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Neuromuscular response amplitude to mechanical stimulation using large-array surface electromyography in participants with and without chronic low back pain

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ABSTRACT

Purpose: The present study aimed to compare the neuromuscular response under various mechanical stimulations of the lumbar spine in participants with and without chronic low back pain (cLBP). *Methods:* Four mechanical stimulations, characterized by forces ranging from 75 to 225 N, were delivered using a servo-controlled linear actuator motor to the L3 spinous process of 25 healthy participants and 26 participants with cLBP. Lumbar neuromuscular responses were recorded using 64-electrodes large surface electromyography arrays. Between-group differences in the dose–response relationship (neuromuscular response amplitude according to each force level) were assessed using mixed model ANOVAs. *Results:* No differences between groups were shown (all p values > .05). A significant linear relationship was observed between forces and neuromuscular response amplitudes ($p < .001$) indicating an increase in response amplitudes with increasing stimulation force. Responses were observed throughout the lumbar region with highest response amplitudes in the vicinity of the contacted vertebra. *Conclusion:* The neuromuscular response amplitude triggered by localized lumbar mechanical stimulations does not differ between participants with and without cLBP. Moreover, even though stimulations were delivered at specific spinal segment, a neuromuscular response, although rapidly decreasing, was observed in areas distant from the contact site.

1. Introduction

Low back pain (LBP) is a common pain condition with an estimated 70% life-time prevalence in the general population (Leboeuf-Yde et al., 2009; Walker et al., 2004). Even though pain intensity commonly decreases within a few weeks following a first episode, complete resolution of symptoms is seldom reported (Lemeunier et al., 2012). It has been proposed that individuals with chronic LBP (cLBP) present inefficient spinal stabilization in response to a trunk perturbation resulting in an increased risk of further injury to the spine (Panjabi, 1992; van Dieen et al., 2003). Vertebral stability is believed to be achieved through the proper contribution of three components: the active subsystem, the passive subsystem, and the neural subsystem (Panjabi, 1992). The latter includes, amongst others, the reflexive neuromuscular response following a sudden musculotendinous stretch leading to a rise in the stiffness providing stability. A delayed reflexive neuromuscular response (Magnusson et al., 1996; Radebold et al., 2000, 2001; Reeves et al., 2005) associated to an increase (Lariviere et al., 2010) or decrease (Magnusson et al., 1996) in the response amplitude following a sudden posterior to anterior trunk perturbation has been reported in patients with cLBP compared to healthy individuals. Only one study (Liebetrau et al., 2013) failed to show response amplitude differences and, unlike the aforementioned, these authors used lateral trunk perturbations.

The investigation of the neuromuscular response to mechanical spine stimulation, based on healthy humans (Nougarou et al., 2013, 2014; Page et al., 2014) or animal models (Colloca et al., 2006; Pickar and Kang, 2006; Pickar et al., 2007; Reed et al., 2013, 2014, 2015), has been growing in the past years. Altogether, these studies revealed that the neuromuscular response amplitude and the muscle spindle discharge seem to be related to the rate of force application. Indeed, these responses increase when, either the stimulation peak force is increased (Colloca et al., 2006; Nougarou et al., 2013), the preload force is decreased (Nougarou et al., 2014; Reed et al., 2014) or the

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stimulation duration is shortened (Cao et al., 2013; Page et al., 2014; Pickar and Kang, 2006; Pickar et al., 2007). These studies were all designed to simulate spinal manipulation (SM) which generates neuromuscular responses that may be recorded as early as 50 ms following the mechanical stimulation onset (Colloca and Keller, 2001; Herzog et al., 1999).

Although promising, these investigations have all been performed with recording electrodes situated in the vicinity of the contact site. Consequently, it is not known whether the neuromuscular response to mechanical spine stimulation is localized or widely distributed in the back muscles. Early results by Herzog et al. (1999) and Symons et al. (2000) showed surface electromyography (sEMG) responses as far as the upper limb and lower limb following thoracic and lumbar SM. However, the response seems to rapidly decrease with distance from the contacted vertebra level. Indeed, the muscle spindle discharge frequency during a mechanical spine stimulation in cat model is statistically higher at the contacted vertebra level than the adjacent vertebrae levels (Reed et al., 2015). Similar results have also been reported in patients with LBP by Colloca and Keller (2001) who observed the greatest sEMG responses when stimulations were delivered close to the electrodes and a decrease in magnitude as stimulations were delivered farther from the electrode site.

The aim of the present study was therefore to compare, between participants with and without cLBP, the neuromuscular response amplitude under various mechanical stimulations of the lumbar spine using large sEMG array. It was hypothesized that stimulations of higher force would result in higher neuromuscular response amplitudes in both populations, although response amplitudes would be higher in participants with cLBP. It was also hypothesized that the highest response amplitude would be situated close to the contacted vertebra.

2. Methods

2.1. Participants

Twenty-six participants with nonspecific cLBP (10 females: 16 males) were recruited through an advertisement in the local newspaper and a snowball sampling strategy allowed the recruitment of 25 age- and gender-matched healthy participants (10 females: 15 males). Before the experiment, all volunteers were screened for predetermined inclusion and exclusion criteria and potential participants underwent a physical examination to rule out the presence of any contraindications to mechanical stimulation of the lumbar spine. Inclusion criteria included: aged between 18 and 60 years-old, no history of surgery or fracture in the lumbar region, not presenting a lumbar scoliosis, a neurological disease, osteoporosis or uncontrolled hypertension, and not being pregnant. Participants with cLBP were included if they presented an history of episodic or constant LBP (located between the 12th rib and the inferior gluteal fold) for more than 12 weeks, for which no specific source of pain could be identified (nonspecific cLBP) (Waddell, 2004). All participants provided their informed and written consent in accordance to the University's Human Research Ethics Committee (CER-14-205-07.04).

2.2. Experimental protocol

The 45-min experiment was conducted with the participant lying prone on an adjustable treatment table with, if needed, the table thoracic and/or lumbar segments slightly elevated thereby minimizing the lumbar lordosis. Four different mechanical stimulations were delivered posterior-anteriorly at L3 spinous process by an apparatus using a servo-controlled linear actuator motor (described below). These mechanical stimulations were characterized by a preload force of 20 N over 750 ms followed by an thrust phase of 125 ms leading to a peak force of 75 N, 125 N, 175 N or 225 N resulting in a rate of force application of 440 N/s, 840 N/s, 1240 N/s, and 1640 N/s respectively. Trials were randomized across participants in order to avoid any sequence effect and a five-minute rest period was scheduled between each trial.

2.3. Clinical status assessment

The participants' clinical status was evaluated before the experimental session. The Oswestry disability index (ODI), a 101-point numerical rating scale (NRS) and the Tampa Scale for Kinesiophobia (TSK) were used to respectively quantify lumbar disability, current pain intensity, and fear of movement. These questionnaires have been reported to be reliable and responsive in the management of cLBP and their French versions, which were used, have been validated (Chapman et al., 2011; Vogler et al., 2008).

2.4. sEMG acquisition

The lumbar neuromuscular response was recorded bilaterally using two 64 electrodes adhesive large sEMG array (model ELSCH064; LISiN-OT Bioelettronica; Torino, Italy, Fig. 1a). The array grid consisted of 64 electrodes, 8 rows $\times$ 8 columns (2 mm electrodes diameter, 12.5 mm inter-electrode distance). A small cavity filled with electrolyte gel (AC-CREAM250 V; Spes Medica; Battipaglia, Italy) separated the electrode surfaces from the participants' skin. Each large sEMG array was located approximately 2 cm from the spine, in order to avoid contact with the apparatus padded rod, and centered with the contacted spinous process (L3). Large sEMG array was applied at the beginning of the experimental session with the participant lying prone and the installation was preceded by shaving, gently abrading with fine-grade sandpaper (Red Dot Trace Prep, 3M; St. Paul, MN, USA), and cleaning with alcohol swabs the lumbar region. The bipolar sEMG signals were amplified (64-channel surface EMG amplifier, SEA 64, LISiN-OT Bioelettronica; Torino, Italy – 3 dB bandwidth 10–500) by a factor of 5 000, sampled at 10 240 Hz, and converted to digital form by a 12-bit A/D converter. OT Bioelettronica custom software and Matlab (MathWorks; Natick, MA, USA) were used to collect and process the sEMG data.

2.5. Apparatus

Mechanical stimulations were delivered through an apparatus using a servo-controlled linear actuator motor (Linear Motor Series P01-48 $\times$ 360, LinMot Inc., Zurich, Switzerland) developed and used to precisely deliver pre specified force-time profiles (Fig. 1b). A complete description of the apparatus has been previously published (Descarreaux et al., 2013). Briefly, the linear motor vertically displaced a slider applied directly to the spine through a padded rod (3.8 cm diameter) that serves as the contact point between the apparatus and the spine (L3 spinous process in the present study). The targeted stimulation force-time profile is loaded from a computer and the linear motor is accurately controlled by a microcontroller.

2.6. Data analysis

To quantify the lumbar neuromuscular response, 56 bipolar sEMG signals (no bipolar signals were calculated using the bottom electrode in one row and the top electrode from the next row) were first digitally band-pass filtered in the frequency bandwidth 35–400 Hz (2nd order Butterworth filter) and 60 Hz power line interference and its harmonics were eliminated through notch filters.