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Independent activation in adjacent lumbar extensor muscle compartments

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ABSTRACT

The purpose of this study was to examine compartmentalization in human lumbar spine extensors. Structure and innervation of these muscles would suggest the possibility of more segmentally specific biomechanical functions than have been found in previous studies examining muscle activation patterns during simple spine bending and twisting tasks. We selected specialized tasks to more effectively investigate the degree of independent control possible within lumbar spine extensors. We recorded surface electromyograms (SEMG) from the right posterior lumbar region during performance of two segmentally specific bellydance skills by seven novice and five trained subjects. These movements were performed at two frequencies (0.5 and 1 Hz). Cross-correlations were performed between pairs of rectified, low-pass filtered (6 Hz) SEMG signals to determine temporal lags between rhythmic bursts. Results showed a difference in the timing of muscle activation above and below the third lumbar vertebra. Temporal asynchrony was independent of either skill level or tempo, suggesting a hard-wired capacity for independent control of adjacent muscle compartments. The results have implications for understanding trunk control in the context of postural stability and postural adaptation during locomotion, as well as for lower back functional assessment and rehabilitation.

1. Introduction

Proponents of the partitioning hypothesis (English et al., 1993) or neuromuscular partitioning (Stuart et al., 1988) contend that the fundamental control units of the central nervous system (CNS) are not whole muscles but muscle compartments innervated by their own primary nerve branches, with localized stretch reflexes and distinct biomechanical functions (English et al., 1993). Support for this hypothesis is extensive, including a range of studies using different methods to identify distinct neuromuscular compartments via evoked EMG mapping (English and Weeks, 1989), glycogen depletion (English and Letbetter, 1982; English and Weeks, 1984), response to perturbations (Chanaud and Macpherson, 1991), compartmental specificity of single motor unit activation (English and Weeks, 1984, 1989), associated stretch reflex circuits (Liddell and Sherrington, 1924; Cohen, 1953), and compartmental specification based on mechanical advantage (ter Haar Romeny et al., 1984; van Zuylen et al., 1988; Herrmann and Flanders, 1998; Wickham and Brown, 1998; Staudenmann et al., 2009). A number of studies have examined compartmentalization in the muscles of the upper and lower limbs in animals (see English et al., 1993) and humans (as referenced above), but research on compartmentalization in human trunk muscles is limited. Differential activation of muscle compartments has been found in such trunk muscle as the external obliques (Mirka et al., 1997), rectus abdominus, (Moreside et al., 2008), and lumbar multifidus (Moseley et al., 2003) but to the best of our knowledge there have been no studies that have investigated functional compartmentalization in lumbar erector spinae (ES).

The structure and innervation of lumbar spine extensors suggests the possibility of a more segmentally specific biomechanical function (Bogduk, 1980; Bustami, 1986; Macintosh and Bogduk, 1987) than has been found in previous electromyographic analyses of simple spine bending and twisting tasks. The multi-articulated design of the spine allows for flexible specification of the number of functional units depending on task requirements. An outstanding question is the degree to which segmental specificity is possible through selective activation of muscle compartments. Considering the paraspinals as a group of muscles with different functions (Jonsson, 1973), MacIntosh and Bogduk (1987) described the anatomy of superficial muscles within the posterior lumbar region: the multifidus (MULT), and the medial longissimus thoracis (LT) and lateral iliocostalis lumborum (IL) divisions of the ES. They also identified a deeper portion of the ES, which they contend is often overlooked by anatomists. This compartment is comprised of partially overlapping fascicles running rostro-medially from the iliac crest to insert on each of the lumbar vertebrae. It is sufficiently superficial to be accessible to surface EMG (SEMG) caudal to L3 where it is covered

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only by aponeurosis. The fascicles of the superficial compartment run rostro-laterally from the aponeurosis to the lower costal area, thus acting indirectly on the lumbar vertebrae as they do not insert on the spinal processes. The authors predicted that these two portions of the lumbar ES, superficial and deep, would be capable of different biomechanical functions by virtue of their distinct locations and fiber directions and created a grid to guide the placement of surface electrodes to record differentially between MULT, LT and IL and between the deep and superficial portions of the lumbar ES, accessible to SEMG below and above L3, respectively (Macintosh and Bogduk, 1987).

Studies using a variety of static and dynamic postural tasks in different planes of motion have examined activation patterns of the spine extensors to determine biomechanical functions of individual muscles at different spinal levels (Floyd and Silver, 1955; Morris et al., 1962; Jonsson, 1970; Donisch and Basmajian, 1972; Jonsson, 1973; Pope et al., 1986). None of these studies showed independent activation of adjacent ES muscle bundles within the ipsilateral lumbar region, although differential activity between thoracic and lumbar regions was recorded during a variety of spine bending and twisting tasks (Morris et al., 1962; Donisch and Basmajian, 1972). Since these initial studies, a plethora of research has been conducted on muscle activation patterns, particularly as applied to low back pain and work-related loading of the spine. In several of these studies SEMG has been recorded over the bilateral lumbar region using large arrays of evenly spaced monopolar electrodes in static postures (Finneran et al., 2003; Reger et al., 2006) and during dynamic flexion–extension tasks (Hu et al. 2010). The objective of these studies was to determine whether topographical and amplitude differences in the spatial gradient of muscle activity could distinguish between low back pain patients and healthy individuals. No attempt was made to relate the spatial gradient of activation to specific muscle compartments or to their biomechanical function, nor was the temporal organization of the muscle activation analyzed.

Differential recording from specific compartments of the lumbar spine extensors during dynamic, segmentally specific tasks would provide more insight into the neuromechanical potential of these compartments. In pilot studies using specific bellydance movements, we found temporal asynchrony in the activation of ES at lower thoracic vs. lumbar vertebral levels. Certain movements elicited anti-phase antagonistic activation in contralateral spine extensors at different segmental levels, while others showed temporal asynchrony in ipsilateral ES muscles at different segmental levels. We chose frontal plane pelvic 'figure eight' movements, which can be performed in two different directions, as the movement paradigm expected to elicit separate, asynchronous compartmental activation.

The goal of the present study was to determine the degree of independent compartmental control, assessed by quantifying temporal asynchronies in muscle activation, across different segmental levels of the lumbar paraspinals. We predicted that whereas global spine bending would show synchronous activation, the lumbar spine extensors above and below L3 would be activated at different phases of the figure eight movement cycles, respectively. We further predicted that the difference in activation timing between these regions would vary with the type (simple bend vs. figure eight) and direction (maya vs. serpentine) of movement.

The study also addressed the question of whether the ability to independently activate muscle compartments would depend on skill level (degree of learning) or increased movement tempo (task difficulty). We predicted that less trained subjects would activate muscles more synchronously and that muscles would be activated more synchronously for movements performed at faster tempos (loss of independent control).

2. Methods

2.1. Subjects

Fourteen healthy female subjects aged 19–56 years (mean 34.8 ± 11.8) participated voluntarily and signed an informed consent form. The study was approved by the Research Ethics Board Office, McGill University. Subjects were classified as novices (0–1 year of training, $N = 7$, mean = 0.3 ± 0.23, range 0–0.6 years) or trained (more than 1 year of training, $N = 7$, mean = 14.3 ± 10.3, range 3–29 years). All subjects were without musculoskeletal disability or injury, however, one subject had an obvious lumbar scoliosis. In an initial data collection session, EMG only was recorded from 12 subjects (subjects 1–12 in Table 1). Subjects 11Tr and 2No from the first collection session and two new novice subjects participated in a second session several months later, during which kinematic data were collected in addition to EMG.

2.2. Kinematics

Kinematics were recorded from the four subjects in the second data collection session using the VICON 6 camera system and standard Plug-in-Gait full body marker set. Kinematic data were sampled at 200 Hz. The subject was oriented such that lateral displacement to the right was in the positive x direction, forward sagittal displacement was in the positive y direction, and upward vertical displacement was in the positive z direction.

2.3. EMG

Muscle EMG patterns were recorded using custom-made differential bipolar surface electrodes with circular stainless steel contacts of diameter 3 mm, and inter-contact distance 13.5 mm (centre-to-centre). These electrodes have high selectivity due to their small size. The gain was adjusted between 100 and 1000. Input impedance was 10 GΩ, with 2 pF capacitance. Slope of the cut-off was −15 db per decade. Electrodes had internal 30–500 Hz first order band-pass filters. EMG was sampled at 2000 Hz and stored in a computer for digital processing. Signals were recorded from the extensors of the lumbar spine accessible to surface EMG (Macintosh and Bogduk, 1987). Electrode placement was based on the grid created by MacIntosh and Bogduk (1987) to differentially record from thoracic (superficial) vs. lumbar (deep) portions of the lumbar ES where their fibres are accessible to SEMG above and below L3, respectively. Additionally, placement locations were selected to record separately from MULT, LT and IL. Fig. 1 illustrates electrode placement on a representative subject. Specific lumbar vertebrae and other anatomical landmarks were determined through manual palpation.

Prior to EMG recording the skin was shaved where necessary and cleaned with alcohol swabs. A small amount of electrode gel was applied to the contacts prior to securing the electrodes to the skin with double-sided medical grade tape. Eight electrodes were placed over the right lumbar region. Electrodes 1 and 2 were positioned to record activity from MULT at L5 and L4 levels, respectively. Electrodes 3, 5 and 7 were positioned to record from LT at levels L4, L2–3 and L1, respectively. Electrodes 4, 6 and 8 were positioned to record from IL at levels L4, L2–3 and L1, respectively. Electrodes were aligned with the estimated fibre direction as indicated by anatomical diagrams and cadaver dissections. After placement, electrode signals were tested while recording lumbar alternating flexion/extension motions.

2.4. Procedure

Two types of common intermediate level bellydance movements, maya (Maya) and serpentine (Serp) were chosen based on