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Decreasing the required lumbar extensor moment induces earlier onset of flexion relaxation

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ABSTRACT

Flexion relaxation (FR) is characterized by the lumbar erector spinae (LES) becoming myoelectrically silent near full trunk flexion. This study was designed to: (1) determine if decreasing the lumbar moment during flexion would induce FR to occur earlier; (2) characterize thoracic and abdominal muscle activity during FR. Ten male participants performed four trunk flexion/extension movement conditions; lumbar moment was altered by attaching 0, 5, 10, or 15 lb counterweights to the torso. Electromyography (EMG) was recorded from eight trunk muscles. Lumbar moment, lumbar flexion and trunk inclination angles were calculated at the critical point of LES inactivation (CPLES). Results demonstrated that counterweights decreased the lumbar moment and lumbar flexion angle at CPLES ($p < 0.0001$ and $p = 0.0029$, respectively); the hypothesis that FR occurs earlier when lumbar moment is reduced was accepted. The counterweights did not alter trunk inclination at CPLES ($p = 0.1987$); this is believed to result from an altered hip to spine flexion ratio when counterweights were attached. Lumbar multifidus demonstrated FR, similar to LES, while thoracic muscles remained active throughout flexion. Abdominal muscles activated at the same instant as CPLES, except in the 15 lb condition where abdominal muscles activated before CPLES resulting in a period of increased co-contraction.

1. Introduction

Flexion relaxation is characterized by a reduction in spine extensor muscle activation during trunk flexion that generally occurs in individuals free from back pain (Allen, 1948; Floyd and Silver, 1951, 1955). While flexion relaxation reliably occurs in healthy individuals, there is evidence that flexion relaxation does not occur in patients suffering from chronic low back pain; this population maintains muscle activity throughout the full trunk flexion range of motion (Golding, 1952; Ahern et al., 1988; Mannion et al., 2001). Clinically, the absence of flexion relaxation is currently used as an objective measure of low back pain (Neblett et al., 2003), and chronic pain interventions use flexion relaxation as a goal for biofeedback retraining (Neblett et al., 2010; Moore et al., 2015). However, a better understanding of the factors that affect flexion relaxation is warranted in order to apply this technique effectively in a clinical population (Geisser et al., 2005).

The proposed mechanism for flexion relaxation is that passive tissues that are slack in a neutral spine position become stretched during spine flexion and begin to resist the externally applied moments about lumbar joints (Pauly, 1966; Wolf et al., 1979; McGill and Kippers, 1994). This increase in passive tension thereby reduces the required level of active force production in extensor spine muscles leading to full cessation of the electromyographic (EMG) signal. Flexion relaxation is most commonly observed in the lumbar erector spinae at the L3/L4 spine level (Floyd and Silver, 1951; Pauly, 1966; Shirado et al., 1995; Solomonow et al., 2003; Olson et al., 2006; Shin and Mirka, 2007; Jin et al., 2012; Hashemirad et al., 2009; Schinkel-Ivy et al., 2013), but has also been observed at the L2/L3 (Allen, 1948; Golding, 1952; Morin and Portnoy, 1956; Morris et al., 1962; Shin et al., 2004; Olson et al., 2004) and L4/L5 spine levels (Wolf et al., 1979; Golding, 1952; Dickey et al., 2003; Olson et al., 2004). The passive spine structures are commonly hypothesized to generate the lumbar extensor moment, yet the thoracic erector spinae and latissimus dorsi may also actively contribute to the lumbar moment, thereby reducing the active requirements of the lumbar erector spinae. Floyd and Silver (1955) mention that thoracic erector spinae also exhibits flexion relaxation, although later studies found that thoracic erector spinae maintained activity during full trunk flexion

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(Morris et al., 1962; Pauly, 1966). Indwelling EMG has been used to determine that lumbar multifidus also demonstrates flexion relaxation (Morris et al., 1962; Pauly, 1966; Donish and Basmajian, 1972). While surface EMG recordings of lumbar erector spinae commonly show flexion relaxation, indwelling EMG of iliocostalis lumborum has shown that activity is maintained during full trunk flexion (Andersson et al., 1996); quadratus lumborum also maintained activity in the same study. The abdominal muscles have largely been ignored in studies of flexion relaxation, although they have been suspected of being responsible for generating the moment to achieve the last few degrees of trunk flexion after the extensor muscles have become inactive (Solomonow et al., 2003; Olson et al., 2004).

The instant the lumbar erector spinae muscles become inactive is termed the critical point of flexion relaxation and it is the most common outcome measure in the analysis of flexion relaxation. Often the lumbar flexion angle—either in absolute degrees (Gupta, 2001; Shin and Mirka, 2007; Hu et al., 2013) or normalized to maximum lumbar flexion (Kippers and Parker, 1984; Sarti et al., 2001; Schinkel-Ivy et al., 2014)—measured at the critical point is compared between conditions. Both the L4/L5 moment and trunk inclination angles—thoracic spine segment with respect to global reference system—at the critical point have also been emphasized as important measures of flexion relaxation (Olson et al., 2004; Howarth and Mastragostino, 2013; Zwambag and Brown, 2015). Repeated trunk flexion and the addition of loads to the trunk or hands have been shown to delay flexion relaxation in healthy participants, resulting in greater flexion angles (Dickey et al., 2003; Solomonow et al., 2003) and L4/L5 extensor moments (Howarth and Mastragostino, 2013) at the critical point. It is believed that flexion relaxation is delayed in these studies by decreasing the capability of passive tissues to generate extensor moments and by increasing the required extensor moment, respectively. These findings therefore corroborate the hypothesis that flexion relaxation occurs when the passive tissues are able to support the lumbar moment; as expected, adding loads to the hands or trunks increased the L4/L5 moment and delayed flexion relaxation. This hypothesis would also suggest that flexion relaxation should occur earlier if the L4/L5 moment was reduced; however, this remains to be determined.

The purpose of this study was thus to investigate how reducing the L4/L5 moment affected the onset of flexion relaxation. It was hypothesized that counterweights acting through a pulley attached to the thoracic spine would reduce the L4/L5 moment. Consequently, less passive tissue strain would be required to equilibrate the external moment and the critical point for lumbar erector spinae inactivation would occur earlier in the flexion movement with less lumbar flexion and trunk inclination. A secondary purpose of this study was to characterize the activity of the surrounding musculature during trunk flexion. It was hypothesized that abdominal muscles would become activated after the lumbar erector spinae become inactive and that their activity would be increased with larger loads attached to the pulley. Lumbar and thoracic erector spinae, latissimus dorsi, and multifidus were hypothesized to demonstrate a reduction in activity throughout trunk flexion as larger loads were attached to the pulley.

2. Methods

2.1. Participant characteristics

Ten healthy male participants (mean ± SD; age: 25 ± 2.5 years; height: 181 ± 5.8 cm; mass: 82 ± 11.2 kg) were recruited from the university. Participants had no previous history of low back pain. The research ethics board at the university approved this study.

2.2. Experimental set-up

Standard bipolar Ag/AgCl surface electrodes (Blue Sensor, Medicotest Inc., Ølstykke, Denmark) were used to record bilateral muscle activations from lumbar and thoracic erector spinae, latissimus dorsi, rectus abdominus, external oblique, and internal oblique. Electrodes were placed along muscle fibre directions at L3, T9, and T12 spine levels for lumbar and thoracic erector spinae and latissimus dorsi, respectively. Electrodes were placed along muscle fibres ~2 cm lateral to the naval for rectus abdominus, ~14 cm lateral to the midline for external oblique, and ~2 cm medial and inferior to the anterior superior iliac spines for internal oblique (Brown and McGill, 2010). These electrode sites have been shown to adequately reflect abdominal wall activation and reduce crosstalk (McGill, 1996). Ground electrodes were placed over the anterior superior iliac spines; all electrode sites were shaved, if necessary, and cleaned with isopropyl alcohol. Muscle activations of multifidus at both the L1 and L4 spine levels were recorded using fine-wire EMG. Multifidus EMG was limited to the right side to avoid obstructing the line of sight of kinematic markers (described later). Bipolar 44 μm gauge fine wire nickel alloy electrodes with 2 mm exposed tips bent into hooks (50 mm × 25 gauge, Chalgren Enterprises Inc., Gilroy, CA, USA) were inserted into the multifidus muscle with a 27 gauge hypodermic needle, ~1.5 cm lateral to the L1 and L4 spinous processes in a slight craniomedial orientation. Prior to needle insertion, multifidus muscle thicknesses (mean ± SD; 3.2 ± 0.50 and 3.9 ± 0.54 cm at L1 and L4, respectively) were measured as the distance from erector spinae aponeurosis to lumbar laminae using ultrasound (M-Turbo, Sonosite Inc., Bothell, WA, USA). This was to ensure that needles were inserted into the middle of the muscle bellies. Electromyographic data were differentially amplified (AMT-8, Bortec Biomedical, Calgary, Canada; bandwidth 10–1000 Hz; common-mode rejection ratio = 115 dB at 60 Hz; input impedance = 10 GΩ) and recorded at 2048 Hz.

Participants performed three maximal voluntary isometric contractions (MVICs) targeting each muscle group. For lumbar and thoracic erector spinae, and multifidus, participants adopted the prone Beiring Sørensen position and manual resistance was applied against the generated trunk extensor moment (Vera-Garcia et al., 2006). For latissimus dorsi, participants stood and performed a rowing (humeral extension) action while an experimenter provided manual resistance (Beaudette et al., 2014). For abdominal muscles participants sat with knees bent and trunk slightly reclined on the edge of a bench and manual resistance was applied as participants generated moments about each of trunk flexion, left and right axial twist, and left and right lateral bend.

Rigid bodies consisting of two kinematic markers (Optotrack, NDI Inc., Waterloo, Canada) were placed over the spinous processes of T12 and S1. Single markers were attached to the head of the 5th metatarsal, lateral malleolus, lateral knee, and greater trochanter on the participants' left side. Kinematic data were recorded at 32 Hz. Participants stood on a force plate (AMTI Inc., Watertown, USA); ground reaction forces and moments were amplified and collected at 2048 Hz.

A harness was strapped to the participants' torso allowing a cable and fixed pulley to be connected to the trunk at approximately the T5 spine level. The pulley was mounted overhead so that masses attached to the cable generated an extensor moment about the lumbar spine (Fig. 1). Therefore, any mass attached to the pulley acted to reduce the flexion moment of the torso.

2.3. Protocol

A repeated measures randomized block design was used for this study. For every trial, participants were instructed to stand in a