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A systems-level perspective of the biomechanics of the trunk flexion-extension movement: Part II – Fatigued low back conditions

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ABSTRACT

Our companion paper demonstrated the importance of a systems-level perspective on spine biomechanics by showing the effects of lower extremity constraints during simple, trunk flexion-extension motions. This paper explores the impact of trunk muscle fatigue and stress-relaxation of lumbar passive tissues on this systems-level response. Twelve participants performed experimental protocols to achieve lumbar passive tissue stress-relaxation fatigue and lumbar muscle fatigue. Participants performed full range of sagittal-plane trunk flexion-extension under unconstrained stoop movement and pelvic/lower extremity constrained stoop movement. They performed these motions both before and after the fatigue protocols and trunk kinematics and muscle activities in trunk and lower extremity muscles were monitored. Under the condition of passive tissue fatigue, low back muscles and lower extremity muscles revealed significantly increased activation level (21% and 22%, respectively) in the free stoop condition but under the restricted stoop condition, there was no significant effect of the protocol. Under the lumbar muscle fatigue condition, a significant antagonistic and lower extremity activation effect (34% increase in abdominal muscles, 16% increase in lower extremity muscles) was observed in the free stooping condition while these variables were not affected by the protocol under the restricted stooping condition.

Relevance to industry: Fatigue of the lumbar musculature and passive tissues is prevalent in jobs requiring full trunk flexion postures. Developing accurate biomechanical models of spinal stress in these full stooping postures can help in the development of appropriate interventions to reduce the prevalence of back injuries in these jobs.

1. Introduction

Abnormal low back conditions such as lumbar muscle fatigue or laxity in ligamentous tissues of the low back have been widely investigated to achieve a better understanding of the mechanism of low back stability (Granata et al., 2004; McGill and Cholewicki, 2001; Rogers and Granata, 2006). Many of these studies have focused on the tissues of the torso and have not considered the potential influence of the structures of the lower extremities; the pelvis often being regarded as a rigid, stable body in most previous models (e.g. Bergmark, 1989; Cholewicki and McGill, 1996; Cholewicki et al., 1998; Granata and Orishimo, 2001; Granata and Rogers, 2007). As discussed in the companion article (Jin and Mirka, 2015), there is evidence in the literature to support a systems-level (i.e., trunk, pelvis and lower extremities) approach for a more comprehensive understanding of trunk stability – particularly at near full flexion postures.

Previous studies have shown that both active and passive tissues in the low back play important roles in providing the necessary restorative moments and spinal stability during trunk flexion and extension exertions (Granata and Rogers, 2007; Granata and Gottipati, 2008). The flexion-relaxation phenomenon (FRP) has been used as a useful technique to identify the role of the active and passive tissues in achieving spinal stability and biomechanical equilibrium and has been used to study abnormalities of the low back tissues (Colloca and Hinrichs, 2005; Neblett et al., 2003; Watson et al., 1997). The existing literature has a number of studies showing how the condition of the low back tissues (e.g., muscle fatigue and laxity in passive tissues) influence FRP (Descarreaux et al., 2008; Solomonow et al., 2003; Shin and Mirka,

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2007), and demonstrate a reduction of the trunk stiffness and dynamic stability of the torso (Rogers and Granata, 2006; Granata and Gottipati, 2008; Granata et al., 2004; Moorhouse and Granata, 2007). Clearly, these studies provide a good theoretical and empirical basis to understand the synergistic interaction between active and passive lumbar tissues around full flexion postures. However, the studies are limited in that they have only focused on the local system (e.g., multifidus muscles) and global system (e.g., lateral erector spinae, rectus abdominis muscles etc.) as proposed by Bergmark (1989), and have not considered the potential influence of the structures of the super global systems (i.e., lower extremities) as proposed by Jin and Mirka (2015).

It is our stance that the local system, the global system and the super global systems are strongly connected, and that the generation of internal trunk extension torque, especially passive moment, for flexion-extension is not only controlled by the local and global system but also influenced by super global system. On this basis, the goal of current study was to understand alternative strategies to supply the necessary moment generation capacity in low back under various abnormal low back conditions. It is hypothesized that the muscle activation pattern of the local, global and super global system will have a complementary interaction to achieve the biomechanical equilibrium between the internal and external moments around the full trunk flexion posture. It is also hypothesized that there will be significant differences in the complementary interactions according to the type of fatigue (muscle or passive tissue) to which the lumbar region is exposed.

2. Methods

2.1. Participants

Sections *2.1 Participants* and *2.2 Apparatus* are identical to those of the companion article (Jin and Mirka, 2015).

2.2. Apparatus

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2.3. Experimental design

There were two independent variables, POSTURE (two levels: free stooping and restricted stooping) and TIME (two levels: 0 (pre-protocol) and 1 (post-protocol)). The description of the dependent variables is identical to that shown in the companion article (Jin and Mirka, 2015).

2.4. Task and procedure

Upon arrival the experimental procedures were described to the participant and written informed consent was obtained. Participant was fitted with motion and EMG sensors and then performed the MVC exertions. Participants performed two repetitions of the isometric trunk flexion and extension MVC exertions in the lumbar dynamometer while assuming a 20° trunk flexion posture. MVC exertions for the gluteus maximus and biceps femoris were performed against manual resistance provided by the experimenter while the participant assumed an upright standing posture (two repetitions for each).

Prior to performing the experimental trials, the participants stood in an open space (no restrictions on pelvis or thighs) in an upright comfortable posture and then bent forward to a full trunk flexion posture. These baseline data defined full range of trunk flexion. The participants were then asked to perform a series of slow, controlled flexion and extension trunk motions consisting of two free stooping trials and two restricted stooping trials. Each of these trials consisted of a 5 s flexion motion (to full flexion), 4 s of holding at full flexion and then 5 s to extend back to upright posture in time with a metronome sound (one beat per second). The order of the free stooping vs. restricted stooping sequences was randomized across participants and this full-flexion test routine is referred to as TEST.

Upon the completion of the preliminary testing activities, the participants then executed one of three randomly assigned experimental protocols (one week interval between protocols): (1) Protocol A (passive tissue fatigue): alternately perform 25 s of full flexion in the seated posture and 5 s of upright sitting continuously for 10 min; (2) Protocol B (muscular fatigue) alternately perform 25 s static posture holding at 45° trunk flexion in seated posture and 5 s of upright sitting continuously for 10 min; and (3) Protocol C (combined fatigue) consecutively perform 25 s of seated full flexion, 5 s of upright sitting, 25 s of seated static posture holding at 45° trunk flexion and 5 s of upright sitting continuously for 10 min. These protocols were performed in a seated posture to avoid the confounding effects of lower extremity fatigue. When the 10-min protocol was completed, the TEST routine was performed. The analysis of data from Protocol A and Protocol B are considered in the current paper.

2.5. Data processing

2.5.1. Kinematic variables

Much of the data processing for the kinematics variables is consistent with that described in the companion article (Jin and Mirka, 2015), but there are some notable variances. The thoracic flexion angle was captured by the difference of the pitch angles between the sensor on xiphoid process and the S1 sensor. The lumbar flexion angle (i.e., lumbar curvature) was captured by the difference of the pitch angles between the T12 sensor and the S1 sensor, representing total movement of the five lumbar spine segments. The EMG-Off variables were expressed as a lumbar flexion angle at which the trunk extensor musculature demonstrated flexion-relaxation phenomenon. The percentage of range of flexion was calculated using the lumbar flexion (LF) angle during flexion-extension. Two calibration data included the LF angle in upright standing measured before each protocol and the LF angle in full flexion measured after the muscle fatigue protocol (Equation (1)) (Dolan et al., 1994). The full flexion data after muscle fatigue protocol were employed to provide fair condition to calculate the percentage of flexion in all protocols because less flexion shown in this condition. A preliminary study showed less flexion in the muscle fatigue condition and confirmed that this method guarantees both protocols reach to 100% range of motion; the muscle fatigue condition did not reach to 100% flexion with the calibration data of the LF angle in full flexion captured before experiment.

$$\text{Percentage Flexion}(\%) = \frac{\left[\text{LF} - \text{LF}_{\text{standing}}\right]}{\left[\text{LF}_{\text{fullflexion}} - \text{LF}_{\text{standing}}\right]} \times 100 \qquad (1)$$

In the experimental trials the specified range of lumbar flexion angles in which the rectified signals were averaged (herein called the 80–20 range) began during the flexion motion as the participant reached 80% of the full lumbar flexion angle and continued through the full flexion posture and then ended as the participant passed through that same angle (20% of extension motion) during the returning extension motion. Data processing for EMG data is identical to that of the companion article (Jin and Mirka, 2015).