PARASPINAL MUSCLE SPINDLE RESPONSES TO THE DURATION OF A SPINAL MANIPULATION UNDER FORCE CONTROL

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ABSTRACT

Objective: More than 90% of chiropractic patients receive high-velocity, low-amplitude spinal manipulation (HVLA-SM) as part of their chiropractic care. The purpose of the current study was determined how the duration of a lumbar HVLA-SM given under force control affects the discharge of paraspinal muscle spindle afferents.

Methods: Experiments were performed on deeply anesthetized adult cats treated in accordance with the Guiding Principles in the Care and Use of Animals approved by the American Physiological Society. Muscle spindle afferents were identified in the dorsal roots. Neural activity was recorded from individual spindles located in the low back predominately from multifidus and longissimus muscles. Spinal manipulative loads were applied to the L6 vertebra. Force-time profiles were half-sine waves with impulse durations of 25, 50, 100, 200, 400, and 800 milliseconds, delivered at constant magnitudes of 33%, 66%, or 100% body weight. The relationships between spinal manipulation duration and muscle spindle responses were determined using a randomized block design.

Results: Mean instantaneous discharge frequency increased with decreasing impulse duration. There appeared to be a threshold effect for impulse duration below which the increase in muscle spindle discharge changed greatly with decreasing impulse duration and above which the discharge did not substantially change with decreasing impulse duration. This threshold was in the vicinity of the duration of an HVLA-SM applied clinically (~200 milliseconds). After the manipulation, muscle spindle afferents often became silent, but manipulation duration had little effect on this duration and also had little effect on the time it took for the afferents to recover their initial resting discharge.

Conclusions: The findings suggest that one biomechanical characteristic of an HVLA-SM is its capacity to load paraspinal muscle spindles at a rate where their velocity sensitivity predominates over their length sensitivity.

Key Indexing Terms: Muscle Spindles; Action Potentials; Lumbar Vertebra

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High-velocity, low-amplitude spinal manipulation (HVLA-SM) is routinely used by doctors of chiropractic. More than 90% of chiropractic patients receive this form of treatment as part of their chiropractic care. Manipulation in general and spinal manipulation, specifically, may be viewed as one of two forms of manual therapy, mobilization being the second. These body-based interventions can be classified, to a large extent, based on their loading pattern and loading rate or the duration over which they are applied. Manipulation is applied as an impulse load using a high-velocity thrust of small amplitude. When applied manually, typically, the practitioner brings a joint to its end range of motion and then moves it slightly beyond what the patient can accomplish through voluntary activity alone. The clinician controls the velocity, magnitude and direction of the impulse, and the art or skill of spinal manipulation lies in the clinician’s ability to control these 3 factors. Mobilization is typically...
delivered using repetitive passive movement applied at low velocity and with varying amplitudes from slight movement near the neutral position to large movement toward the end range of motion.2,6

The biomechanical features of HVLA-SM, as performed by chiropractors, have been investigated experimentally. The HVLA-SM can be characterized by its force-time profile: velocity referring to its rate of application and amplitude referring to either the force or displacement imparted to the spinal tissues. Inspection of the force-time profile of an HVLA-SM7,8 likens it to a half-sine wave. The group of Hessell et al8 identified two characteristics common to a manually delivered spinal manipulation: a preload (static load, no velocity) followed by a larger impulse-type load (dynamic load, high velocity). In the lumbar spine, measurements recorded from practitioners indicate preload forces range between 20 and 180 N, and peak impulse forces range between 220 and 550 N.7,9 Often, the preload force is approximately 25% of the impulse force. Impulse durations range from 200 and 420 milliseconds,7,9 depending upon the part of the vertebral column being manipulated. Thus, force rates range from 500 to 2750 N/s.

The relative displacements between lumbar vertebrae during an HVLA-SM appear relatively small. In the human cadaveric lumbar spine, Ianuzzi and Khalsa10 simulated a side-posture HVLA-SM using force-time characteristics described above. The manipulated vertebra translated approximately 1.5 ± 0.5 mm and rotated 2° to 3.5° ± 1.0° in the direction of the applied force. These movements were found to be within a range occurring during physiological motions and were therefore considered safe. Smith et al11 delivered an HVLA-SM to the L2 spinous using a mechanical adjusting device (the Activator Adjusting Instrument; Activator Methods International, Ltd, Phoenix, Ariz).12 This mechanically assisted HVLA-SM delivered a force-time profile lower in amplitude (53 N), shorter in duration (17 milliseconds), and with a faster force rate (3100 N/s), compared with a manually applied HVLA-SM. The L2 vertebra translated 0.71 ± 0.03 mm and rotated 0.53° ± 0.15° in the direction of the applied impulse. Nathan and Keller13 measured similar vertebral displacements in the lumbar spine of human volunteers receiving a mechanically assisted HVLA-SM. Impulses delivered to the L2 spinous produced 1.62 ± 1.06 mm peak axial displacement (in the longitudinal plane), 0.48 ± 0.1 mm shear displacement (in the transverse plane), and 0.89° ± 0.49° of rotation between L3 and L4.

Despite our knowledge of the biomechanical characteristics of an HVLA-SM, little is known about the biological mechanisms underlying its therapeutic effects. Many mechanisms have been proposed, and current thinking emphasizes changes in both spinal biomechanics and neurophysiological systems.14-16 To better understand the importance and, perhaps, the necessity for optimizing the high-velocity component of a spinal manipulation, it is important to know how these systems are affected by the force-time profile of an HVLA-SM. If these systems do contribute to spinal manipulation’s therapeutic effects, it seems reasonable to expect a change to occur because the duration of the force-time profile approaches a critical value. Pickar and Wheeler17 showed that a 200-millisecond duration HVLA-SM increased, by 200 Hz, the instantaneous discharge frequency of primary afferent neurons from muscle spindles and Golgi tendon organs in the lumbar multifidus in an anesthetized cat model. More recently, a preliminary investigation in a small population of low-threshold mechanoreceptors suggested that the relationship between neural discharge and impulse duration was not linear. It increased disproportionately as the impulse duration became similar to that given during an HVLA-SM.18 The purpose of the current study was to confirm and extend these findings by determining how lumbar paraspinal muscle spindle afferents respond to the duration of an impulse load under conditions of force control.

**METHODS**

**General**

Experiments were performed on 46 deeply anesthetized adult cats. All cats were treated in accordance with the Guiding Principles in the Care and Use of Animals approved by the American Physiological Society. Anesthesia was induced with 100% O2/5% halothane and maintained with 100% O2/3% halothane. Catheters were placed in a common carotid artery and an external jugular vein to monitor blood pressure and introduce fluids. The trachea was intubated, and the cat ventilated mechanically using a Harvard Respirator (model 681; Harvard Apparatus, South Natick, Mass). Anesthetic was then maintained with Nembutal (35 mg/kg IV), and the halothane was withdrawn. Additional Nembutal (5 mg/kg) was administered when the cat showed a withdrawal reflex to noxious pinching of the toe pad, when mean arterial pressure increased above 120 mm Hg, or when the cat exhibited a pressure response to surgical manipulation. Arterial pH, PCO2, and PO2 were monitored every 60 to 90 minutes using an i-Stat pH/blood gas analyzer (i-Stat Corp, East Windsor, NJ). Arterial blood gas values were maintained within the reference range (pH 7.32-7.43; PCO2, 32-37 mm Hg; PO2, >85 mm Hg). Arterial pH and PCO2 were corrected by infusing sodium bicarbonate and by adjusting the ventilator. PO2 was maintained by bleeding 100% O2 into the intake line of the ventilator.

The spinal column was prepared for neural recordings from the dorsal roots and for manipulation of the L6 vertebra using an experimental preparation similar to that previously described in detail.19 An L4-5 laminectomy was performed bilaterally exposing the L5-6 spinal cord segments. The
musculature on the right side of the spinal column remained intact except for its attachments to the posterior portions of these vertebrae. The L6-7 vertebrae and associated paraspinal tissues remained completely intact bilaterally, including lumbodorsal fascia, multifidus, longissimus, and iliocostalis muscles. The lumbar spine was mechanically secured at the L4 spinous process and the iliac crests using a Kopf spinal unit (David Kopf Instruments, Tujunga, Calif.). The skin margins surrounding the lumbar spine were elevated and tied to metal rods, thus forming a pool. The paraspinal tissues were bathed in warm mineral oil (37°C) to prevent desiccation and to prevent the electrodes from short circuiting.

The dura mater was incised and the L6 sensory nerve root isolated for electrophysiological recordings. The L6 spinal nerve innervates fascicles of the multifidus and longissimus muscles attaching to the L6 vertebra.²⁰ The L6 dorsal root was cut close to its entrance into the spinal cord and placed on a small platform. Thin filaments from the root were teased using forceps under a dissecting microscope until impulse activity from a single unit with a receptive field in the paraspinal muscles could be identified. The sciatic nerve on the right side was cut close to its emergence from the iliac fossa to reduce afferent input from the hindlimb. Action potentials were passed through a high-impedance probe (HIP511, Grass, West Warwick, RI) and then amplified (P511K, Grass). Action potentials were monitored using an audiomonitor (Grass) and the video display of a TA5000 chart recorder (Gould, Valley View, Ohio). Action potentials were digitized (22 kHz) (DR890 Neurocorder, Neurodata, New York, NY) and recorded onto VCR tape for playback and offline analysis. Signals were displayed on a digital storage oscilloscope (Tektronics, Beaverton, Ore) to determine the conduction velocity of single units. Data analysis was performed using a PC-based data acquisition system (Spike 2, Cambridge Electronic Design, Cambridge, UK).

**Mechanical Loading of a Vertebra**

With the preparation prone, impulse loads were applied to the L6 vertebra in a dorsal-ventral direction using the output from an arbitrary waveform generator. The waveform generator commanded an electronic feedback control system (Lever System Model 310; Aurora Scientific, Aurora, Ontario, Canada) that controlled the force applied at the L6 spinous process and measured the delivered force and length. The control system was attached to the L6 spinous process via a pair of adjustable tissue forceps (1 × 2 teeth), which were clamped tightly onto the lateral surfaces of the L6 spinous process. The forceps were narrow, requiring only a thin, narrow, slit (approximately 2 mm long) along either side of the L6 spinous process for attachment. Little of the multifidus muscle was detached from the vertebra using this method because most of the muscle fibers attach to the spinous process via a tendinous insertion onto its caudal edge.²¹

The response of a muscle spindle to 6 impulse loads of differing durations was determined. Six durations (25, 50, 100, 200, 400, and 800 milliseconds) and one of 3 amplitudes (33%, 66%, or 100% body weight [BW]) were delivered to each cat. Force-time profiles were half-sine waves. This shape, the 3 amplitudes and the durations less than 400 milliseconds were meant to simulate and encompass the force-time profile of an HVLA-SM given by a clinician;²²,²³ however, no preload was given. The 400- and 800-millisecond durations were considered longer than that given during an HVLA-SM. The loading amplitudes yielded vertebral displacements of 1.2 ± 0.2, 2.0 ± 0.5, and 3.3 ± 1.1 mm (mean ± SD), respectively. The presentation order of the 6 impulse durations was randomized to minimize potential ordering effects introduced by the mechanical nonlinearity of the spinal tissues. Presentation of each impulse was separated by 10 minutes to allow recovery. Before each impulse, the L6 vertebra was positioned identically. Thus, each afferent was considered a block within which the input variable was randomized (Data Reduction).

**Electrophysiological Recordings and their Classification**

Single-unit recordings were obtained in the dorsal roots from paraspinal muscle spindle afferents. Activity from a putative muscle spindle in the lumbar spine was first identified by gently compressing the lumbar paraspinal tissues or by manually moving the L6 vertebra ventralward and evoking a high frequency. Only afferents whose discharge was highest in response to probing the back muscles compared with the gluteal, hip, or leg regions were used. Dynamic sensitivity of the receptive ending was assessed using a 10-second ramp and hold load. Under displacement control, a ramp (1 mm/s) was delivered to the paraspinal muscles by translating the L6 vertebra ventralward to a magnitude that loaded the paraspinal tissues with 50% to 60% of the cat’s BW. This value was determined empirically; it did not tear the fragile dorsal root filaments from the electrode. Afferent activity during the ramp and hold load was resolved into dynamic and static components: the dynamic component was represented by the peak instantaneous discharge frequency during the ramp; and the static component was represented by the afferent’s mean discharge frequency during the hold, between 0.5 and 2.5 seconds after the end of the ramp. A dynamic index was calculated by subtracting the static from the dynamic component. Receptive endings of muscle spindle afferents were classified as primary or secondary, based upon their dynamic index.²⁴,²⁵ Muscle spindle afferents having dynamic indices ≥20 Hz were considered to terminate in primary endings, and those less than 20 Hz were considered to terminate in secondary endings based upon the criteria previously used to classify muscle spindles in the cervical...
region of cats. The terms primary afferents and primary endings or secondary afferents and secondary endings are often used interchangeably.

After delivering the 6 impulse loads, we opened up the intact lumbodorsal fascia and used a variety of approaches to confirm that the single unit was from a lumbar paraspinal muscle spindle. We removed the sacrocaudalis dorsalis lateralis (lumbococcygeus) muscle, which lies between the lumbar multifidus and longissimus muscles, to improve the mechanical isolation of the latter two muscles. First and second sacral nerves innervate the lumbococcygeus muscle so that none of the afferent recordings were lost by its removal. That the source of neural activity was from a receptive ending in the lumbar longissimus or multifidus muscles was confirmed by using von Frey hairs (Stoelting Co, Wood Dale, Ill) to determine that the most sensitive area for mechanically activating the afferent was in the low back.

Two methods were used to confirm that neural activity was from a muscle spindle: decreased discharge to a muscle twitch and increased discharge to succinylcholine injection (100-300 µg/kg, intra-arterial). An afferent’s response to muscle contraction was determined using needle electrodes inserted into the muscle on either side of the receptive field. Because deep paraspinal muscle nerves are short and difficult to isolate, the afferent’s response to muscle contraction was determined by direct muscle stimulation (0.08-14 mA, 0.045-0.5 milliseconds) using a constant current stimulus isolation unit (Grass Instrument, PSIU6) and a square wave stimulator (Grass Instrument, S88). Two needle electrodes were typically inserted into either side of the most sensitive portion of the afferent’s receptive field.

Because it was not possible to isolate the muscle nerve, nerve conduction velocity was obtained by stimulating the L6 spinal nerve after inserting two needle electrodes in the vicinity of the L6-7 intervertebral foramina (where the L6 posterior ramus joins the spinal nerve) and recording the action potential at the dorsal root filament. Conduction velocity was determined by dividing the conduction distance by the conduction time. Conduction time was determined using Spike 2 to measure the time between the onset of stimulation and occurrence of the action potential at the recording electrode. Conduction distance was determined by measuring the length of a thin thread extending from the recording electrode along the dorsal root and spinal nerve to its entrance at the intervertebral foramen. These distances were approximate. Typically conduction times were ≤1 millisecond, and conduction distances approximately 45 mm. At these short conduction times, a 10% error in conduction distance would miscalculate conduction velocity by approximately 5 m/s.

Data Reduction

Muscle spindle activity (ie, an afferent’s firing rate) was converted to instantaneous frequency (IF) by taking the reciprocal of the time interval between consecutive action potentials. The mean IF (reported in spikes per second [Hz]) was calculated during the control period (10 seconds before the impulse load), during the impulse load, and for 40 seconds after the impulse load in consecutive 5-second bins. For the control period, the coefficient of variation in IF (SD/mean IF) was also determined. The response of a muscle spindle to the manipulation was calculated as a difference by subtracting mean IF during the control period from mean IF during the manipulation. After mechanical loading, muscle spindles can become silent. The duration of the silent period was calculated as the time between the end of the impulse load and occurrence of the first action potential. In addition, the latency to recovery for muscle spindle discharge after the impulse load was determined. Recovery was calculated as the time interval from the end of the manipulation to the time mean IF returned to within 1 Hz of the mean IF during control or to within control mean IF ± the product of coefficient of variation and mean IF during the control period, whichever occurred first.

Statistics

The relationships between spinal manipulation duration and muscle spindle responses (change in instantaneous discharge frequency, duration of the silent period, or latency to recovery) were determined using a randomized block design. Each block was one afferent. Responses across manipulation durations were analyzed using a two-way analysis of variance while controlling for block as a factor. The overall F test indicated whether any of the mean responses were the same across manipulation durations. Testing was done at the .05 level of significance. For statistically significant differences, a test of trend was conducted to investigate for linear, quadratic and cubic relationships among the responses. Analyses were conducted using SAS (version 8, SAS Institute, Cary, NC); contrast coefficients for the tests of trend were obtained using S-Plus (version 6.2, Insightful, Seattle, Wash).

Results

Each afferent’s receptive field was located in the low back region and the majority were in the lumbar paraspinal muscles. For 35 of 46 afferents, the most sensitive portion of the receptive field was in the longissimus muscle; for 9 afferents, it was in the multifidus muscle; and for one afferent each, it was in the iliocostalis muscle or near the crest of the ileum. The most sensitive portion of the receptive field was close to a lumbar facet joint for 12 of the 46 afferents and was located medially for 29 of the 46 afferents (ie, either in the multifidus muscle or the medial border of the longissimus muscle). The most sensitive portion of the receptive field for the remaining 5 afferents was positioned relatively lateral. Nineteen afferents were classified as having
primary endings based upon having a dynamic sensitivity of 20 Hz or higher (Methods); the remaining 27 afferents were classified as having secondary endings. Conduction velocities were obtained for 37 of the 46 afferents and ranged from 6.0 to 74.6 m/s (45.3 ± 14.8 [mean ± SD]). Fig 1 shows the distribution of conduction velocities based upon the classification of muscle spindle endings. Primary afferents had a mean conduction velocity of 42.4 m/s (range, 6.0-61.0; n = 15), and secondary afferents had a mean conduction velocity of 47.2 m/s (range, 21.2-74.7 m/s; n = 22). The distributions overlapped substantially.

Fig 2 shows original recordings from one afferent (afferent 14 in Fig 3) to each of the impulse durations, and Fig 3 contains profile plots for each of the 46 paraspinal muscle afferents demonstrating their response patterns to the impulse. Most muscle spindle afferents (32 of 46) exhibited a full response.

The second type of response was designated “limited response” and was characterized by increases in mean IF to some of the 6 durations. Of the 46 afferents, 12 showed a limited response (afferents 3, 4, 10, 13, 16, 17, 18, 26, 32, 37, 41, and 44). Often, mean IF continued to increase between durations of 800 and 50 milliseconds, followed by little increase or a decrease at the 25-millisecond duration. In 8 of these 12 afferents (afferents 3, 4, 10, 16, 18, 26, 32, and 37), the 25-millisecond duration appeared to unload the spindle indicated by the negative values for mean IF in Fig 3. Thus, 44 of the 46 muscle spindle afferents responded with an increase in mean IF as impulse duration decreased from 800 to 50 milliseconds. Full and limited responses occurred in both primary and secondary endings and at all force levels. However, no secondary endings receiving a manipulation of 100% BW showed a limited type of response.

The third type of response was designated as “no-response”. This occurred in two of 46 afferents (1 and 2) and was characterized by little change in mean IF at each of the 6 durations to the lowest amplitude impulse. Although these two afferents did not respond to 33% BW manipulations, they did respond to mechanical prodding of their receptive field as well as to the ramp and hold load delivered at 50 to 60% body stretch used to classify their endings as secondary (Methods). Thus, these two afferents were mechanically responsive but not to the impulse-type loads.

The pattern of responses for the 46 afferents is summarized in the box plots of Fig 4 and is characterized by 4 features: (1) as a population, the response of primary muscle spindle endings to the half-sine wave loading was greater in magnitude than the response of secondary endings at each of the impulse durations; (2) the mean change in IF for both primary and secondary afferents significantly increased as impulse duration was shortened from 800 to 25 milliseconds ($F_{5,89} = 33.8, P < .001$ for primary; $F_{5,125} = 26.3, P < .001$ for secondary); (3) The increase in discharge across the 6 durations was nonlinear. A trend test indicated a cubic relationship between mean change in IF and manipulation duration ($P = .004$) for the primary afferents and a quadratic relationship ($P = .002$) for the secondary afferents. Inspection of Figs 3 and 4 suggested that an inflection point occurred as the impulse duration became shorter than 200 ms, in the range of that during an HVLA-SM. The cubic relationship for the primary endings suggested that the response of these afferents saturated at the shortest HVLA-SM duration; (4) as the impulse duration became shorter and similar to that of an HVLA-SM, the
variability in discharge frequency increased. As shown in Fig 4, at a manipulation duration of 800 milliseconds, 50% of all afferents increased their discharge over a 60-Hz range (from 28 to 88 Hz); at a duration of 400 milliseconds, 50% increased their discharge over a 125-Hz range (from 38 to 163 Hz), whereas at a 100-millisecond duration, 50% increased their discharge over a 410-Hz range (from 110 to 520 Hz).

Afferents often became silent and then resumed their discharge after the impulse load. Table 1 summarizes these responses. The mean duration of silent period tended to differ, but not significantly, across impulse durations for primary afferents (F5,84 = 2.08, P = .08) but not secondary afferents (F5,115 = 0.69, P = .63). The silent period of the primary afferents tended to become shorter as the impulse load became shorter with recovery ranging from approximately 9 to 18 seconds. Secondary afferents recovered faster within 8 seconds.

DISCUSSION

Two major findings arise from this study. The first is that impulse loads with force-time profiles similar to that of a manually delivered HVLA-SM evoked a higher frequency discharge from lumbar paraspinal muscle spindles compared with similar force profiles but slower loading velocities. Muscle spindles discharged in a nonlinear fashion, their discharge increasing as impulse duration shortened. Thus, there appeared to be a threshold effect for duration below which the increase in discharge changed little with impulse duration and above which the increase in discharge increased greatly with impulse duration. This occurred for both primary and secondary muscle spindle endings. In addition, primary endings responded with a greater discharge frequency compared with secondary endings at all impulse durations, although the difference was not evaluated statistically. Primary afferents became silent after the impulse load for less than a second, whereas secondary endings did not become silent. The discharge of primary afferents recovered to control values within 17 seconds after the impulse load, with the time to recovery decreasing as impulse duration decreased. The discharge of secondary afferents recovered within 8 seconds of the impulse load.

The second major finding from this study is that the conduction velocities of muscle spindle afferents with primary endings (Group Ia) and secondary endings (group II)
from the axial lumbar muscles were similar and relatively slow. These characteristics are similar to that previously reported in the biventer cervicis and complexus muscles of the feline cervical spine and unlike those from appendicular muscles. In the feline hindlimb, group Ia and group II afferents can be distinguished and classified based upon their conduction velocity. Group Ia muscle spindle afferents conduct between 60 and 120 m/s, and group II afferents conduct between 35 and 60 m/s. In the cervical muscles (except the splenius muscle), this bimodal distribution of conduction velocities does not occur. Substantial overlap occurs with group Ia afferents conducting from 25 to 90 m/s and group II afferents from 13 to 65 m/s. Similarly, we found that paraspinal lumbar muscle spindle afferents conduct in a range from 6 to 74.7 m/s. However, unlike in the cervical muscles where the mean conduction velocity of group Ia was greater than group II (approximately 50 m/s vs approximately 33 m/s), the mean conduction velocities were similar between groups Ia and II lumbar paraspinal muscle spindle afferents.

Past studies have characterized the passive properties of muscle spindles by studying their discharge properties to changes in muscle length including small stretches, large stretches, derivatives of length including velocity, and acceleration. These studies have largely been performed in leg muscles of the cat. In the present study, because each manipulation’s profile was half a sinusoidal wave, it is of particular interest to compare these passive properties to the effects observed during controlled sinusoidal stretching applied at different frequencies. Each impulse load we used could be described by its sinusoidal frequency by doubling the half-sine wave duration and taking its reciprocal. Fig 4 (x-axis) shows the sinusoidal frequency for each impulse duration. In hindlimb muscles, the relationship between small amplitude sinusoidal stretching and muscle spindle sensitivity originally described by Matthews and Stein has been redrawn and is shown in Fig 5. Spindle sensitivity remains relatively constant at low-stretching frequencies and increases with increasing frequency. The relatively low sensitivity at low frequencies is thought to reflect the length-dependent properties of muscle spindles; their velocity-dependent properties predominate as stretch frequency increases.

The corner frequency (the inflection point shown in Fig 5) represents the frequency at which the influences of length and velocity are equal. In the cat soleus muscle, corner frequencies range from 0.9 to 2.3 Hz for primary and from 0.2 to 2.5 Hz for secondary endings.

Despite that impulse force and not vertebral displacement was controlled in the present study, the effect of impulse duration on the discharge of paraspinal muscle spindles was remarkably similar in pattern to the effects observed during controlled sinusoidal stretch of the soleus muscle (compare Figs 3 and 4 with Fig 5). Spindle discharge remained relatively low for impulse frequencies of 0.6 and 1.25 Hz (800- and 400-millisecond duration, respectively) but rapidly increased with an impulse frequency of 2.5 Hz (200 milliseconds). Because clinically, an HVLA-SM is typically delivered in less than 200 milliseconds, these

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<th>Latency to recovery (s)</th>
<th>Type of ending</th>
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<td>25 milliseconds</td>
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<td>Mean (SD)</td>
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<td>Primary (n = 18)</td>
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Of the 46 afferents, 3 were omitted from the analysis because they did not have a resting discharge. n, Number of observations per duration.
findings suggest that one biomechanical characteristic of an HVLA-SM is its capacity to load paraspinal muscle spindles at a rate where their velocity sensitivity predominates over their length sensitivity. Whether the resulting high-frequency discharge contributes to a therapeutic effect remains to be determined.

The relationship Matthews and Stein found between spindle sensitivity and the frequency of sinusoidal stretching is based upon small amplitude stretches, that is, 0.05 to 0.2 mm. Small-amplitude stretches load muscle spindles in their linear range where their input-output relationship is more predictable. In the present study, we controlled the amplitude of the manipulation by applying loads that were 33, 66, and 100% BW, and in turn, these loads produced vertebral displacements ranging from 1.2 to 3.3 mm. Because the manipulations were applied along a dorsal-ventral axis, which is roughly perpendicular to the long axis of the multifidus and longissimus muscles, the HVLA-SM likely stretched these muscles by a relatively small amount; the horizontal loading vector was small. However, it is difficult to estimate the actual change in length without substantial error because insufficient morphometric data are available regarding muscle lengths and angles of insertions in the cat spine.

Clinically, a preload typically precedes the impulse load, but its magnitude can vary greatly. In the present experiments, we did not determine how the presence of a preload before the impulse load affected muscle spindle discharge. However, the number of action potentials during the 200-millisecond HVLA-SM ranged from two to 17 spikes (eg, see Fig 2). By comparison with a previous study where a 200-millisecond HVLA-SM ranged from two to 17 spikes (eg, see Fig 2). By comparison with a previous study where a 25% BW preload preceded a 100% BW impulse,17 inspection of their original recording (inset in Fig 7 of Reference [17]) shows that manipulation increased muscle spindle discharge by 12 spikes. The apparent lack of effect produced by the preload is consistent with previous findings showing that spindle endings appear to reset themselves at longer muscle lengths, thus retaining their high sensitivity to muscle stretch. Muscle history – dependent effects on spindle discharge may contribute to this resetting (see Reference [33] for review). These effects have been observed both in appendicular and lumbar paraspinal muscles. Based upon these observations, we do not think the presence of a preload would change the relationship we observed between manipulation duration and muscle spindle discharge.

It is interesting that the discharge from several afferents decreased as impulse duration became shorter. Although 32 of the 46 afferents showed a full response, the discharge from 12 of the 46 afferents decreased in response to the 100- or 25-millisecond durations (5 and 20 Hz). At least two factors may have contributed to this finding. Brown et al found that relatively larger displacements were required to drive spindle discharge at certain sinusoidal stretching frequencies. These so-called “humps” in the displacement-discharge curves (a larger displacement to get the same discharge) were observed in 30% of soleus muscle spindles and in 80% of the gastrocnemius muscle spindles they studied. The humps were attributed to the mechanical properties of muscle where localized areas of the muscle either did not move in the direction of the superimposed sinusoidal stretch or where the stretch amplitude appeared damped. However, the humps occurred at frequencies from 100 to 250 Hz, frequencies substantially higher compared with those used in the present study. Local resonances in the paraspinal muscles may be different from that in the hindlimb muscle by used Brown et al. In addition, we applied a dorsal-ventral translation to the L6 vertebra, but the L7 vertebra was unrestrained and could engage in coupled motions. Coupled motions could have altered mechanical transmission to the muscle spindle, ultimately reducing the amount of stretch. Second, Matthews and Stein applied several cycles of sinusoidal stretching to the soleus muscle and found numerous cycles during which the spindles were not driven. The net effect from the ensemble population of muscle spindles was a decrease in the spike density arriving in the central nervous system. This phenomenon also occurred at high-stretching frequencies (100-300 Hz). In the present study, each afferent received only one half-sine wave per impulse duration, raising the possibility that the limited response measured in 12 of the 46 muscle spindle afferents was analogous to one of the off cycles observed by Matthews and Stein. Although speculative, a successful HVLA-SM may be one in which the limited response pattern of paraspinal muscles spindles is minimized, thus increasing the probability density of afferent input to the central nervous system. The factors that could minimize the limited response are unknown.

**Conclusion**

In conclusion, we suggest that spinal manipulation, when delivered manually with high velocity and low amplitude as a half-sinusoidal wave, engages an inherent signaling property belonging to the muscle spindle apparatus. We speculate that this provides a novel stimulus to the central nervous system because the ensuing spike trains from the population of muscle spindles are higher in frequency than that typically generated in groups Ia and II afferents from paraspinal muscles. Although voluntary motions of peripheral joints, for example, during locomotion, can stretch appendicular muscles sufficiently fast to elicit discharge frequencies over 200 Hz, we are not aware of data from axial tissues showing that voluntary trunk motion produces similar loading rates and elicits such high discharge frequencies. Nearly 3 decades ago, Korr proposed that spinal manipulation’s therapeutic effects may arise in part from the barrage of afferent impulses in muscle spindle afferents the central effects of which ultimately change motor circuits. Increasing evidence shows that short-lasting, high-frequency bursts from primary afferents can shape the function of spinal cord neurons.
Group Ia afferent discharge alters synaptic efficacy at alpha motoneurons and may affect their susceptibility to reaching threshold.40 Similarly, short-lasting, high-frequency stimulation of smaller diameter A-0 and C-fibers affects synaptic efficiency at dorsal horn neurons by producing long-term potentiation and depression.41 These effects can last up to 1 hour after the initial sensory barrage.41,42 Knowing how primary sensory neurons respond to the mechanical inputs that characterize manual therapies should help us understand the mechanisms underlying these therapeutic approaches.

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Practical Application

- More than 90% of chiropractic patients receive HVLA-SM as part of their chiropractic care.
- Impulse loads with force-time profiles similar to that of a manually delivered HVLA-SM evoked a higher-frequency discharge from lumbar paraspinal muscle spindles compared with force-time profiles representing low amplitude but slower loading velocities.
- There appeared to be a threshold effect for duration below which the increase in discharge changed little with impulse duration and above which the increase in discharge increased greatly with impulse duration.
- The conduction velocities of muscle spindle afferents with primary endings (group Ia) and secondary endings (group II) from the axial lumbar muscles were similar and relatively slow in contrast appendicular muscles.
- The findings suggest that one biomechanical characteristic of an HVLA-SM is its capacity to load paraspinal muscle spindles at a rate where their velocity sensitivity predominates over their length sensitivity.

REFERENCES


