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Acceleration of clinician hand movements during spinal manipulative therapy☆

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ABSTRACT

This study used an observational design to examine the kinematics of spinal manipulative therapy (SMT) by determining the acceleration characteristics of the manipulative input at the cervical, thoracic, and lumbar spinal regions. Studies of SMT have been restricted to measuring the forces that result from the manipulative input. Several studies have indicated the rate of force development is a key parameter of clinically delivered SMT. Despite this, the movement strategies employed during SMT, including acceleration, have not been directly measured. Participants ($n = 29$) were recruited from a private practice chiropractic clinic. A wireless accelerometer attached to the clinician's hand was used to characterize the thrust phase of the SMT treatments. Significant differences were found across each spinal region for acceleration amplitude parameters ($p < 0.0001$). Post-hoc analysis indicated that amplitudes significantly increased in order from thoracic to cervical to lumbar regions ($p < 0.0001$). Spinal level was also a significant factor in determining the temporal parameters of hand acceleration during SMT ($p < 0.0005$). This study provides a description of the acceleration properties of clinically delivered SMT. Consistent with that reported for SMT forces, acceleration amplitudes varied significantly across spinal regions with relatively little differences in acceleration latencies. Notably, acceleration amplitudes and latencies were not associated with each other within spinal regions. These findings indicate that changes in acceleration amplitude, rather than latency, are used to tailor SMT to individuals.

1. Introduction

Spinal manipulative therapy (SMT) is a widely administered treatment for acute and chronic spinal conditions and is often described as a high velocity, low amplitude thrust, although these parameters have not been directly quantified (Maigne and Guillon, 2000; Symons et al., 2002; Rogers and Triano, 2003; Sran et al., 2004). Although research directed towards understanding the mechanisms of SMT has increased dramatically, the most fundamental biomechanical aspects of this intervention are incompletely understood (Herzog et al., 1993a; Maigne and Guillon, 2000; Keller et al., 2003; Cramer et al., 2006; Salem and Klein, 2013).

The quantification of the effects of spinal manipulation on targeted spinal tissues has been examined experimentally (Colloca et al., 2003). Studies have examined such aspects as the spinal loads (Kawchuk et al., 1992; Herzog et al., 1993a; Kirstukas and Backman, 1999; Triano, 2001; Sran et al., 2004; Tsung et al., 2005; Kawchuk et al., 2006), intradiscal pressure (Maigne and Guillon, 2000), spinal movements and the resulting physiologic responses (Colloca et al., 2003, 2004; Colloca and Keller, 2004; Ianuzzi and Khalsa, 2005; Lee et al., 2005; Fernandez-de-las-Penas et al., 2007; Colloca et al., 2007). The results of the aforementioned studies have made considerable progress in describing the effects of SMT on the recipient tissues. Outside of force-time histories, (Maigne and Guillon, 2000; Keller et al., 2003; Ross et al., 2004; Sran et al., 2004), comparatively little is known regarding the exact nature of the thrust delivered by the practitioner. Surprisingly, the kinematic descriptors of high velocity/low amplitude (Triano, 2001; Herzog et al., 2001; Symons et al., 2002; Kawchuk et al., 2006) have never been directly measured with respect to the manipulative input.

The intent of a spinal manipulative thrust is to cause a rapid displacement of one spinal vertebra relative to another (Haas, 1990; Triano, 2001). In order for the mechanical input from the clinician

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to achieve the desired joint movement, the clinician must deliver a thrust of appropriate magnitude and timing. Thus, SMT can be conceptualized as having two distinct components; 1) the mechanical input delivered by the practitioner and 2) the mechanical response of the tissues to that input (Evans and Lucas, 2010). The purpose of this study was to describe and compare the acceleration characteristics of the spinal manipulative input at the cervical, thoracic and lumbar spinal regions.

2. Materials and methods

All participants were undergoing SMT for the treatment of mechanical neck and/or back pain at a private outpatient chiropractic clinic. All were over 18 years of age and had undergone an initial assessment and a minimum of three previous treatments. Pregnant women were excluded due to treatment positioning requirements. Informed consent was obtained prior to study participation. All procedures were approved by The University of Manitoba Human Research Ethics Board. A total of 84 SMT trials were collected from 29 participants as most participants were undergoing SMT treatment at more than one spinal level. Demographic and physical characteristics of enrolled participants are presented in Table 1.

All data were collected during typical clinical encounters during which patients underwent a reassessment of their status to determine an appropriate course of SMT management. Prior to delivery of SMT, a wireless tri-axial accelerometer (G-Link, Microstrain Inc., Williston, VT., USA) was attached to the dorsal aspect of the clinician's hand, in alignment with the long axis of the third metacarpal, using adhesive tape. The SMT procedures were delivered as per standard clinical practice and included cervical (rotary), thoracic (bilateral thenar) and lumbar (spinous pull) manipulations (Fig. 1). SMT was delivered by a licensed chiropractor with more than 20 years of experience.

The accelerometer was calibrated at the beginning of each experimental session utilizing the gravitational orientation method (Webber and Kriellaars, 2004). Acceleration data was captured at 617 Hz using a wireless data acquisition system (Agile-Link, Microstrain Inc., Williston, VT. USA) and reviewed immediately after each SMT delivery to verify a successful collection. A single axis, identified in pilot studies using high speed video recordings, was utilized for data analysis. Specifically, each individual SMT technique was matched to a corresponding axis which best captured the clinician's hand movement during that manipulation (Cervical and lumbar = channel 1, x-axis; thoracic = channel 3, z-axis). For this, acceleration and video data (240 frames/second, Casio EX-100, Casio, USA) were recorded simultaneously during several SMT trials at each spinal level.

2.1. Data analysis

After the raw acceleration data was plotted, the SMT event was isolated from the larger data file and bandpass filtered (0.1–50 Hz, 4th order Butterworth) using DADiSP/SE 6.5 (Newton, MA). To objectively determine the onset of the SMT event within the acceleration waveform, jerk was first determined using numerical differentiation of the acceleration data. Jerk is the rate of change of acceleration. Next, the standard deviation of the jerk baseline was calculated using a 200 ms epoch prior to the SMT event. The time at which jerk exceeded 2 standard deviations above baseline was taken as the onset of the SMT event within the acceleration waveform. The typical SMT acceleration waveform consisted of a triphasic response from which various amplitude and latency parameters were derived that characterized the initial two peaks: P_1 and P_2 (Fig. 2). P_1 represents acceleration of the clinician's hand from the pre-loading position and includes the peak acceleration achieved by the clinician during the SMT event. P_2 begins when the acceleration signal crosses at the zero point and contains the primary deceleration component including the reversal of the hand following compression and recoil of the tissues. The third phase of the acceleration waveform, P_3, was not included in the analysis as it corresponds to the resolution phase following the treatment thrust and is not considered clinically meaningful (Herzog, 2000). Key parameters derived from each SMT waveform included amplitude for individual peaks (P_1, P_2) as well as the peak to peak amplitude (P_{1-2}). Latencies (L_1, L_2) were calculated for individual peaks as well as the inter-peak latency (L_{1-2}) (Fig. 2). All P_2 and P_{1-2} amplitudes were arbitrarily assigned positive values for ease of analysis and interpretation. To determine whether early aspects of the SMT event were coupled to later components, the values for the slope of the rise to P_1 ($P_{1\ slope}$) as well as peak jerk at the onset of SMT ($P_{1\ jerk}$) were correlated against the remaining amplitude and temporal parameters.

2.2. Statistical analysis

Statistical analysis was performed using Statistica software (version 6.0, StatSoft, Tulsa OK). Acceleration amplitude and latency values were analyzed using a 2 × 3 analysis of variance (ANOVA) to test for main effects of gender (female, male) and spinal level (cervical, thoracic, and lumbar). Tukey's post-hoc tests were used to determine significant pair-wise comparisons. Additional analysis (Pearson product moment correlation) was completed within each spinal level to explore potential relationships between amplitude and latency parameters. Statistical significance for all tests was defined as an alpha level of $p < 0.05$.

3. Results

The acceleration-time histories, including peak mean amplitudes and latencies, displayed a similar tri-phasic pattern across all spinal levels (Fig. 3). A strong main effect of spinal level was present for all amplitude parameters; P_1 ($F_{2,78} = 91.15$, $p < 0.0001$), P_2 ($F_{2,78} = 22.16$, $p < 0.0001$) and P_{1-2} ($F_{2,78} = 68.13$, $p < 0.0001$). For all amplitude parameters (P_1, P_2, P_{1-2}), post-hoc analysis indicated that amplitudes were significantly different between all spinal levels and increased in order from thoracic to cervical to lumbar (Fig. 4; $p < 0.0001$).

Main effects of gender were present for both P_1 ($F_{1,78} = 10.50$, $p = 0.0017$) and P_{1-2} ($F_{1,78} = 6.95$, $p = 0.0101$), however, no main effect of gender was present for P_2 amplitude ($F_{1,78} = 1.62$, $p = 0.2066$). Post-hoc analysis indicated that gender differences were present only at the lumbar spinal level. Specifically, P_1 and P_{1-2} amplitudes were larger in males ($p < 0.0001$ and $p < 0.0002$, respectively). In contrast, there were no significant differences between gender for P_1 and P_{1-2} amplitudes at either the cervical or thoracic levels ($p > 0.99$).

Spinal level was also a significant factor in determining the temporal parameters of hand acceleration during SMT (Fig. 5); L_1 ($F_{2,78} = 8.62$, $p = 0.0004$), L_2 ($F_{2,78} = 26.43$, $p < 0.0001$), and L_{1-2} ($F_{2,78} = 16.31$, $p < 0.0001$). In general, latencies decreased across spinal levels from thoracic to cervical to lumbar. For each

Table 1
Physical characteristics of subjects (mean ± standard deviation).

	Age (yrs)	Height (m)	Weight (kg)	BMI (kg/m^2)
Male ($n = 8$)	48.8 ± 13.3	1.76 ± 0.07	90.5 ± 12.2	29.0 ± 3.0
Female ($n = 21$)	49.8 ± 11.6	1.62 ± 0.08	76.3 ± 17.8	28.8 ± 5.9