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Relationships between muscle electrical activity and the control of inter-vertebral motion during a forward bending task

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ABSTRACT

Muscle strengthening exercises are commonly used in primary care for the treatment of chronic, non-specific low back pain (CNSLBP) as it has been theorised that increased muscle activity contributes to the stabilisation of inter-vertebral motion segments during bending and other spinal movements, however this has never been demonstrated *in vivo*.

This study used contemporaneous quantitative fluoroscopy (QF) and surface electromyography (sEMG) to investigate relationships between continuous inter-vertebral motion variables and muscle electrical activity in the lumbar multifidus (LMU), lumbar and thoracic erector spinae (LES and TES) during standardised lumbar flexion and return in 18 healthy male human subjects.

Our results demonstrated that the variability in the sharing of angular motion (i.e. Motion Share Variability MSV) and motion segment laxity during a bending task were significantly ($p < 0.05$) negatively correlated (Spearman) with muscle electrical activity throughout the participant bend for both locally and globally acting muscle groups. MSV was also strongly correlated with L2-3 laxity.

The former suggests a damping mechanism reducing irregular displacements (i.e. less variability in the sharing of segmental motion) during bending and an action of spinal stabilisation by muscles at segmental levels, and the latter a synergy between laxity at L2-3 and MSV. While this has previously been theorised, it has never been shown *in vivo* at the inter-vertebral level. These assessments may be considered for use in validation studies of exercise programs for CNSLBP, however further replication is required.

1. Background

Low back pain (LBP) has been linked with spinal instability, and its association with trunk muscle activity has therefore been investigated during numerous tasks. Whilst Ahern (1988) found paraspinal muscle activity to be lower in a low back pain population compared to pain free controls, the consensus is that muscle activity increases in such populations as a stabilisation mechanism (Kuriyama and Ito, 2005; Sanchez-Zuriaga et al., 2015; Van Dieen et al., 2003). Motor control strategies to stiffen the spine (Gardner-Morse et al., 1995; Cholewicki and McGill, 1996) therefore include increasing trunk muscle co-contraction (Granata and Marras, 2000), and augmenting local or global paraspinal muscle activation (Bergmark, 1989; Reeves et al., 2006). This provides a rationale for the use of motor control exercises as an intervention in LBP groups (Hodges and Richardson, 1996; Saragiotto et al., 2016).

Whilst the literature supports the idea of training muscular capacity to improve spinal stability, benefits are broadly attributed to the lumbar spine as whole, and there is only limited understanding of the influence of muscle activity on kinematics at segmental levels. Kaigle et al. (1998), using sEMG and spinous pins, studied concurrent lumbar inter-vertebral flexion and return motion and spinal muscle electrical activity in live subjects and found inter-vertebral ranges of motion (IV-RoM) to be reduced with increased muscle activity. Our own group replicated this finding using sEMG and quantitative fluoroscopy (QF). QF is "an objective assessment of the spine in motion using fluoroscopy (moving video x-rays) and automated computer processing algorithms which calculate intersegmental kinematic parameters throughout the motion" (Breen et al., 2012). Utilising QF and sEMG concurrently relationships were found between the timing of the activity of three different spinal muscles and maximum IV-RoM at different segmental levels (du Rose and Breen, 2016a,b). QF has also been used to measure the initial rate of the attainment of inter-vertebral rotational motion, referred to in this paper as 'laxity', and a parameter termed Motion Sharing Variability (MSV). Laxity is believed by some to represent the dynamic neutral zone (Breen et al., 2015), and MSV is a measure of the variability in how inter-segmental angular rotation is shared across the measured spine throughout a bending cycle (Breen and Breen, 2018).

There is evidence from modelling studies that impaired neuromuscular control can leave the lumbar spine vulnerable to buckling under even light loads (Gardner-Morse et al., 1995, Cholewicki and McGill, 1996). Attention is therefore turning to the relationships between muscle activity and inter-vertebral stability in chronic, non-specific low

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back pain (CNSLBP). The need is to identify a sub-group that might ultimately benefit from back exercises on the basis of improved inter-vertebral stability. However, IV-RoM is a highly variable parameter and has been found not to discriminate patients with chronic, non-specific low back pain from healthy controls (Mellor, 2014). By contrast, the inter-vertebral mid-range measures of inter-vertebral laxity and MSV can be regarded as indicators of reduced restraint and control respectively. While the former is regarded as an expression of motion segment sub-failure (Panjabi, 1992), the latter has been shown to be greater in an undifferentiated CNSLBP population than in healthy controls during recumbent bending (Mellor, 2014). Laxity can be measured using QF as the initial attainment rate (Teyhen et al., 2005, Mellor et al., 2009, du Rose and Breen, 2016a,b) and MSV from multilevel continuous QF studies (Mellor, 2014, Breen and Breen, 2018). The sEMG data from the back muscles can be recorded contemporaneously.

It can be hypothesised that muscle activity has a damping effect on both laxity and MSV (Reeves et al., 2011) and will be negatively associated with them. Due to the nature of QF imaging, and the requirement to record sEMG concurrently, it was only feasible to measure these parameters during a single plane of motion, so that ionising radiation dose received by any one participant was minimal. Forward bending is the most commonly evaluated task when investigating lumbar biomechanics, and was therefore considered the most appropriate movement for study. The aim of this investigation was therefore to use QF and sEMG concurrently, to determine whether relationships exist between kinematic motion parameters (i.e. MSV and laxity) and mean paraspinal muscle activity recorded during a standardised forward bending task.

2. Methods

Twenty males with no recent history of low back pain were recruited from the AECC University College student population. Ethical approval was provided by the National Research Ethics Service (Bristol 10/H0106/65), and all participants gave written consent. The inclusion and exclusion criteria are outlined in Table 1.

2.1. Data collection

Quantitative fluoroscopy and surface electromyography were used concurrently to acquire lumbar inter-vertebral images and record paraspinal myoelectric activity.

2.2. Surface electromyography (sEMG)

Prior to the image acquisition, participants' skin was prepared for the application of sEMG electrodes by light abrasion, cleaning with alcohol and when necessary shaving of the area. Disposable Ag-AgCl electrodes were then bilaterally applied using a 20 mm centre to centre inter-electrode distance, to the thoracic erector spinae (TES) (5 cm lateral to the T9 spinous process), the lumbar erector spinae (LES) (2 cm lateral to the L2 spinous process), and the superficial lumbar multifidus (LMU) (2 cm lateral to L5 spinous process, along a line between the posterior superior iliac spine and the spinous process of L1). Biopac wireless transmitters (Bionomadix Dual Channel Wireless EMG) were fastened to the lower back with the use of Velcro adhesive pads. As there was found to be no significant difference between left and right sides at any level during the bending task, the average of the mean amplitudes recorded from both sides was used in the analysis.

The sEMG signals were recorded using a sampling rate of 2000 Hz, a common mode rejection ratio (CMRR) of 110 dB and an input impedance of 1000 M Ohms. All sEMG signals were band pass filtered (10–500 Hz) and full wave rectified. Smoothing was applied with a time constant of 300 ms, and the mean root mean square (RMS) amplitude was then calculated over the twenty second duration of each bending cycle, normalised to a sub-maximal voluntary contraction (sMVC), and expressed as a percentage of this contraction. To obtain the sMVC, each participant was asked to lie prone with their hands behind their head. They then raised their torso off the bench and held for five seconds whilst their legs and pelvis were stabilised. The procedure was repeated three times, and the average recording was taken as the reference contraction value (sMVC).

Table 1
Eligibility criteria.

Inclusion	Exclusion
Male (aged 20–40 years)	Poor understanding of English
Ability to understand written English	Ongoing treatment for osteoporosis
Willing to participate and capable of providing informed consent	History of spinal, abdominal or pelvic surgery
BMI less than 30	BMI greater than 30
No history of low back pain (that affected ADL's for at least one day over previous year)	Exposure to medical radiation greater than 8 mSv within the past 2 years

2.3. Image acquisition and processing

A Siemens Arcadis Avantic VC10A digital fluoroscope (CE0123) was used to collect the fluoroscopic images at 15 Hz during a standardised sagittal forward bending and return task. Participants were guided at a constant rate through a range of 60° of flexion, and the return to an upright neutral position, by following a rotating motion frame (Fig. 1). Myoelectric paraspinal activity was recorded concomitantly. The QF motion frame and the sEMG recordings were synchronised with the use of a bespoke trip switch attached to the motion frame. When the motion frame began to move, a data point was registered on the sEMG timeline. The entire bending sequence was approximately 20 s in duration.

Participants were asked to stand with their right hand side next to a motion frame, and to place their forearms on a rotating arm rest. Practice flexion and return sequences (without radiation) were then performed at 20° increments to ensure participant tolerance. Upon commencement of image recording, the motion frame guided each participant through 60° of forward flexion and the return to a neutral upright position. The pelvis was restrained using a belt applied to the anterior superior iliac spine (ASIS) attached to the motion frame, and a bracing pad applied to the lower sacral segments. The image field was

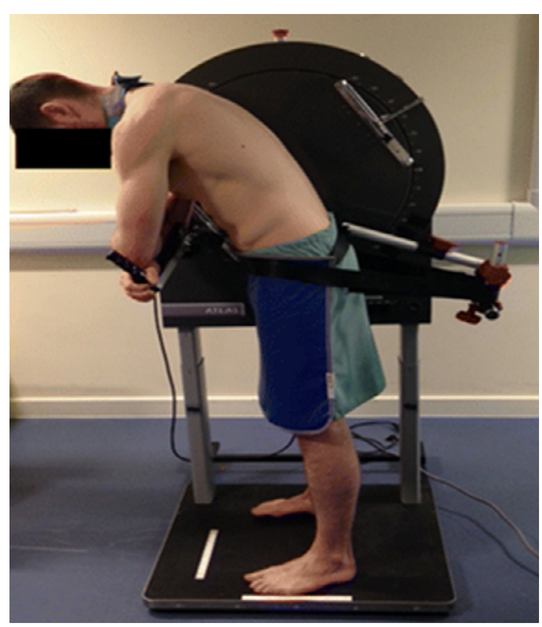

Fig. 1. Motion frame apparatus.