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# Spinal manipulation force and duration affect vertebral movement and neuromuscular responses ☆

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**Abstract**

*Background.* Previous study in human subjects has documented biomechanical and neurophysiological responses to impulsive spinal manipulative thrusts, but very little is known about the neuromechanical effects of varying thrust force–time profiles.

*Methods.* Ten adolescent Merino sheep were anesthetized and posteroanterior mechanical thrusts were applied to the L3 spinous process using a computer-controlled, mechanical testing apparatus. Three variable pulse durations (10, 100, 200 ms, force = 80 N) and three variable force amplitudes (20, 40, 60 N, pulse duration = 100 ms) were examined for their effect on lumbar motion response (L3 displacement, L1, L2 acceleration) and normalized multifidus electromyographic response (L3, L4) using a repeated measures analysis of variance.

*Findings.* Increasing L3 posteroanterior force amplitude resulted in a fourfold linear increase in L3 posteroanterior vertebral displacement ($p < 0.001$) and adjacent segment (L1, L2) posteroanterior acceleration response ($p < 0.001$). L3 displacement was linearly correlated ($p < 0.001$) to the acceleration response over the 20–80 N force range (100 ms). At constant force, 10 ms thrusts resulted in nearly fivefold lower L3 displacements and significantly increased segmental (L2) acceleration responses compared to the 100 ms (19%, $p = 0.005$) and 200 ms (16%, $p = 0.023$) thrusts. Normalized electromyographic responses increased linearly with increasing force amplitude at higher amplitudes and were appreciably affected by mechanical excitation pulse duration.

*Interpretation.* Changes in the biomechanical and neuromuscular response of the ovine lumbar spine were observed in response to changes in the force–time characteristics of the spinal manipulative thrusts and may be an underlying mechanism in related clinical outcomes.


*Keywords:* Biomechanics; Dynamic loading; Electromyography; Lumbar spine; Spinal manipulation

## 1. Introduction

In the treatment of patients with pain of musculoskeletal origin, chiropractic practitioners typically employ short duration, high velocity thrusts (manipulation) designed to restore pain-free movement of the musculoskeletal system and to decrease disability (Meeker and Haldeman, 2002). Of the numerous treatments

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utilized for spinal manipulative therapy (SMT), however, very few studies have examined mechanical variables that may influence physiological responses and putative effects associated with chiropractic therapy (Colloca et al., 2004). Because SMT is a mechanical intervention it is inherently logical to assume that its mechanisms of therapeutic benefit may lie in the underlying mechanical properties of the applied force (mechanical mechanisms), the body's response to such force (mechanical or physiologic mechanisms), or a combination of these and other factors. However, clinical trials have been equivocal in terms of the beneficial nature of these procedures to most comparison treatments (Meeker and Haldeman, 2002; Bronfort et al., 2004). Moreover, although basic science research directed towards understanding the mechanisms of SMT has increased dramatically during the past 15 years, the most fundamental biomechanical aspects of spinal manipulations are still lacking (Herzog, 2000).

From a biomechanical perspective, human cadaver and in vivo studies have characterized the forces and force–time histories associated with various SMT techniques (Gal et al., 1997a,b; Gal et al., 1995; Colloca et al., 2004; Keller et al., 2003; Nathan and Keller, 1994; Maigne and Guillon, 2000; Herzog et al., 1993; Triano and Schultz, 1997). Information on the force–displacement response of functional spinal units have been reported using both in vitro (Gal et al., 1997b) and in vivo (Nathan and Keller, 1994; Keller et al., 2003) studies, and more recently basic science research studies have begun to characterize the temporal relationships between mechanical stimulation and neurophysiological responses (Colloca et al., 2000, 2003, 2004; Sung et al., 2005). Neuromuscular reflex responses have been observed in the paraspinal musculature when SMT is applied to different spinal regions in asymptomatic subjects, and differences have been reported among these responses for different SMT techniques (Herzog et al., 1999; Symons et al., 2000). Differences in paraspinal neuromuscular reflex amplitude have also been reported in patients with low back pain, which is hypothesized to be indicative of the patients underlying clinical status (Colloca and Keller, 2001). Recent animal experimental studies also suggest that pulse duration, not force amplitude during SMT play a prominent role in the neurophysiological response of the lumbar spine (Sung et al., 2005).

Few studies have quantified both the biomechanical and neuromuscular responses associated with dynamic mechanical stimulation. Thus, the aim of this study was to investigate the effects of varying PA mechanical stimulation force–time profiles on lumbar vertebral motion response. Both force amplitude and duration were hypothesized to alter the motion characteristics of the lumbar spine. In addition, we hypothesized that mechanical stimulus force amplitude and duration would affect neurophysiological (EMG) response of the lumbar spine.

## 2. Methods

### 2.1. Animal preparation

Ten adolescent Merino sheep (mean 46.5; SD 5.6 kg) were examined using a research protocol approved by the Animal Ethics Committee and institutional board review board of the Institute of Medical and Veterinary Science (Adelaide, South Australia). Following anesthesia, the animals were placed in a standardized prone-lying position with the abdomen and thorax supported by a rigid wooden platform and foam padding, respectively, thereby positioning the lumbar spine parallel to the operating table and load frame.

Bony prominences of the L1–L3 spinous process were exposed using electrocaudery, and finely threaded, 1.8 mm diameter intraosseous stainless-steel pins were rigidly fixed to the L1 and L2 lumbar spinous processes under fluoroscopic guidance. Dynamic (0.3 Hz–10 KHz), low noise (0.0003 g RMS resolution), AC-coupled piezoelectric, integral sensor, 10-g tri-axial accelerometers (Crossbow Model CXL100HF3, Crossbow Technology, Inc., San Jose, CA, USA) were subsequently attached to the L1 and L2 intraosseous pins. The $x$-, $y$- and $z$-axes of the accelerometer were oriented with respect to the medial–lateral (ML), posterior–anterior (PA) and cranial–caudal or axial (AX) axes of the vertebrae. The natural frequency of the pin and transducer, determined intraoperatively by "tapping" the pins in the ML and AX axes, was greater than 80 Hz. Only PA axis motion responses are presented in this paper.

Four 28-gauge concentric bipolar needle electro myographic (nEMG) electrodes (model EL451, Biopac Systems, Inc. Santa Barbara, CA, USA) were inserted bilaterally into the multifidus musculature adjacent to L3 and L4. The nEMG electrodes were 460 μm in diameter and 3.0 cm long with a recording area of 0.06 $mm^2$. The electrodes were spaced 2 cm apart each right and left and the leads were secured to the draping with clips and adhesive tape. Prior to draping and surgery a monopolar ground needle electrode (Model EL452, Biopac Systems, Inc.) was inserted into the fascia adjacent to the sheep trochanter.

### 2.2. Mechanical testing apparatus

A custom, computer-controlled mechanical testing apparatus was used to deliver a uniform "pulse" mechanical excitation directly to the L3 spinous process of the sheep spine under load control (Fig. 1). The apparatus was comprised of a linear voice coil actuator