# Comparison of Mechanical Force of Manually Assisted Chiropractic Adjusting Instruments

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## Abstract

**Objective:** To quantify the force-time and force-delivery characteristics of six commonly used handheld chiropractic adjusting devices.

**Methods:** Four spring-loaded instruments, the Activator Adjusting Instrument; Activator II Adjusting Instrument, Activator III Adjusting Instrument, and Activator IV Adjusting Instrument, and two electromechanical devices, the Harrison Handheld Adjusting Instrument and Neuromechanical Impulse Adjusting Instrument, were applied to a dynamic load cell. A total of 10 force-time histories were obtained at each of three force excursion settings (minimum to maximum) for each of the six adjusting instruments at preload of approximately 20 N.

**Results:** The minimum-to-maximum force excursion settings for the spring-loaded mechanical adjusting instruments produced similar minimum-to-maximum peak forces that were not appreciably different for most excursion settings. The electromechanical adjusting instruments produced short duration (~2-4 ms), with more linear minimum-to-maximum peak forces. The force-time profile of the electromechanical devices resulted in a more uniform and greater energy dynamic frequency response in comparison to the spring-loaded mechanical adjusting instruments.

**Conclusions:** The handheld, electromechanical instruments produced substantially larger peak forces and ranges of forces in comparison to the handheld, spring-loaded mechanical devices. The electromechanical instruments produced greater dynamic frequency area ratios than their mechanical counterparts. Knowledge of the force-time history and force-frequency response characteristics of spinal manipulative instruments may provide basic benchmarks and may assist in understanding mechanical responses in the clinical setting. (J Manipulative Physiol Ther 2005;28:414-422)

**Key Indexing Terms:** *Biomechanics; Chiropractic; Spine*

Spinal manipulation is the most commonly performed therapeutic procedure provided by doctors of chiropractic.[1] Chiropractic techniques have evolved to provide the clinician with choices in the delivery of particular force-time profiles deemed appropriate for a patient or condition. Clinicians rely on mechanical advantages in performing spinal manipulation through patient positioning, mechanical assistance from a table, or handheld instruments.[2] Specifically, manual articular manipulative and adjusting procedures have been classified into four categories to better describe the technique and mechanism of force production: specific contact thrust procedures using

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**Fig 1.** *Mechanical force manually assisted chiropractic adjusting instruments. (L-R) The AAI, AAI 2, AAI 3, AAI 4, HAI, and NMI.*

high-velocity, low-amplitude (HVLA) thrusts; nonspecific contact thrust procedures (ie, mobilization); manual force, mechanically assisted procedures (ie, drop tables or flexion-distraction tables); and mechanical force, manually assisted procedures (MFMA; ie, stationary or handheld instruments).[3] Mechanical force, manually assisted procedures have been reported to be the second most popular chiropractic adjusting technique, used by 72% of chiropractors on 21% of their patients.[4]

Spinal manipulative techniques have been studied for their clinical effectiveness.[5,6] The majority of randomized controlled clinical trials in patients with low back pain, neck pain, and headache[7-12] have been conducted using HVLA thrusts. Studies have also compared HVLA to MFMA procedures.[13-15] Although clinical outcome studies have gained attention, basic experimental investigations that might assist in explaining biomechanical mechanisms are lacking.[16] Quantifying the characteristics of chiropractic technique is a logical and important first step in understanding a spinal manipulative procedure.

Consequently, a number of studies have investigated the forces produced during a variety of spinal manipulative procedures.[17-24] In one of the earliest reported comprehensive studies, Kawchuk and Herzog[23] analyzed the force-time profiles of several HVLA and MFMA cervical spine mani pulation (lateral break, Gonstead, Activator, toggle, rotation). Their methods, however, did not include a detailed description of the data sampling procedures, and, as pointed out previously,[18] it is possible that the MFMA results reported by these authors were inaccurate. Keller et al[18] examined both the force-time and force-frequency response of the handheld Activator II Adjusting Instrument (AAI 2, Activator Methods International, Ltd, Phoenix, Ariz). The AAI 2 is a unique MFMA-type device in that it produces a very short duration (<5 ms) impulsive-type force. As a result, analysis of the force-time response requires precise triggering and high-speed data sampling to accurately record the force-time history.

To improve the force-frequency characteristics of the spring-loaded AAI, the AAI 2, AAI 3, and AAI 4 have been developed.[25] Little biomechanical data exist on the AAI, and no study to date has reported the force-time and force-frequency characteristics of the AAI 3 or AAI 4. In addition, over the past several years, other handheld MFMA-type devices, most notably the Harrison Handheld Adjusting Instrument (HAI) (Harrison CBP Seminars, Evanston, Wyo) and the Neuromechanical Impulse Adjusting Instrument (NMI) (Neuromechanical Innovations, Phoenix, Ariz), have been developed for chiropractic treatment. The purpose of this study was to compare the force-time history, force-frequency response, and force-delivery characteristics of these six commonly used handheld spinal manipulation devices.

## Methods

Two different experiments were performed to investigate the mechanical characteristics of six commonly used MFMA chiropractic adjusting/spinal manipulative tools—a shuttlecock flight experiment and a standard bench-type force calibration test. Initially, a shuttlecock experiment was conducted to compare a handheld, spring-activated mechanical adjusting instrument (AAI 2) and a handheld, solenoid-driven electromechanical device (HAI) at the Biomechanics Laboratory at the Department of Sciences of Physical Activity, Universite du Quebec a Trois-Rivieres, Trois-Rivieres, Quebec, Canada. At the time of the shuttlecock experiment, these two instruments represented the latest versions of handheld adjusting instruments available from their respective manufacturers. The AAI 3 or AAI 4 (Activator Methods International) and the NMI were not available in the marketplace at the time of the shuttlecock experiments. Inasmuch, after the release of these two devices, further mechanical tests were conducted, namely, standard bench-type force calibration tests on all six chiropractic adjusting instruments, the AAI, AAI 2, AAI 3, AAI 4, HAI, and NMI (Fig 1).

### Shuttlecock Flight Experiments

The AAI 2 and HAI devices were compared using a video analysis of shuttlecock experiment. Each instrument was attached solidly to a table and oriented vertically (Fig 2). A shuttlecock ($m$ = 4.8 g) was placed over the stylus of each instrument, and the instrument was engaged to fire

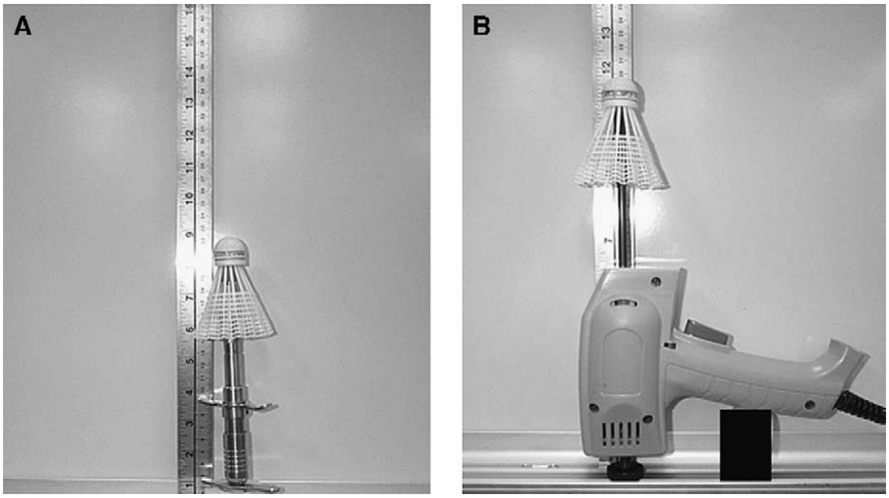


**Fig 2.** *The AAI 2 (A) and HAI (B) were attached rigidly and vertically to a frame with a ruler in the background. A shuttlecock was ejected by these instruments, and the height of flight in centimeters and the duration of flight in seconds were measured by video.*

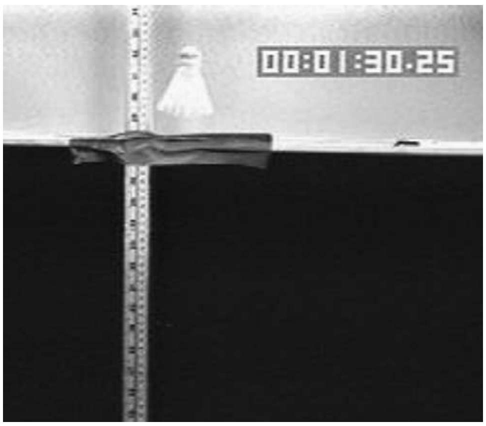


**Fig 3.** *Projectile height of the shuttlecock was measured against a ruler background from videotape with a time sequence subsequent to each thrust.*

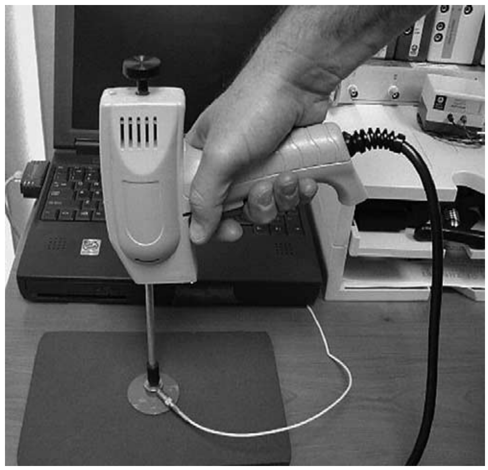

**Fig 4.** *Bench test experiment setup. The HAI is shown contacting a table top mounted load cell.*

to project the shuttlecock as a projectile. A metric ruler was fixed in the background and a high-speed video camera (model WV-CL350, Peak Performance Technologies, Inc., Englewood, Colo) was placed 2 m from the table and perpendicular to the direction of the moving object to record the flight paths of the projectiles.

The flights of the shuttlecock projectiles were recorded at a frame rate of 60 Hz using a Panasonic AG-1960 (modified for 120 Hz recording) video recorder. An SMPT time code was added to the film by means of a HORITA time code generator (model: RM-50 II, Mission Viejo, Calif). Height measurements and time codes were recorded for beginning (origin) and at the maximum height of the shuttlecock projectiles (Fig 3). Total flight height was obtained by subtracting the height of origin from the maximum trajectory of the shuttlecock. Flight times were obtained from the corresponding time codes.

### Bench Test Experiments

Force-time profiles of the AAI 2 and HAI and three additional spring-loaded devices, the AAI, AAI 3, and AAI 4, and another electromechanical device, NMI (Fig 1), were tested by means of thrusting into a dynamic load cell (PCB model 200A02, PCB Piezotronics, Depew, NY) rigidly mounted to a table top (Fig 4). A constant current amplifier (PCB model 483A02) was used to acquire the dynamic force-time histories. The load cell force range and resolution were 445 and 0.0089 N, respectively. The load cell has a low-frequency and high-frequency response of 0.001 and 75 000 Hz, respectively. Ten force-time histories were obtained from each of the six chiropractic adjusting instruments at each of three force settings and a preload of approximately 20 N. Forces were sampled at 32 768 samples per second over a period of 0.5 seconds using a 16-bit

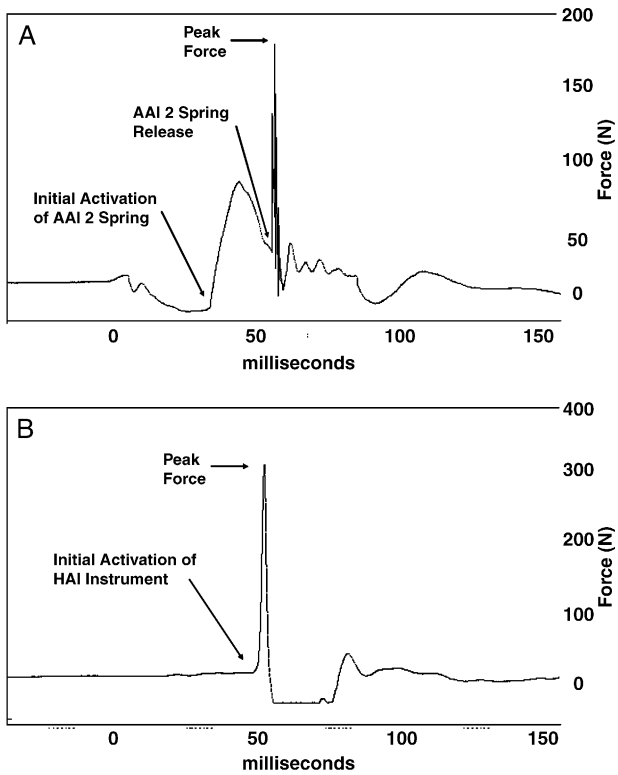


**Fig 5.** *Typical force-time profiles for spring-loaded (AAI 2) (A) and electromechanical (HAI) (B) instruments. (A) The force-time profile for a typical maximum setting AAI 2 thrust is characterized by an initial peak consistent with compression of the instrument's member spring upon initial activation followed by a complex waveform of ~5 ms duration and peak force of approximately 150 N consistent with the thrusting phase of the device and secondary peaks representing the rebound of the device. (B) The force-time profile for a typical maximum setting HAI thrust is characterized by a simple waveform of ~4 ms duration and peak force of approximately 300 N.*

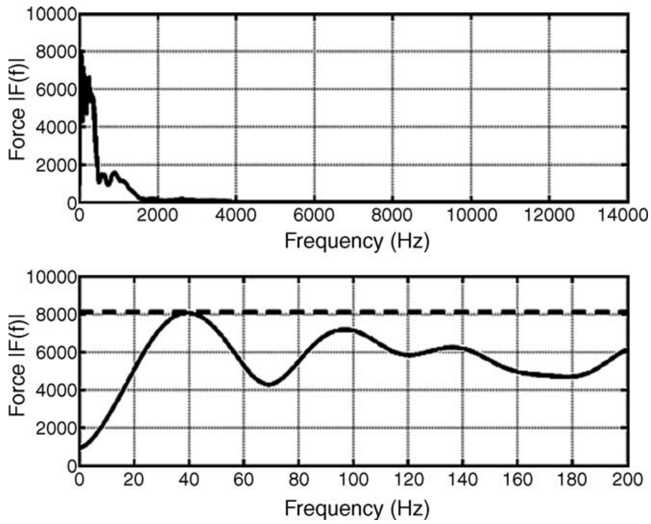


**Fig 6.** *Fourier-transformed NMI force-time history (maximum setting, test 005). The upper graph shows the force amplitude over a frequency range 0.38 Hz to 12.5 kHz. The lower graph shows the frequency response up to 200 Hz for which the dynamic force amplitude area ratio and energy were 69.5% and 1120 kN Hz, respectively. See text for definitions of dynamic area ratio and energy.*

analog-to-digital converter. The resulting force-time history data were stored on a portable computer.

Each instrument was engaged to fire for 10 trials at three force excursion settings defined as minimum, middle, and maximum. For the handheld spring-activated AAI and AAI 2 devices, the minimum setting consisted of one revolution of its expansion control knob from the closed position, the middle setting consisted of three revolutions from the closed position, and the maximum position was with the expansion control knob fully extended to seven revolutions. The effective distance of expansion control knob of the AAI 2 is 5.4 mm. The AAI 3 has three distinct settings that were compared, whereas the AAI 4 has four settings that were investigated. For the handheld electromechanical HAI instrument, the minimum setting consisted of one revolution of the expansion control knob, the middle setting was two revolutions, and the maximum setting was four revolutions, or the maximum expansion that the device permits. The effective distance of the expansion control knob of the HAI instrument is 5.0 mm. The electromechanical NMI device has three force settings selected by means of a switch.

Peak forces were computed from the force-time histories, and the force impulse, $\int f dt$, was calculated using a 60-ms time window centered about the force peak. Preload force was removed from each data file. A fast Fourier transform (FFT) was applied to the force-time histories, and the resulting force amplitude vs frequency plots were used to determine the frequency domain response of each device. The frequency domain response was quantified in terms of two scalar parameters: the dynamic force amplitude area ratio and the total energy over frequency range. The former is the ratio of peak FFT force amplitude × 200 Hz divided by the FFT force amplitude area over 200 Hz.[18] The maximum dynamic force amplitude area ratio is 1.0 or 100% and represents a uniform or constant force amplitude over the frequency range of interest (0-200 Hz in this case). The total energy represents the cumulative sum of the FFT force magnitude × frequency increment and has units of kilonewton hertz.

## Results

Maximum force setting force-time profiles for the HAI electronic adjusting instrument and the AAI 2 mechanical adjusting instrument are shown in Fig 5. Similar characteristics of spring-loaded mechanical adjusting instruments include an initial preload and spring compression force-time profile consistent with deformation of the device, and a 2- to 5-ms period of oscillation. In the case of the mechanical adjusting instrument, release of the spring produces a rapidly

**Table 1.** *Distances (cm) traveled by the shuttlecock for maximum, middle, and minimum force settings for the HAI and AAI 2*

| | AAI 2 | | HAI | |
|---|---|---|---|---|
| Setting | Mean | SD | Mean | SD |
| Maximum (cm) | 39.8 | 1.48 | 53.8 | 0.055 |
| Time (s) | 0.25 | 0.014 | 0.34 | 0.009 |
| Middle (cm) | 36.1 | 0.74 | 46.1 | 0.84 |
| Time (s) | 0.22 | 0.005 | 0.32 | 0.004 |
| Minimum (cm) | 32.6 | 0.62 | 18.1 | <0.001 |
| Time (s) | 0.25 | 0.009 | 0.20 | 0.009 |

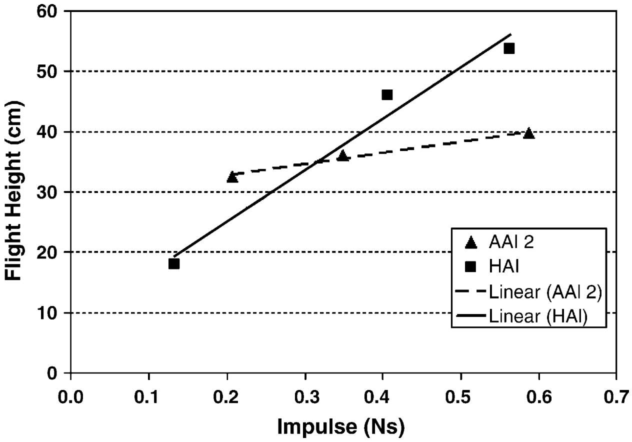


**Fig 7.** *Scatterplot comparison and linear correlation of the shuttlecock flight height vs impulse for each of the force settings examined for the HAI and AAI 2.*

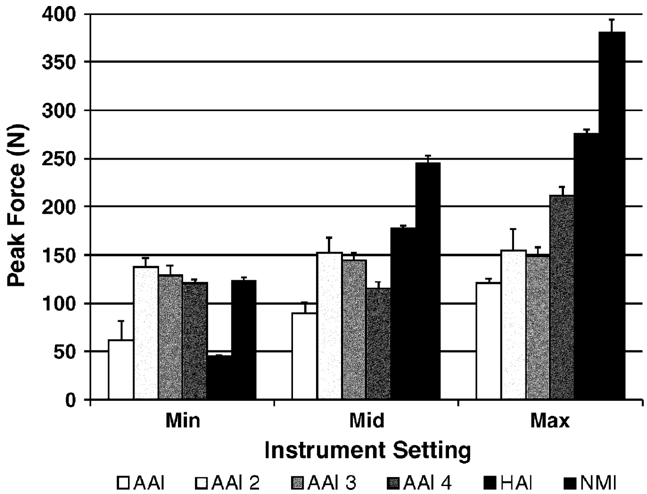


**Fig 8.** *Mean peak force comparison of the six chiropractic adjusting devices, the AAI, AAI 2, AAI 3, AAI 4, and the electromechanical devices, the HAI and the NMI, at the respective maximum (max), middle (mid), and minimum (min) force settings. Settings 2, 3, and 4 are presented for the AAI 4. Error bars represent standard deviations of the mean.*

oscillating waveform of approximately 5 ms duration. Spring recoil produces several lower amplitude oscillations that last another 15 ms after the main rapidly fluctuating main oscillation. In contrast, the force-time profiles of the electromechanical adjusting instruments more closely resemble a half sine wave with a pulse duration of approximately 2 to 5 ms as the primary mechanical device oscillation. In the case of the NMI device (~2 ms primary oscillation pulse duration), the magnitude of the force amplitude–frequency spectrum decreased to near zero above 1.5 kHz. Relative to the peak frequency amplitude (8055 at 39.5 Hz), the NMI instrument exhibited a force amplitude equal to 50% or greater than the peak amplitude for frequencies above 20 Hz (Fig 6).

Mean flight heights and time duration of flights for the HAI and AAI 2 at maximum, middle, and minimum settings are shown in Table 1. A much greater range of shuttlecock flight heights and time durations of flight were observed for the HAI than for the AAI 2. The mean shuttlecock flight heights ranged from 18.1 to 53.8 cm for the HAI and 32.6 to 39.8 cm for the AAI 2 for the minimum to maximum settings. Mean shuttlecock flight time durations ranged from 0.20 to 0.34 s for the HAI and 0.22 to 0.25 for the AAI 2. Fig 7 provides a comparison of the shuttlecock flight height vs impulse for each of the force settings examined for the HAI and AAI 2. The shuttlecock vertical flight height increased linearly in proportion to peak force in the case of the AAI 2 thrusts ($R^2 = 0.984$), but the range of flight height vs impulse was small. In the case of the HAI thrusts, the greater impulse and wider range of impulses for each of the force settings produced a linear correlation ($R^2 = 0.974$) proportionally greater change shuttlecock flight height among the three force settings.

Fig 8 presents mean peak force results for the six chiropractic adjusting instruments at the minimum, middle, and maximum force settings. For the spring-loaded mechanical devices, peak forces increased by 100% from the minimum to maximum setting for the AAI (61.5-121.0 N) and AAI 4 (121.0-211.6 N), but this trend was not observed for the AAI 2 or AAI 3. From the minimum to maximum setting, peak force increased only 11% (137.8-154.4 N) for the AAI 2, and 14% (128.2-149.0 N) for the AAI 3. Similarly, mean peak forces obtained from the AAI 4 were 123.1, 121.0, 114.9, and 211.6 N for settings 1 through 4, respectively. The AAI 4 has four settings which made comparison to the other devices problematic. However, we observed that the force-time profile was nearly identical for its settings 1, 2, and 3 (123, 121, and 114 N), respectively. Thus, for Figs 8-11, we chose to report setting 2 of the AAI 4 as the "minimum" setting. Appreciably larger ranges in peak forces were observed for the electromechanical adjusting instruments. A sixfold increase in peak force was obtained from the minimum to maximum force settings, respectively, for the HAI (44.9-275.0 N) and NMI (123.5-380.2 N) adjusting instruments.

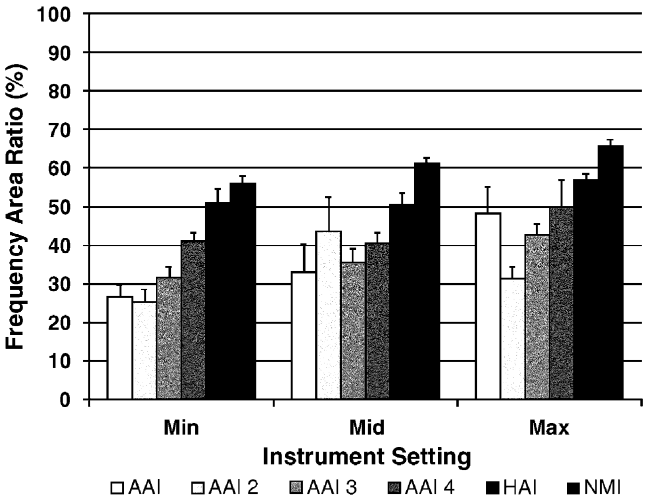


**Fig 9.** *Mean frequency area ratio comparison of the five chiropractic adjusting devices, the AAI, AAI 2, AAI 3, AAI 4, and the electromechanical devices, the HAI and the NMI, at the respective maximum, middle, and minimum force settings. Settings 2, 3, and 4 are presented for the AAI 4. Error bars represent standard deviations of the mean.*

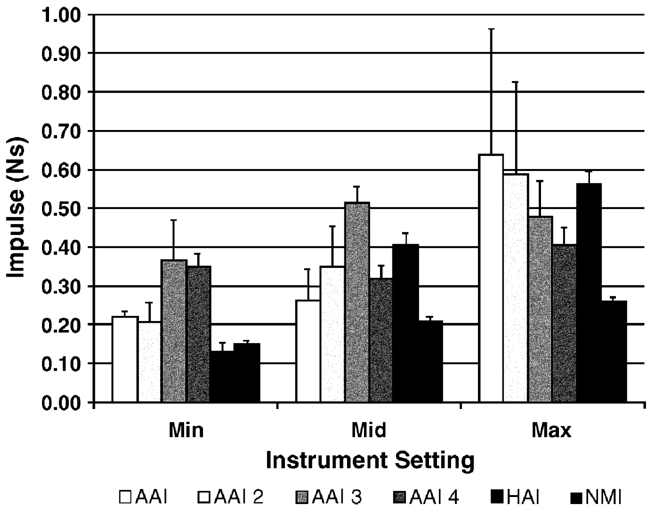


**Fig 11.** *Mean impulse comparison of the five chiropractic adjusting devices, the AAI, AAI 2, AAI 3, AAI 4, and the electromechanical devices, the HAI and the NMI, at the respective maximum, middle, and minimum force settings. Settings 2, 3, and 4 are presented for the AAI 4. Error bars represent standard deviations of the mean.*

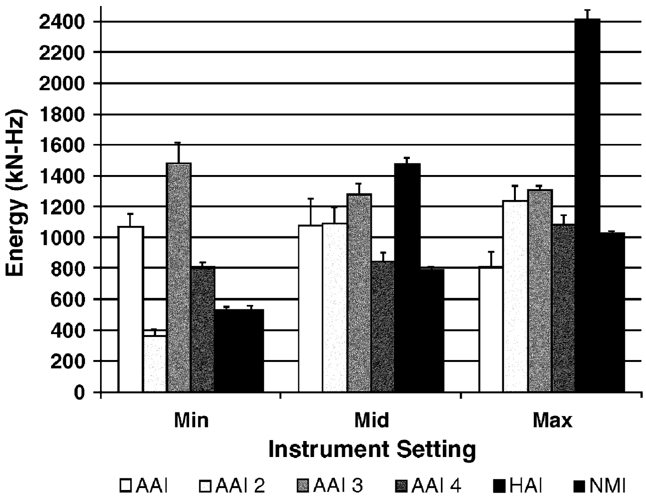


**Fig 10.** *Mean energy comparison of the five chiropractic adjusting devices, the AAI, AAI 2, AAI 3, AAI 4, and the electromechanical devices, the HAI and the NMI, at the respective maximum, middle, and minimum force settings. Settings 2, 3, and 4 are presented for the AAI 4. Error bars represent standard deviations of the mean.*

The mean frequency area ratios for the six chiropractic adjusting instruments are summarized in Fig 9. The electromechanical instruments produced greater dynamic frequency area ratios in comparison to the mechanical devices for all force settings examined. Among the spring-loaded devices, the original AAI produced a greater frequency area ratio (48%) than the AAI 2 or AAI 3 (43%). The dynamic frequency area ratio measured from the AAI 4 (50%) was similar to the AAI. Electromechanical devices appreciably improved the frequency area ratio over the spring-loaded devices for all instrument settings. The NMI device at the maximum setting produced the greatest frequency area ratio (66%) among the five devices. With the exception of the AAI 2, the frequency domain energy response (kilonewton hertz) was similar among the three spring-activated instrument settings examined (Fig 10). The mean energy response decreased from the minimum to maximum settings for the AAI (1067-813 kN Hz). For the AAI 2, the mean energy response increased approximately fourfold from the minimum to maximum settings (364-1234 kN Hz). The AAI 3 produced a relatively similar mean energy response for all three of its settings (1483, 1277, and 1305 kN Hz for the minimum to maximum settings, respectively). The greatest mean energy response was observed for the AAI 3 at the minimum setting (1483 kN Hz). In contrast, the mean energy responses for the electromechanical devices increased consistently two- and fivefold for the NMI (532.7-1026.0 kN Hz) and HAI (531.6-2413.0 kN Hz) devices, respectively, from the minimum to maximum settings.

The force impulse ranged from 0.22 to 0.64 N s for the AAI, 0.21 to 0.59 N s for the AAI 2, 0.37 to 0.51 N s for the AAI 3, and 0.35 to 0.40 N s for the AAI 4 from the minimum to maximum settings (Fig 11). Force impulse ranged from 0.13 to 0.56 N s and 0.14 to 0.31 N s for the HAI and NMI devices, respectively.

## Discussion

To understand the biomechanical consequences of chiropractic adjustment/spinal manipulation more fully, chiropractic researchers are currently focusing on quantifying the applied forces associated with spinal manipulation and the mechanical response of the spine to these forces.[2,17,18,21,23,26,27] Basic experiments to quantify the forces transmitted during MFMA spinal manipulation as presented in the current study are important first steps in understanding the mechanics of spinal manipulation. In comparison to manual spinal manipulation (without the use of instruments), larger magnitude forces have been reported to be used by clinicians when treating the sacroiliac joint or lumbar spine[21] as opposed to the cervical spine.[23,24] In this study, the electromechanical devices were found to produce larger peak forces and ranges of force in comparison to the mechanical instrument and, thus, may offer clinicians a wider selection and range of peak forces in the delivery of chiropractic manipulation.

Peak forces transmitted with the HAI and NMI devices at the maximum setting averaged 275 and 380 N, respectively, which is higher than the Activator devices (121, 154, 149, and 211 N) for the AAI, AAI 2, AAI 3, and AAI 4, respectively. It is hypothesized that higher peak forces may cause a greater magnitude vertebral displacements during chiropractic adjustments.[28] Previous biomechanical comparisons of MFMA and HVLA spinal manipulation have raised the issue of effective transmitted force distribution locally to the spine. Specifically, global measures of loading have been found to overestimate the local effective forces at the target site.[17] Herzog et al[17] reported average peak forces of 238.2 N for reinforced hypothenar contact HVLA spinal manipulation applied to the thoracic spine. In this work, the average peak local force was found to act over a target area of 25 $mm^2$. When comparing these data with MFMA spinal manipulation, the cross-sectional area of the styli attached to MFMA devices ranges from 100 to 27 $mm^2$. Thus, it is possible that the local forces applied with the AAI normalized to a 25-$mm^2$ area may be the same as those observed here for HVLA hypothenar contact spinal manipulation,[16] whereas the HAI and NMI device acting over the same contact area may deliver higher forces. It should be noted, however, that each of the MFMA devices delivers forces over a very short time interval (<5 ms) as opposed to HVLA spinal manipulation ($\approx$150 ms), which may result in much lower force impulse imparted to the spine. These differences, together with distinctions of articular cavitation responses, vertebral movements, and spinal reflex activities, all reflect possible considerations when studying different forms of chiropractic adjustment/spinal manipulation.[16,29-35]

The force-time and frequency-response parameters determined for the HAI and AAI 2 instruments did not correlate linearly with the shuttlecock experiments. Rather, shuttlecock flight height showed a nonlinear dependency on force and frequency parameters, wherein the flight height increased less in comparison to the peak force or frequency parameters. Shuttlecock flight height correlated with the respective impulses of the two devices, however. The shuttlecock experiment, although novel, possesses limitations because of the coefficients of drag on the shuttlecock during its flight among other factors related to indirect measurements of transmitted force. In addition, any deviation of the shuttlecock flight path from 90° of its origin results in experimental error from geometry. Although attempts were made throughout the experiment to ensure a plumb shuttlecock flight path along the line of the background ruler, it was inherently not possible to maintain an exact 90° flight path, which subsequently affected the results.

Questions may arise whether the results from our bench tests on a table-mounted transducer can be extrapolated to data obtained in actual patients. A difference in stiffness response would be expected from a load cell mounted to a table compared to that obtained in patients; we believe that controlling the testing material by using a standard bench is appropriate for this study design. We have reported the force-time profiles of the Activator devices both from tests on a steel beam[18] as well as thrusts delivered to normal subjects and actual patients.[26,27] A review of these data shows little difference in the imparted force-time profiles to patients or rigid structures. In addition, the sampling frequency was chosen to ensure that the primary peak force-time profile of the various instruments was accurately captured, which in the case of the NMI device was only approximately 2 ms in duration. Fifty samples over a 2-ms duration (25 kHz) was deemed more than adequate to characterize the primary peak force-time response of this device, and 32 768 samples per second was chosen as this was the next power of 2 integer above 25 kHz. Subsequent Fourier transforms of the adjusting instrument force vectors indicated that there was little or no frequency content above 2 kHz, which is over an order of magnitude lower than the sampling frequency. The results of this study suggest that a sampling frequency of 4 kHz or higher should be used to characterize the force-time response of the chiropractic adjusting instruments examined in this study.

Because the spinal column is a viscoelastic structure, increased mobility (motion response) will occur when the manipulation or mobilization therapy is applied at certain loading rates and frequencies. The relative stiffness of different regions of the thoracolumbar spine may vary with the mechanical stimulus frequency.[26,36] Other important considerations in studying the biomechanics of spinal manipulation include the nonlinear, load-deformation behavior of the human spine. Inherent nonlinearities in the load-deformation characteristics of the spine result in variations in the measured posterior to anterior displacement and stiffness that are dependent on the magnitude of the applied force. For example, posterior to anterior mobilization studies have reported an increase in posterior to anterior stiffness when the peak force applied is increased.[37,38] Greater forces, thus, may result in greater intersegmental and segmental motion responses of functional spinal units.[28,39,40] A structural model of the lumbar spine has been developed to characterize the sagittal plane static, sinusoidal, and impulsive motion response of lumbar spine segments.[39] The model provides data on segmental and intersegmental motion patterns that are otherwise difficult to obtain experimentally. Knowledge of the transmitted forces during chiropractic adjustment/spinal manipulation as presented in the current study and others, thus, can be modeled to contribute to the understanding of the motion response of the vertebral column. Such information is important in assessing the characteristics of chiropractic treatments.

Each of the chiropractic adjusting instruments examined in this study produced relatively large amplitude (maximum setting) force-time histories with primarily peak pulse durations less than 5 ms. Forces that are relatively large in magnitude, but act for a very short time (less than the natural period of oscillation of the structure), are called "impulsive."[18] Impulsive forces acting on a mass will result in a sudden change in velocity, but are typically associated with smaller amplitude displacements in comparison to longer duration forces. However, the manner in which the structure is mechanically excited will depend on the frequency content of the instrument's force-time history, and significant displacements can be produced provided that the force-time history contains frequency components at or near the natural frequencies of oscillation of the structure. In this study, the frequency area ratio of each device was computed to estimate the overall frequency content or relative frequency distribution of the impulsive force within a frequency range that was consistent with the first few natural frequencies of vibration of the spine subjected to posterior-anterior forces.[39] We found that the HAI and NMI produced a higher frequency area ratio (more uniform frequency distribution) in comparison to the Activator adjusting instruments examined. The frequency area ratio results reported herein differ from those previously reported for the AAI 3 and AAI 4. Namely, the results of the current study indicate that the mean frequency area ratio of the AAI 3 is lower than the original Activator 3 design, which was reportedly developed to improve the force-frequency spectrum of the Activator line of instruments.[25] Likewise, the dynamic frequency area ratio of the AAI 4 has not appreciably improved over the original AAI. A possible explanation for this discrepancy is that the data cited by Fuhr and Menke[25] were obtained by us using a prototype of the AAI 3 device, and not the commercial instrument ultimately manufactured. The present study presents the first comprehensive force-time and force-frequency data for several impulsive force chiropractic adjusting instruments that are currently being manufactured.

Of potential clinical interest is the finding that the motion response of the spine is closely coupled to the frequency or the time history of the applied force. External mechanical forces applied at or near the natural frequency of the structure are associated with appreciably greater displacements (over twofold) in comparison to external forces that are static or quasi-static.[39] Thus, it may be possible to achieve comparable posterior-anterior segmental motion responses for lower applied forces during spinal manipulation, provided that the forces are delivered over time intervals at or near the period corresponding to the natural frequency. We propose, because of the more uniform frequency response (haversine force-time profile) of the electromechanical devices, a testable hypothesis arising from the current study involves measuring the mechanical and physiological response of the spine among different MFMA devices at the same force settings but different frequencies. Further research into the force-time and force-frequency inputs of chiropractic adjustment/spinal manipulation on mechanical, physiological, and clinical responses in patients may help to optimize chiropractic interventions and treatment regimens.

## Conclusion

In this study, the handheld, electromechanical HAI and NMI instruments produced a greater peak force and larger range of forces in comparison to the handheld, spring-loaded Activator devices. The electromechanical instruments were faster and produced greater dynamic frequency range (area ratios) than the spring-activated Activator instruments. Knowledge of the force-time history and force-frequency response characteristics of spinal manipulative instruments may provide basic benchmarks and may assist in understanding mechanical responses in the clinical setting.

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