

## ORIGINAL ARTICLES



### Response of Muscle Proprioceptors to Spinal Manipulative-like Loads in the Anesthetized Cat

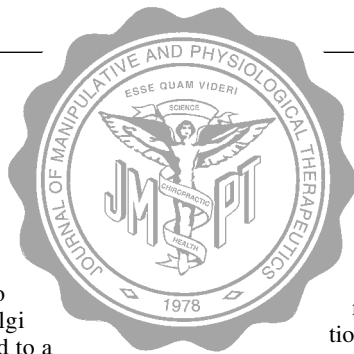
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#### ABSTRACT

**Objective:** The mechanisms underlying the benefits of spinal manipulation are not well understood. Neurophysiological mechanisms likely mediate its effects, at least in part, yet we know little about how the nervous system is affected by spinal manipulation. The purpose of the present study was to determine whether muscle spindles and Golgi tendon organs in paraspinal muscles respond to a mechanical load whose force-time profile is similar to that of a spinal manipulation.

**Methods:** Experiments were performed on 10 anesthetized adult cats. The L6 dorsal root was isolated for electrophysiological recordings while the L6-L7 vertebrae and associated paraspinal tissues on one side of the vertebral column were left intact. Single unit recordings were obtained from 5 muscle spindles, 4 Golgi tendon organs, and 1 presumed Pacinian corpuscle afferent with receptive fields in paraspinal muscles. Loads were applied at the spinous process of the L6 vertebra through use of an electronic feedback control system. The load simulated the force-time profile of a spinal manipulation. Loads were applied in compressive and distractive directions and at 2 different angles (0 degrees and 45 degrees) with respect to the long axis of the vertebral column.

**Results:** Golgi tendon organ afferent discharge frequency increased more to the impulse than to the preload during 13 of



15 spinal manipulations. Generally, the 4 Golgi tendon organ afferents became silent immediately at the end of each impulse. Similarly, muscle spindle discharge frequency increased more to the impulse than to the preload during 10 of 16 manipulations. Distractive manipulations loaded the spindles more effectively than compressive manipulations. After 7 of these 10 manipulations, muscle spindles became silent for  $1.3 \pm 0.6$  seconds (range, 0.1-4.3 seconds). Six of the 16 manipulations unloaded the muscle spindles. A presumed Pacinian corpuscle responded to the impulse of a manipulative-like load but not to loads with a slower force-time profile.

**Conclusion:** The data suggest that the high-velocity, short-duration load delivered during the impulse of a spinal manipulation can stimulate muscle spindles and Golgi tendon organs more than the preload. The physiologically relevant portion of the manipulation may relate to its ability to increase as well as decrease the discharge of muscle proprioceptors. In addition, the preload, even in the absence of the impulse, can change the discharge of paraspinal muscle spindles. Loading of the vertebral column during a sham manipulation may affect the discharge of paraspinal proprioceptors. (*J Manipulative Physiol Ther* 2001;24:2-11)

**Key Indexing Terms:** Chiropractic; Muscle Spindles; Golgi Tendon Organs

#### INTRODUCTION

The mechanisms underlying the benefits of spinal manipulation are not well understood. Biomechanical and neuro-

physiological processes likely mediate its effects,<sup>1</sup> although changes in circulation have also been suggested.<sup>2</sup> These mechanisms may be synergistic; biomechanical changes in the vertebral column might affect the nervous system, and conversely.

The mechanical force introduced into the vertebral column during a spinal manipulation may directly alter segmental biomechanics by releasing trapped meniscoids, releasing adhesions, and reducing distortion of the annulus fibrosus.<sup>3-6</sup> These mechanical changes are thought to restore zygapophyseal joint mobility and joint play.<sup>5</sup> In fact, authoritative discussion of spinal manipulation considers "the goal of manipulation [to be] to restore maximal, pain-free movement of the musculoskeletal system."<sup>7</sup>

Spinal manipulation may affect impulse-based neural activity by altering the inflow of sensory information to the spinal cord. Mechanical forces introduced into the vertebral column may stimulate or inhibit<sup>9-11</sup> receptive nerve endings

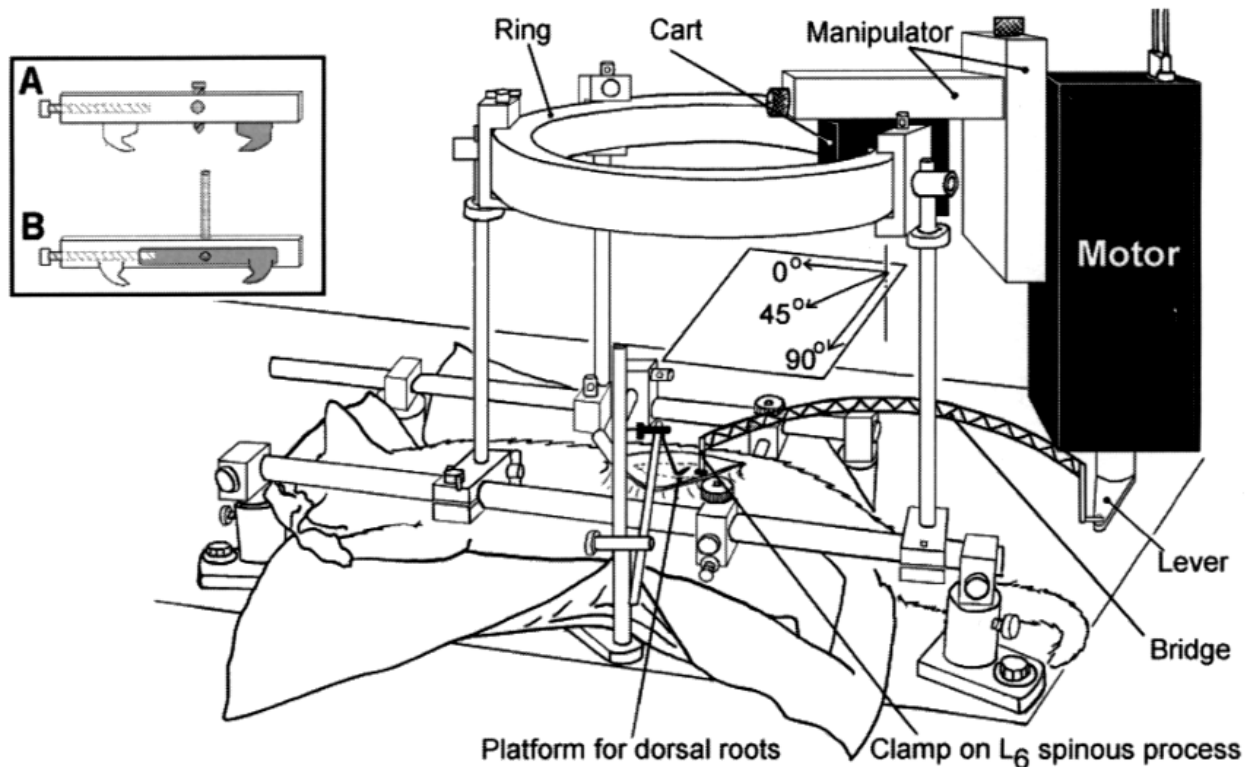
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**Fig 1.** Schematic of preparation. Inset: Top (A) and medial (B) views of clamp that attached to spinous process of L6 vertebra

in paraspinal tissues, including skin, muscle, tendons, ligaments, facet joints, and intervertebral disk. Thus, spinal manipulation may remove a source of aberrant sensory input or possibly add a novel input. The manipulation-induced changes in sensory input are thought to affect central neural integration within motor, nociceptive, and/or autonomic neuronal pools and thereby elicit changes in efferent somatomotor and visceromotor activity.<sup>8</sup>

Gillette<sup>11</sup> presented a speculative yet comprehensive analysis of the receptive nerve endings potentially affected by chiropractic adjustments. He suggested that 40 types of mechanoreceptive endings in the skin and deep tissues of the paraspinal region could be activated by spinal manipulation because they have mechanical thresholds below the level of mechanical force applied during a manipulation. The mechanoreceptors include proprioceptors (muscle spindles, both primary and secondary endings, and Golgi tendon organs [GTOs]), low threshold mechanoreceptors, high threshold mechanoreceptors, high threshold mechanonociceptors, and high threshold polymodal nociceptors.<sup>11</sup> Thus all classifications of sensory afferents—ie, fibers of groups Ia, Ib, II, III, and IV—could contribute to the impulse-based neural mechanisms. Whether and how the discharge of this diverse group of receptive endings mediates the physiologic effects of spinal manipulation awaits elucidation.

Korr<sup>8</sup> proposed that spinal manipulation increases joint mobility by producing a barrage of impulses in muscle spindle afferents, ultimately silencing facilitated  $\gamma$ -motoneurons. He hypothesized that  $\gamma$ -motoneuron discharge is elevated to

muscles of vertebral segments in need of spinal manipulation. The high gain of the  $\gamma$  loop impairs joint mobility by sensitizing the myotatic stretch reflex to abnormally small changes in muscle length. The barrage of impulses from muscle spindle afferents in response to the spinal manipulation reduces the gain of the  $\gamma$  loop through an undetermined neural pathway. It should be clearly recognized that this mechanism has not been subjected to experimental investigation and remains hypothetical.

Despite the proposed involvement of either large-diameter afferents or small-diameter afferents in the effects of spinal manipulation, we do not know how any paraspinal afferent responds to spinal manipulation. The purpose of the present study was to determine how large-diameter, muscle spindle, and GTO afferents respond to spinal manipulation. In addition, we report the response of one afferent whose receptive ending was presumed to be a Pacinian corpuscle.

## MATERIALS AND METHODS

### General

Experiments were performed on 10 adult cats. The cats were treated in accordance with the Guiding Principles in the Care and Use of Animals approved by the American Physiological Society. The preparation has been described in detail previously.<sup>12</sup> Briefly, anesthesia was induced and maintained through use of 5% halothane and 3% halothane, respectively. 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

was ventilated mechanically through use of a Harvard Respirator (model 681; Harvard Apparatus, South Natick, Mass). After the catheters had been positioned and the trachea intubated, the preparation was maintained on anesthesia through intravenous use of pentobarbital sodium (35 mg/kg). Arterial pH, PCO<sub>2</sub>, and PO<sub>2</sub> were monitored every 60 minutes by means of a Corning 238 pH/blood gas analyzer (Ciba-Corning Diagnostics Corp, East Walpole, Mass). Arterial blood gas values were maintained within the normal range (pH 7.32 to 7.43; PCO<sub>2</sub>, 32-37 mm Hg; PO<sub>2</sub> >85 mm Hg). Arterial pH and PCO<sub>2</sub> were corrected by infusing sodium bicarbonate and by adjusting the ventilator. PO<sub>2</sub> was maintained by bleeding 100% O<sub>2</sub> into the intake line of the ventilator.

The right L6 dorsal root was isolated for electrophysiological recordings while the L6-L7 vertebrae and associated paraspinal tissues on the right side of the vertebral column were left intact. The distal cut ends of the root were placed on a small platform. Thin filaments were teased to obtain single unit recordings from sensory neurons with receptive fields in the paraspinal muscles.

### Vertebral Loading

Fig 1 is a schematic of the preparation used to provide spinal manipulative-like loads to the vertebral column. Loads were applied to the L6 vertebra at its spinous process. A specially fabricated C-clamp (Fig 1, *inset*) was attached to the L6 vertebra by cradling the caudal and cranial edges of the L6 spinous process. A rigid bridge was connected at one end to a vertical post rising from the spinous process clamp and at the other end to the lever arm of an electronically controlled feedback motor (see next section). The lever arm thus transmitted the mechanical load to the spinous process of the L6 vertebra via the rigid bridge.

### Electronic Feedback Control System

Loads were applied at the spinous process of the L6 vertebra through use of an electronic feedback control system (Lever System Model 310, Aurora Scientific, Aurora, Ontario). The magnitude and time course of the load were controlled by an input signal at the front panel of the electronic feedback interface. An arbitrary waveform generator was programmed to replicate the force-time profile of a spinal manipulation, as previously described by Hessel et al.<sup>13</sup> The amplitude-time profile from Hessel et al (see their second figure<sup>13</sup>) was scanned and digitized through use of graphing software (Origin, version 5.0, OriginLab Corporation [formerly Microcal Software, Inc], Northampton, Mass). Windows-based computer software for the arbitrary waveform generator (Waveform DSP2, Wavetek, Everett, Wash) enabled one to "copy and paste" the x-y coordinate pairs directly from the Windows 95 (Microsoft, Redmond, Wash) clipboard into a DSP2 file. The digitized waveform was downloaded from a DSP2 file into the arbitrary waveform generator. Thus the physical tracing of a waveform in the "real" world was re-created as a digitized signal in the waveform generator. The full-scale amplitude resolution of the waveform was set to 100% times the body weight of the cat.

The motor could deliver mechanical loads of up to 5 kg in 0.5-g increments and did not generate electric artifacts during neural recordings. The 3-portion spinal manipulative load consisted of 4 phases: (1) *control* (duration, 1.0-3.0 seconds); the preload, consisting of (2) *ramp-up* (duration, 3.0 seconds) and (3) *plateau* (duration, 3.0 seconds; force, 25% body weight); and (4) *impulse* (duration, 200 ms; peak force, 100% body weight; see the load tracings in Figs 2 and 4).

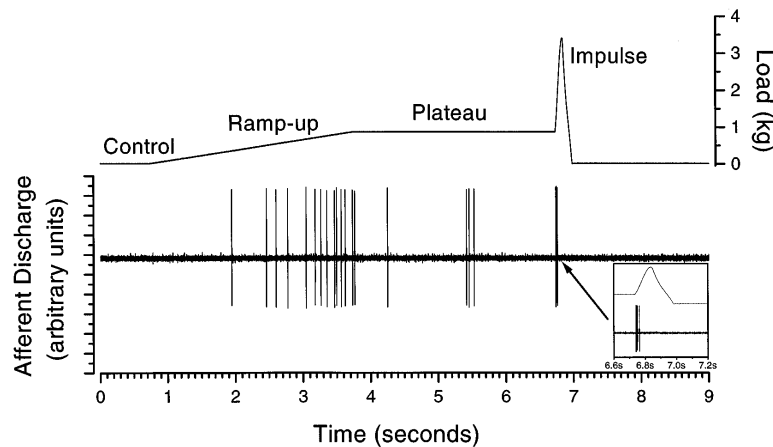
### Controlling the Direction and Angle of the Spinal Manipulative-like Load

Loads to the L6 vertebra were induced within the cat's longitudinal plane. The motor's vertical position was adjusted through use of a heavy-duty manipulator (shown in Fig 1). The lever arm was positioned level with the attachment of the spinous process clamp to the L6 spinous process. Coupled motions of the vertebrae out of the longitudinal plane may have arisen but were not determined. Loads could be applied at angles relative to the vertebral column by moving the cart (shown in Fig 1) along the circular aluminum ring. Manipulative-like loads directed into the center of the ring were called "distractive," and loads directed away from the center of the ring were called "compressive," in reference to their effects on the right L6-L7 articulation.

### Electrophysiological Recordings

Single unit activity was recorded from dorsal root neurons with receptive fields in the paraspinal muscles. Thin filaments from the L6 dorsal root were teased by means of forceps under a dissecting microscope and placed on a monopolar stainless steel hook electrode. Filaments were teased until impulse activity from a single unit could be identified. Action potentials were passed through a high-impedance probe (Grass HIP511, West Warwick, RI) and then amplified (Grass P511K). Action potentials were monitored through use of an audiomonitor (Grass) and the video display of a TA5000 chart recorder (Gould Electronics, Inc, Eastlake, Ohio). Action potentials were recorded on the chart recorder and simultaneously digitized (DR890 Neurorecorder, Neurodata, Inc, New York, NY) and recorded onto videotape for playback and offline analysis. Signals were displayed on a digital storage oscilloscope (Gould, Inc) to determine a unit's conduction velocity. Data analysis was performed through use of a personal computer-based data acquisition system (RC Electronics Inc, Santa Barbara, Calif).

Afferents were classified as muscle proprioceptors—ie, GTOs—or muscle spindles on the basis of their resting discharge, sensitivity to succinylcholine (100 µg/kg, intraarterial), conduction velocity, and von Frey threshold.<sup>14-16</sup> No effort was made to differentiate between primary and secondary spindle afferents. In addition, muscle spindle afferents were not differentiated from GTOs by their responses to electrically induced muscle contraction. The receptive field of each afferent was initially identified by stroking or compressing paraspinal tissues through the overlying, intact dorsal lumbar fascia by means of a cotton-tipped applicator. Afferents could be activated over a broad area of the paraspinal tissues; however, the greatest response was typi-



**Fig 2.** Original tracing of GTO's response to spinal manipulative-like load. Inset shows expanded time scale of GTO's discharge during impulse.

cally evoked from a relatively well-circumscribed area in the paravertebral region. The mechanical threshold of each afferent in this sensitive area was quantitated by means of calibrated nylon filaments (von Frey-like hairs; Stoelting Physiology Equipment, Wood Dale, Ill).

## RESULTS

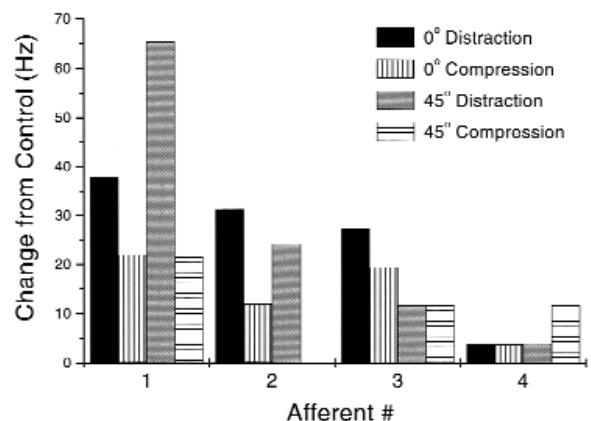
### Classification of Afferents

Single unit recordings were obtained from 10 afferents with receptive fields in the multifidus or longissimus muscles of the lumbar spine. All but one of the afferents were classified as muscle proprioceptors—ie, muscle spindles or GTOs—on the basis of their resting discharge, sensitivity to succinylcholine, conduction velocity, and von Frey threshold. Five afferents were classified as muscle spindles. They discharged at rest (range, 15-98 Hz) and responded with a high-frequency discharge to succinylcholine injection (100 µg/kg, intraarterial). The conduction velocity of the muscle spindle afferents was  $48.4 \pm 8$  m/s (mean  $\pm$  SE; range, 28-74 m/s). Four afferents were classified as GTOs. They had no resting discharge and responded with a low-frequency, short-lasting, and sometimes irregular discharge to succinylcholine injection. The mean conduction velocity of the 4 GTOs was  $51.8 \pm 3.2$  m/s (range, 47-60 m/s).

Von Frey thresholds of the 9 proprioceptive afferents were low (range, 0.4-164.3 g). The magnitude of the mechanical threshold was similar for the muscle spindles and the GTOs, though it tended to be higher for the GTOs. However, it should be recognized that the use of von Frey filaments is an imperfect way to determine the sensitivity of receptive endings located deep in tissues because the intervening tissue mass can redistribute the load applied at the tip of the von Frey hair. Nevertheless, this tool indicated that these afferents had low mechanical thresholds.

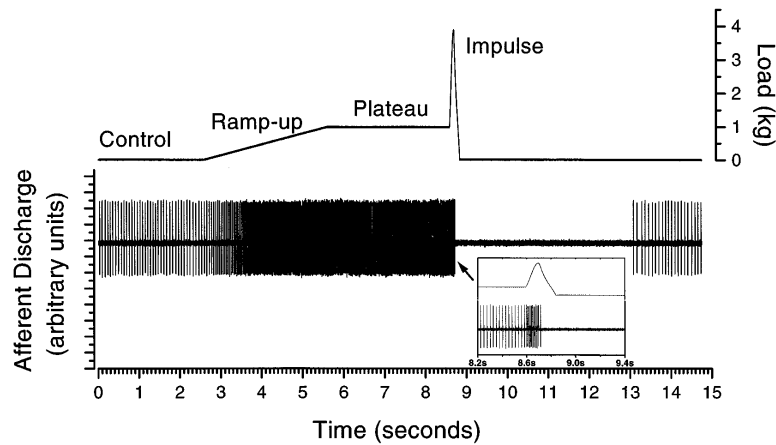
### Golgi Tendon Organs

**Responses to spinal manipulative-like loads.** Fifteen manipulative-like loads were applied to the L6 spinous process while the



**Fig 3.** Response of GTO afferents to change in direction and angle of impulse. Afferent discharge on y axis is actual rate during impulse, because discharge rate during control period was 0 Hz (see Table).

discharge of 4 GTO afferents was recorded. Fig 2 is an original recording from a GTO during one loading protocol. The Table shows the discharge frequency of each afferent during the rest (control), preload (ramp-up and plateau), and impulse portions of the manipulation. GTOs had no resting discharge. The preload generally had little affect on the GTOs, increasing their discharge by more than 10 Hz during only 3 of the 15 manipulations. The discharge frequency of the GTOs increased more to the impulse of the manipulation than to the loads preparatory to the impulse. The impulse increased the discharge frequency of the GTOs by  $21 \pm 4$  Hz in comparison with control during all manipulations. Similarly, the impulse increased the discharge frequency of the GTOs by  $19 \pm 4$  Hz in comparison with ramp-up and plateau during 14 and 13 of the 15 manipulations, respectively. During 2 manipulative-like loads, the preload evoked a discharge similar in magnitude to that evoked by the



**Fig 4.** Original tracing of muscle spindle's response to spinal manipulative-like load. Inset shows spindle's discharge on expanded time scale immediately before, during, and shortly after impulse.

**Table.** Summary of Golgi tendon organ responses to spinal manipulative-like loads

| Cat no. | Manipulation |                 | Control (Hz) | Preload      |              | Impulse (Hz) | Recovery time (s) |
|---------|--------------|-----------------|--------------|--------------|--------------|--------------|-------------------|
|         | Direction    | Angle (degrees) |              | Ramp-up (Hz) | Plateau (Hz) |              |                   |
| 1       | 0            | Distractive     | 0            | 1            | 0            | 38           | 0                 |
| 1       | 0            | Compressive     | 0            | 0            | 0            | 22           | 0                 |
| 1       | 45           | Distractive     | 0            | 2            | 0            | 65           | 0                 |
| 1       | 45           | Compressive     | 0            | 0            | 0            | 22           | 0                 |
| 2       | 0            | Distractive     | 0            | 11           | 34           | 31           | 0                 |
| 2       | 0            | Compressive     | 0            | 0            | 0            | 12           | 0.3               |
| 2       | 45           | Distractive     | 0            | 14           | 41           | 24           | 0                 |
| 3       | 0            | Distractive     | 0            | 0            | 0            | 27           | 0                 |
| 3       | 0            | Compressive     | 0            | 5            | 1            | 20           | 0                 |
| 3       | 45           | Distractive     | 0            | 14           | 1            | 12           | 0                 |
| 3       | 45           | Compressive     | 0            | 0            | 0            | 12           | 19.8              |
| 4       | 0            | Distractive     | 0            | 0            | 0            | 4            | 0                 |
| 4       | 0            | Compressive     | 0            | 0            | 0            | 4            | 0                 |
| 4       | 45           | Distractive     | 0            | 0            | 0            | 4            | 0                 |
| 4       | 45           | Compressive     | 0            | 0            | 0            | 12           | 0.3               |

impulse; during 1 manipulative-like load, the plateau evoked a discharge substantially higher than that evoked by the impulse (41 Hz vs 24 Hz, respectively).

**Responses to a change in direction or angle of a spinal manipulative-like load.** Manipulations applied in both the distractive and the compressive directions stimulated the GTOs (Fig 3). In 3 of the 4 afferents, the largest change in GTO activity in response to the impulse occurred during manipulation in the distractive direction. In one afferent, a compressive impulse direction evoked the largest change in discharge frequency (Fig 3). Manipulation in the distractive direction increased the discharge frequency by the greatest magnitude (compare the greatest change in discharge by afferents 1, 2, and 3 during distraction [65, 31, and 27 Hz, respectively] with that by afferent 4 during compression [12 Hz]).

Although the GTOs as a group did not respond uniformly to either the direction or the angle of the manipulation, Fig 3 suggests that an individual GTO could respond preferentially to the direction or angle of load. For example, afferent 1 was increasingly responsive to manipulation applied in the dis-

tractive direction as its angle changed from 0 to 45 degrees, but it was equally responsive to a compressive manipulation regardless of the angle. Afferent 2 was also responsive to distractive manipulation but became decreasingly so as the angle changed from 0 to 45 degrees. On the other hand, afferent 3 was most responsive to manipulation applied at 0 degrees and became increasingly responsive as the direction changed from compressive to distractive. When the manipulation was applied at 45 degrees, this afferent was equally responsive to distractive and compressive manipulations.

**Recovery time.** In general, the 4 GTOs became silent immediately at the end of the impulse (Table). One GTO continued to discharge for 20 seconds after the end of the manipulation. This prolonged recovery time occurred after compressive loading.

#### Muscle Spindles

**Responses to spinal manipulative-like loads.** Sixteen manipulative-like loads were applied to the L6 spinous process while the discharge of 5 muscle spindle afferents was being recorded.

Fig 4 shows a representative recording from one muscle spindle afferent during a single loading protocol. Fig 5 compares muscle spindle responses to the impulse and to the plateau during each spinal manipulative-like load. During 10 of 16 spinal manipulative-like loads, the impulse increased muscle spindle discharge more than did the plateau (as indicated by the symbols above the diagonal line in Fig 5). The magnitude of the discharge evoked by the impulse was greater than that evoked by the plateau during these 10 manipulations. Muscle spindle discharge increased  $201\% \pm 57\%$  (mean  $\pm$  SE; range, 34% to 597%) during the impulse but increased only  $29\% \pm 20\%$  (range, 9% to 163%) during the plateau. Distractive manipulations stimulated muscle spindle afferents more effectively than compressive manipulations. On the other hand, the impulse unloaded muscle spindle afferents during 6 of the 16 manipulations. Five of these 6 manipulations were in the compressive direction. It is worth noting that the plateau phase stimulated muscle spindle afferents during 9 of the 16 manipulations (as indicated by the symbols in quadrants I and II).

**Responses to a change in direction or angle of a spinal manipulative-like load.** Muscle spindle afferents whose discharge increased during the impulse at 0 degrees of distraction similarly increased during the impulse at 45 degrees of distraction (Fig 6, B, C, and D). However, changing the angle of the manipulation could dramatically alter the response of a muscle spindle (in Fig 6, B and Fig 6, D, compare 0 degrees and 45 degrees of compression; in Fig 6, E compare 0 degrees and 45 degrees of distraction).

**Recovery time.** Afferent discharge from muscle spindles frequently did not immediately return to control values after each manipulation. Recovery times ranged from 100 ms to 21.2 seconds ( $3.6 \pm 1.3$  seconds) after 11 of 16 manipulations. Recovery was immediate after the remaining 5 manipulations. Of the 10 manipulations in which muscle spindle discharge increased more during the impulse than during the plateau, 7 manipulations resulted in spindle silence after the peak of the impulse (an example appears in Fig 4). Silent periods ranged from 0.1 to 4.3 seconds (mean,  $1.3 \pm 0.6$  seconds).

#### Unclassified Afferent

The response of the one unclassified afferent is worth describing because of its unique response to a spinal manipulative-like load in comparison with a ramp-and-hold load. All loads were applied at 0 degrees of distraction. The afferent was silent at rest. It was classified as rapidly adapting on the basis of its very brief discharge to indentation of the paraspinal tissues (data not shown). This response suggests that its receptive ending was a Pacinian corpuscle. Ramp-and-hold loads of successively increasing magnitude did not stimulate this afferent (Fig 7, A). However, the afferent was responsive to a spinal manipulative-like load (Fig 7, B). The magnitude of the impulse was only 25% that of the highest ramp-and-hold load.

#### DISCUSSION

This study demonstrates that muscle spindles and GTOs with receptive endings in the paraspinal muscles respond to

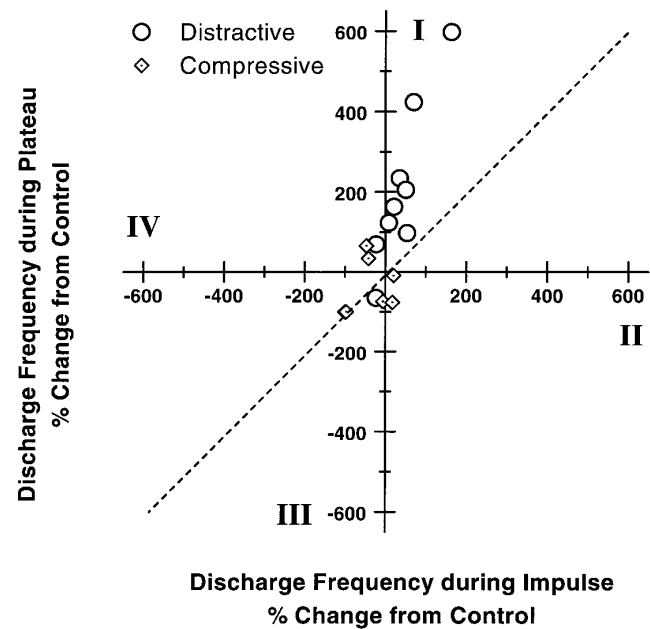
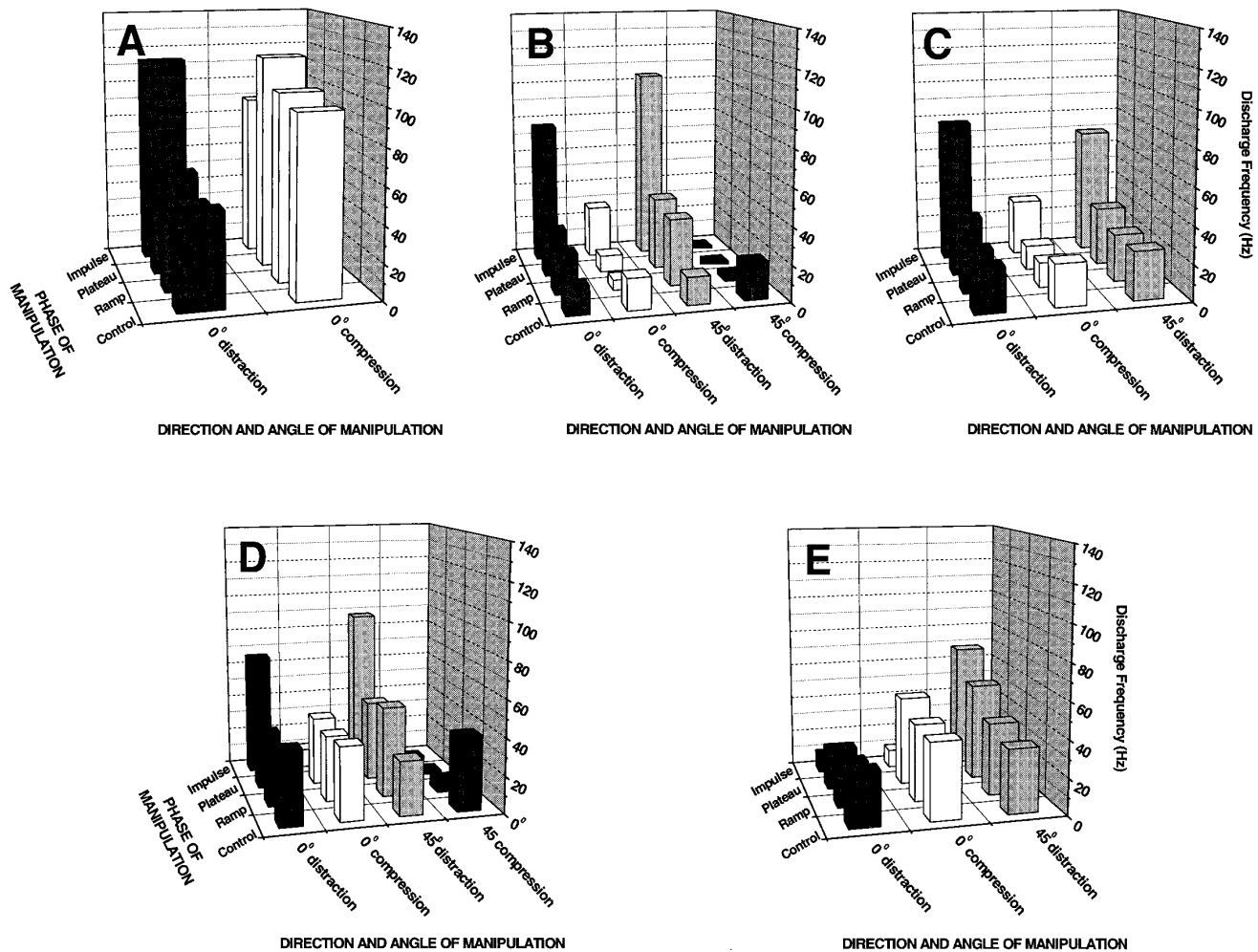


Fig 5. Response of muscle spindle afferents to loading phase of impulse (y axis) in comparison with plateau (x axis). Afferent discharge is expressed as percent increase in comparison with control period.

vertebral loads whose force-time profiles are similar to that of a load delivered during spinal manipulation.<sup>13</sup> The spinal manipulative-like load in the present experiment was applied at the L6 spinous process along the long axis of the vertebral column in anesthetized cats. Muscle spindles discharged at rest, and they responded to the load preparatory to the impulse (preload) and to the impulse of the manipulation. Distraction of the L6-L7 facet loaded the muscle spindles more often than did compression of that facet. Discharge frequency was generally greater in magnitude during the impulse than during the preload. After the impulse, muscle spindles often paused for up to 4 seconds. GTOs were generally silent at rest and did not respond to the preload. The impulse increased the discharge frequency of GTO afferents. The largest increase in GTO afferent activity occurred when the manipulation distracted the L6-L7 facet. However, GTO afferents also responded when manipulation compressed the L6-L7 facet.

Most chiropractic theories underlying the reason for and explaining the effects of spinal manipulation hypothesize a role for the nervous system.<sup>17</sup> The chiropractic subluxation—a structural dysrelationship, typically between contiguous vertebrae—is thought to affect reflex neural activity. As a corollary, correction of the subluxation through the use of spinal manipulation is thought to affect the neuromusculoskeletal system. The unique effect of the impulse portion of a spinal manipulation on the responses of paraspinal proprioceptors may contribute, in part, to the effects of spinal manipulation.

The anatomy and reflex organization of spindles in paraspinal muscles have some unique aspects in comparison with those of the hindlimb. In the cat, hindlimb muscle spin-



**Fig 6.** Responses of 5 muscle spindle afferents to change in direction and angle of spinal manipulative-like load during 4 phases of manipulation.

dles are described as single receptors located both deep in the muscle belly and close to the musculotendinous junction.<sup>18-20</sup> Spindle density ranges from 5 to 45 spindles/g of hindlimb muscle weight.<sup>21</sup> In the cervical spines of human beings<sup>22,23</sup> and cats,<sup>24,25</sup> however, muscle spindles are rarely seen as single entities, and their densities are greater than in the peripheral musculature. Richmond and Abrahams<sup>15,25</sup> describe cervical spindle complexes wherein 2-6 spindles are in close contact with each other or share capsules and/or intrafusal fibers. Spindle density can be 2 to 8 times higher (47-107 spindles/g) in superficial cervical muscles<sup>25</sup> and 10 to 25 times higher (137-460 spindles/g) in deep cervical muscles<sup>24</sup> than in hindlimb muscles. Carlson<sup>26</sup> states that in the lumbar spine of the cat, muscle spindles are present in the longissimus, iliocostalis, sacrocaudalis, intertransversarii, multifidus, and interspinalis muscles; however, quantification and morphologic description of the spindles were not performed.

It is well recognized that in the cat hindlimb, the monosynaptic stretch reflex is elicited by excitation of muscle spindles, which in turn activates  $\alpha$ -motoneurons to the same

muscle in which the spindle is located (homonymous  $\alpha$ -motoneurons).<sup>27-29</sup> The stretch reflex arc uses a single excitatory synapse to homonymous  $\alpha$ -motoneurons.<sup>28,30</sup> The afferent arm of the reflex is comprised of group Ia and group II afferents.<sup>29,31</sup> Each group Ia afferent from a given hindlimb muscle makes functional, monosynaptic connections with 50% to 100% of the homonymous  $\alpha$ -motoneurons.<sup>32,33</sup> Thus, stimulation of muscle spindles from a given hindlimb muscle evokes a monosynaptic excitatory postsynaptic potential (EPSP) in all  $\alpha$ -motoneurons to the same muscle.<sup>34,35</sup>

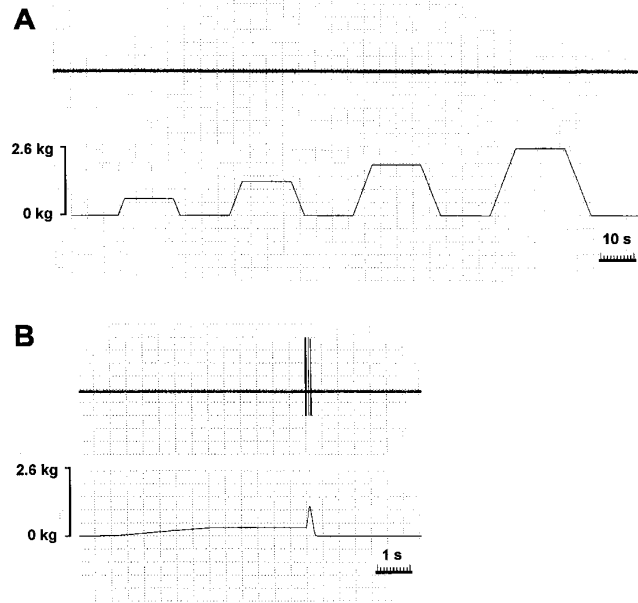
In the cervical spine, monosynaptic reflex connections to homonymous  $\alpha$ -motoneurons are weaker. EPSPs are smaller in amplitude, and group Ia afferents make functional connections with only 10% of the homonymous  $\alpha$ -motoneurons.<sup>36,37</sup> This probably contributes to the absence or weakness of monosynaptic reflexes in cervical muscle.<sup>38</sup> In the lumbar spine of the cat, stretch reflexes can be elicited from the longissimus muscle but not from the iliocostalis muscle. The existence of stretch reflexes from the multifidus muscle in the cat is unknown. Conduction delays suggest that the reflex arc, unlike that in the hindlimb, is not monosyn-

aptic.<sup>28,30,39</sup> The presence of monosynaptic stretch reflexes from the deeper lumbar muscles has not been determined. In human beings, indirect evidence for the presence of muscle spindles and muscle spindle reflexes in lumbar paraspinal muscles was obtained by measuring evoked cerebral potentials in response to vibration of the lumbar paraspinal muscles,<sup>40</sup> which selectively stimulates muscle spindles.<sup>41</sup>

Paraspinal spindle reflexes could contribute to the short-lasting electromyographic (EMG) responses recorded from paraspinal skeletal muscle during spinal manipulation.<sup>42,43</sup> An activator thrust to a transverse process elicits paraspinal EMG activity at the same segmental level within 2-3 ms. However, if the EMG activity was initiated by muscle spindles, it was probably not produced by a monosynaptic reflex. If one assumes an average conduction velocity of 60 m/s and a one-way conduction distance of 3 cm between paraspinal muscles and the ipsilateral dorsal horn at the same segmental level, then the calculated conduction time would be 1 ms. Assuming synaptic delay to be approximately 0.5 ms, the reflex pathway would have to contain more than one synapse. Herzog et al<sup>43</sup> showed that spinal manipulation evoked paraspinal EMG activity in a pattern related to the region of the spine that was manipulated. The EMG responses from paraspinal muscles both near and distant from the site of manipulation occurred 50-200 ms after initiation of the manipulative thrust (impulse). These latencies are too slow for the reflex to be monosynaptic from muscle spindles. Our data support the possibility that muscle spindle reflexes can be initiated from a spinal manipulative impulse. Although the apparent reflex pathway from muscle spindles is likely oligosynaptic, other classes of afferents stimulated by vertebral movement<sup>44,45</sup> may contribute to reflex EMG activity.

Spinal manipulation is often applied to patients on the basis of clinical findings related to reduced segmental range of motion and to palpatory findings indicative of muscle hypertonicity. Spinal manipulation is thought to increase the range of motion and normalize muscle activity. Herzog et al<sup>43</sup> recently demonstrated that in a patient with spontaneous paraspinal muscle EMG activity, spinal manipulation initiated a reflex increase in EMG activity followed by a reduction in the spontaneous EMG activity. On the basis of findings in the present study, we speculate that combined activation of GTO afferents and silencing of muscle spindle afferents during the spinal manipulation can decrease spontaneous EMG activity by reflex inhibition or disfacilitation of  $\alpha$ -motoneurons.

Korr<sup>8</sup> proposed a neurophysiological mechanism to explain abnormal segmental function associated with the subluxation and the effects of spinal manipulation on segmental function. Abnormal segmental function may arise from altered paraspinal muscle activity. Korr suggests that paraspinal muscles of subluxated segments are responding to increased  $\gamma$ -motoneuron discharge. The increased  $\gamma$  bias increases the sensitivity of paraspinal muscle spindles to stretch with consequent activation or facilitation of  $\alpha$ -motoneurons to paraspinal muscles. Korr proposes that spinal manipulation resets the  $\gamma$  bias by producing a high-fre-



**Fig 7.** Response of unclassified afferent to prolonged ramp-and-hold load (A) and spinal manipulative-like load (B) applied to L6 vertebra. Afferent was probably a rapidly adapting receptor, because it responded with very brief discharge to indentation of paraspinal tissues (data not shown). In each figure part, upper trace is electric recording from L6 dorsal root and lower trace is mechanical load applied to L6 vertebra. Note different time scales for figure parts.

quency discharge in muscle spindle and GTO afferents. Although this hypothesis remains speculative because changes in  $\gamma$  bias associated with segments displaying characteristics of a subluxation have never been shown, the results of the present experiments suggest that spinal manipulation does bombard the central nervous system with sensory input from muscle proprioceptors and that this is followed by a prolonged silence. The central effects of these responses to impulse loads is not known, but it is interesting that input from muscle spindle and GTO afferents can converge on common reflex pathways in the central nervous system.<sup>46</sup>

Clinical studies involving sham manipulations should consider the types of sensory inputs they are trying to either mimic or exclude. Sham manipulations that provide a preload but not an impulse may still activate paraspinal muscles afferents. The present study has demonstrated this potential. Further investigation is necessary to clarify how the central nervous system integrates proprioceptive information evoked during each phase of the manipulation.

## CONCLUSION

Our data suggest that short-duration, high-amplitude load delivered during a spinal manipulation can stimulate muscle spindles and GTOs. Some mechanoreceptors (eg, the presumed Pacinian corpuscle) may be stimulated only by the impulse and not by the preload. The results of these experiments confirm the speculation that muscle spindles



and GTOs can be coactivated by spinal manipulative loads.<sup>11</sup> However, the physiologically relevant portion of the manipulation may relate to its ability to increase as well as decrease the muscle proprioceptor discharge. In addition, the preload, even in the absence of the impulse, can alter the discharge of paraspinal muscle spindles. We speculate that loading of the vertebral column during a sham manipulation may affect the discharge of paraspinal proprioceptors.

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