymity in the study design to avoid association of individual adjustors with their data. The target population for the study was the cohort of students at the end of the Full Spine 2 technique course, offered in quarter 6 of the 14-quarter program. These students are just learning the Gonstead listing system[31] and how to set up for adjustments. They do not have experience in performing adjustments beyond having been allowed to perform a limited number of trial thrusts on each other during labs. No force-feedback devices have been utilized in their training.

Data Collection

We measured students' thrusts as close as practical to the beginning and the end of a quarter, 9–10 weeks apart. At the initial data collection session, the participant received an explanation of the procedures, signed a consent form, received a randomized study ID number, and provided information about their height, weight, and sex. The experimenter set up the system (Bertec Acquire; Bertec Corp) to record continuously for a series of 9 thrusts into the mannequin. Each set was delivered with one of 5 listings drawn from the course materials, which specified a segmental contact point on the spine, the side to be adjusted, and the doctor's contact hand (Table 1). All listings for this study were for prone adjustments, and they were presented to students in a random order. Students were allowed practice thrusts to become accustomed to the mannequin. They were then instructed to first thrust 3 times with a normal thrust; then 3 thrusts that would be considered heavy, as might be applied to a large or muscular patient; and then 3 light thrusts, as might be appropriate for a small or frail patient. All 9 thrusts were recorded in the same data file. In all, with 5 listings performed, we recorded 45 thrusts per participant over a 15-minute session.

Data Reduction and Analysis

We used a custom-programmed software tool to split each data stream of 9 thrusts into individual thrusts, extracting time and force information for characteristic features. The force plate outputs forces and moments in 3 dimensions at 1000 points per second. We calculated the resultant force from the 3 force components and found the force and time for these events: the preload onset, thrust onset, peak load, and end of thrust. The software tool could detect many of these points using algorithms for relative maxima and minima, but allowed for manual selection when the force-time profile was unusual.

We tabulated the software output in Excel 2013 and used it to calculate additional thrust parameters: preload magnitude, magnitude just prior to thrust onset (often a brief force decrease, or "valley"), time from thrust onset to peak force, magnitude of peak thrust, rate of loading for the middle one-third of thrust (from linear regression), and time from peak load to resolution of thrust. We performed descriptive statistical analysis on these calculated factors.

We chose the 3 prone 5th-lumbar single-hand (SH) listings, posterior (P), posterior-right-superior (PRS), and posterior-left-superior (PLS), to analyze further for directionality because there should be a single, common location for force application. For thrusts performed with a double thenar maneuver posterior-right-inferior (PRI) and posterior-left-inferior (PLI), our equipment cannot separate the force and direction components of the left hand from the right hand, so the vector is more difficult to interpret. Our interests in looking at force vector are to assess whether students are capable of controlling the x- and y-components (left-right and inferior-superior) of the adjustment according to the lines of drive indicated by the listings. Following a method previously developed for a study of faculty thrusts,[30] the 3-dimensional component forces of the transmitted load were divided by the resultant

Table 1 - Details of Instructions Provided to Student Participants for Adjustment Setups.

Method	Listing	Segmental Contact Point	Doctor's Stance	Contact Point
Double thenar	L1, PRI	Left mammillary process	Stand on the left	Left thenar
Double thenar	L1, PLI	Right mammillary process	Stand on the right	Right thenar
Single hand	L5, P	Inferior aspect of spinous process	Stand on the right	Left hand
Single hand	L5, PRS	Right side of spinous process	Stand on the right	Left hand
Single hand	L5, PLS	Left side of spinous process	Stand on the left	Right hand

Students have previously been taught in classes that a double thenar adjustment involves thrusts from both hands simultaneously, but with emphasis on one side (designated the "contact point"). What is referred to as "single hand" is sometimes called "single-hand pisiform"; students have been taught that the contact point is the volar aspect of the hand overlying the pisiform bone and hook of the hamate. PRI, posterior-right-inferior; PLI, posterior-left-inferior; P, posterior; PRS, posterior-right-superior; PLS, posterior-left-superior with reference to the Palmer-Gonstead-Firth listing system.

force magnitude to produce unit vectors with respect to time for each force component. This gives us a way to look at thrust direction independent of its changing magnitude during the thrust. We calculated the average magnitude of each component over 4 time periods during each thrust: the preload phase, the first one-third of the thrust phase, the middle one-third, and the final one-third of the thrust, ending with the peak force.

RESULTS

While 28 students provided initial recordings, only 16 completed the follow-up session due to scheduling difficulty during finals week. This report will focus on those 16 with complete data sets. Our sample included 11 females and 5 males; all but 1 female were right-handed. The females averaged 1.7 m in height (+/−0.1; range, 1.5–1.8 m) and weighed an average of 62.1 kg (+/−11.7; range, 50.9–90.9 kg). Males averaged 1.8 m in height (+/−0.1; range, 1.7–1.9 m) and weighed an average of 96.9 kg (+/−24.7; range, 75.0–138.6 kg).

Table 2 provides summary values for preload and peak forces. In the initial session, preloads ranged from as little as 3 N (4.45 N = 1 pound) to as high as 169 N. The final session preloads were mostly similar, but with one individual reaching 208 N. On average, in both sessions the men used somewhat heavier preloads than the women. During thrusts, peak forces in the initial session ranged from as little as 66 N for a set of light thrusts to as high as 879 N for a set of heavy thrusts. The final session peak forces were, on average, slightly more forceful. In both sessions men averaged slightly higher peak forces than women. The same male individual who produced the largest peak force in the initial session (879 N) also generated the final session maximum of 1020 N.

Table 3 provides summary values for thrust rates. More forceful thrusts were associated with faster thrust rates, with only 1 exception. Men were generally faster than women, though the differences were small for normal thrusts and negligible for light thrusts.

Table 4 provides summary values for thrust direction factors (unit vectors) for the 5th lumbar SH thrusts. Positive PLS-x values indicate thrusts from left to right, while negative PRS-x and P-x values indicate thrusts from right to left. Negative SH-y values indicate thrusts from inferior to superior.

Figures 1 and 2 show plots of factors that indicate students' abilities to control force magnitude. As a measure of consistency we used the CV at each load range (heavy, normal, and light) for each student (Fig. 1). The CV is the SD divided by the mean, thus scales the SD to the mean, and results in a percentage that is useful in comparing variability of data sets with large differences in means. An ideally consistent set of thrusts would have a CV of 0 since the SD of a set of identical numbers equals 0. The average CV factors for all students at baseline were: heavy, 17%; normal, 16%; and light, 20%. At the end of the quarter, the average CVs were heavy, 15%; normal, 15%; and light, 20%. These roughly indicate a 15%–20%

Table 2 - Group Preload and Peak Forces (in Newtons) for the Initial and Final Assessment Sessions: Means (SD) and Ranges

	Initial Assessment			Final Assessment		
	Heavy	Normal	Light	Heavy	Normal	Light
Female (*n* = 11)						
Preload	47 (29)	27 (47)	43 (27)	26 (42)	36 (26)	29 (36)
Peak	378 (132)	295 (103)	209 (82)	412 (106)	305 (75)	205 (73)
Male (*n* = 5)						
Pr-load	78 (38)	35 (78)	70 (35)	36 (72)	66 (36)	38 (66)
Peak	528 (219)	355 (105)	243 (66)	559 (278)	376 (142)	255 (110)
All (*n* = 16)						
Preload	57 (35)	33 (57)	51 (33)	33 (51)	45 (33)	35 (45)
Peak	425 (178)	314 (107)	220 (79)	458 (191)	327 (106)	221 (89)

Calculations represent 15 thrusts for each participant (3 thrusts for each of 5 listings).

Table 3 - Thrust Speeds for the Initial and Final Assessment Sessions

	Initial Assessment (N/ms)			Final Assessment (N/ms)		
	Heavy	Normal	Light	Heavy	Normal	Light
Female average	2.6 (1.1)	1.9 (0.8)	1.3 (0.6)	2.8 (1.2)	2.0 (1.0)	1.3 (0.7)
Male average	3.8 (2.4)	2.2 (1.1)	1.3 (0.6)	3.9 (2.3)	2.3 (1.1)	1.5 (1.1)
All	3.0 (1.7)	2.0 (0.9)	1.3 (0.6)	3.2 (1.7)	2.1 (1.0)	1.4 (0.8)

Each cell presents the mean and SD of 15 thrusts (3 thrusts for each of 5 listings).

variability between an individual student's 15 thrusts at the same load level (3 thrusts for 5 listings).

We used a normalization calculation to assess student's abilities to control force well enough to distinguish heavy from normal and light thrusts (Fig. 2). The heavy/normal ratio was 1.35 initially and 1.39 at the end of the quarter, and the light/normal ratio was 0.70 initially and 0.67 at the end. The values indicate that students produced on average 35%–39% more force when asked to provide heavier than normal thrusts, and decreased their forces to around 70% or less for light thrusts. Figure 2 shows how those control factors varied across students, loads, and time periods.

DISCUSSION

Our ability to collect follow-up data was hampered by scheduling difficulties around examinations at the end of the quarter. We did not compare the recordings of students who attended only the session early in the quarter to those who completed both. Thus, we do not know if the missing follow-ups contributed any bias to the findings.

It is important to note that the students in this study are very much novice adjusters with little experience thrusting on people or mannequins. As in our previous studies of faculty adjustment thrusts, we see a wide range of peak loads for student adjustments. As in the faculty study, some of the students' light thrusts were in fact larger than other student's heavy thrusts. Males produced more than 200 N more thrust on the average than females at the heavy load level, but nearly the same for normal thrusts. If 200 N were considered a minimum threshold for training purposes, then all but 1 student achieved this criterion at the beginning of the term for normal thrusts and all but 2 achieved it at the end. All but 1 of the students generated more than 200 N force for heavy thrusts. Thus, they are capable of reaching a 200 N minimum, but perhaps lack a sense for what should be normal.

Thrust rates ranged from 0.3 to 2.0 N/ms for light thrusts and from 1.8 to 8.1 N/ms for heavy thrusts; the participant who generated the maximum peak forces also produced the fastest rate. If anything, students show an increase in thrust rate toward the end of the quarter. Were we to consider 3 N/ms as a threshold for accomplishment of a "fast-enough" thrust, then only 1 student passed that criterion at the beginning of the term for normal thrusts; but for heavy thrusts, 7 of 16 had thrust rates faster than 3 N/ms. At the end of the term, only 2 students had rates faster than 3 N/ms for normal thrusts. This student group did not demonstrate an ability to control thrust speed and amplitude separately.

Table 4 indicates important directional components of student thrusts. The most significant proportion of all thrusts was in the posterior-to-anterior direction (z in our coordinate system). The z-components (SH-z in Table 4) averaged 0.97, while x- and y-components of the unit vector were much smaller. Nevertheless, we were able to detect differences in the nonvertical components with respect to listing.

The PRS and PLS listings have opposite setups: while both have a lateral-to-medial component of the thrust, these should come from opposite directions. Almost all students show clear directional differences between the PRS and PLS lateral-to-medial components (PRS-x and PLS-x in the table). However, the P thrusts had a lateral-to-medial component (right-to-left in this study) that they theoretically should not have. For purposes of student-to-student consistency, students were instructed to stand on the right side for P listings. Despite the fact that their thrusts should theoretically not have any left-right or right-left direction, most of their thrusts showed a negative x—indicting that they were thrusting from right to left, which may be related to their standing on the right side. Also, overall the SH thrusts show an inferior-to-superior

Table 4 - Unit Vector Components for Direction in Thrusts on the L5 Segment

	Initial Assessment					Final Assessment				
	PLS-x	P-x	PRS-x	SH-y	SH-z	PLS-x	P-x	PRS-x	SH-y	SH-z
Female average	0.10	−0.10	−0.11	−0.07	0.98	0.09	−0.08	−0.12	−0.10	0.98
Male average	0.17	−0.10	−0.11	−0.02	0.98	0.05	−0.14	−0.12	−0.14	0.97
All	0.12	−0.10	−0.11	−0.06	0.98	0.08	−0.10	−0.12	−0.12	0.97

See Table 1 for details of the PLS, PRS, and P adjustment setups. Each value is the average for all setups of that listing, merging together directions for the heavy, normal, and light thrusts. PLS-x, P-x, and PRS-x are the x components of the unit vector for each of the 3 listings. A positive x value indicates that a thrust was directed from left to right; negative x indicates right to left. The SH-y values are averages of all single-hand thrusts in that assessment session, that is, the pooled y-component for all 3 listings; the negative y-values indicate that thrusts were primarily directed from inferior to superior. SH-z is the z-component (P to A) of all listings pooled.

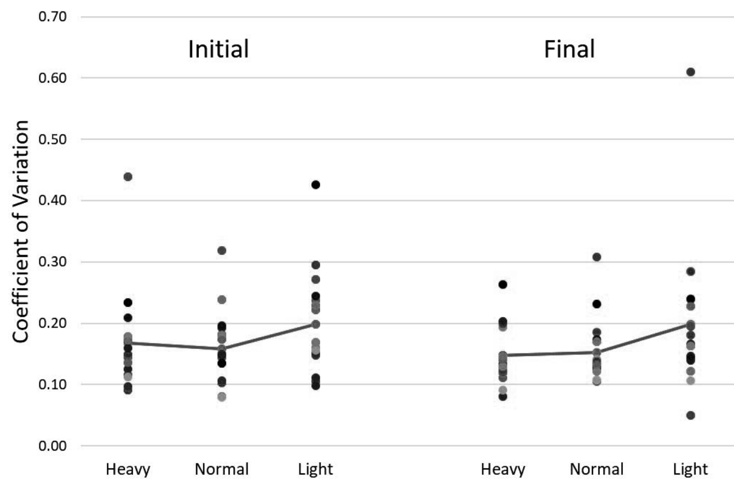

Figure 1 - Consistency measured by CV. (CV = average of peak thrust magnitude at each force level across all listings/SD of those thrust magnitudes). Each dot represents the calculated factor for 1 student. Lines indicate mean across all students.

component (negative SH-y), which is consistent with how they are taught at their level in school.

We should note that some authors have suggested that the only important component of a thrust is that which is perpendicular to the surface of the body part to which it is applied.[32,33] Bereznick et al[32] postulate that no force impinging on the skin surface can have anything but a force component perpendicular to the skin surface due to the very low friction between the skin and underlying tissues. These analyses certainly challenge some of the fundamental principles of the Gonstead technique, which teaches the importance of line of drive away from the vertical. The fact that we were able to measure forces transmitted through our mannequin that were not only P to A cannot settle the issue since our mannequin does not truly have a frictionless skin interface. It is our intent to evaluate what actually was done, not what should be done or what is most mechanically effective.

The ability of students to repeatedly provide consistent thrusts was measured by CV. The values we found ranging between 15% and 20% are higher than we found in a secondary analysis of faculty thrusts from our previous study,[29] in which faculty members' heavy thrusts had CVs of only 12%, 13% for normal thrusts, and 16% for light thrusts. The student values are inflated by a few individuals having CVs in the range of 30%–60%, while no faculty members had values above 25%. However, many students were very consistent, with more than half having CVs of less than 15% for heavy thrusts. In both groups, variability is much greater for light thrusts. Part of this variability was the product of a few individuals with highly variable light thrusts, and partly it is a mathematical feature of the calculation itself, which places the thrust magnitude (mean peak force) in the denominator. Mean peak forces are smaller for lighter thrusts, therefore lighter thrusts tend to produce larger CVs.

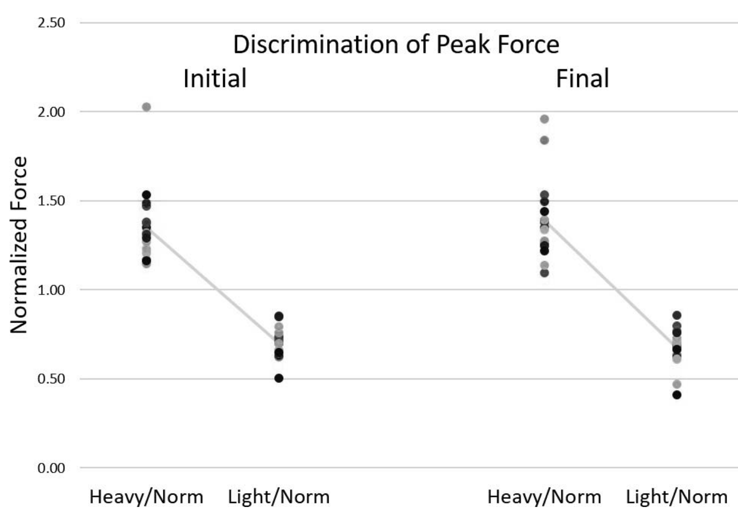

Figure 2 - Discrimination measured by normalized peak force. High/normal is calculated by dividing the high-force peak magnitude by the normal thrust peak load. Light/normal is calculated by dividing the low-force peak magnitude by the normal thrust peak load. Each dot represents the calculated factor for 1 student. Lines indicate mean across all students.

In any case, student CVs were lower at the end of the term, indicating an increase in consistency.

In terms of force discrimination, only 2 students produced more than 1.5 times their normal thrust when asked to perform heavy thrusts. Ten of 16, however, could drop their light thrusts to less than 70% of their normal thrusts. The average increases of 35% and 39% for heavy thrusts (beginning and end of term, respectively) were lower than we found in our secondary analysis of faculty members, who displayed an average of 49% more force in heavy thrusts. However, the students' light thrusts, at 70% and 67% (beginning and end of term, respectively), were less forceful than those of the faculty members, whose average light thrusts were 77% of normal.

Our use of these measures of consistency and discrimination is new, and these measures have not been considered to be important criteria in the past. Triano et al[24] have recently published work looking at consistency and discrimination. They used an experimental design, however, and asked participants to deliver twice their normal thrust, or half of it, and provided feedback to help train this ability. We consider the ability to control thrust magnitude and speed to be important training targets but have not yet created criteria to target.

Others have developed detailed criteria to grade student's performance of adjustments. One recent work used an expert to judge performance based on 12 criteria.[34] Three of the criteria judged adjustment force and speed and direction, but these were not measured, only assessed by the judge. We are moving toward using measured force feedback in a formative setting, giving student feedback and pointing toward target values.

CONCLUSION

At this point, without force feedback being used in the classroom, novice students can produce thrusts that look like those of their teachers and of experienced practitioners, but they may not produce similar speed and force values. They are, however, somewhat consistent within and between sessions and are able to discriminate between light and heavy loads. A natural next step in our educational research will be to measure adjustment factors on more experienced cohorts of students with and without the presence of force-feedback training apparatus.

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