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Combined effect of low back muscle fatigue and passive tissue elongation on the flexion-relaxation response

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ABSTRACT

Previous literature has documented the alterations in the flexion-relaxation response of the lumbar extensor musculature to passive tissue elongation (PTE) and muscle fatigue (MF). There is no study, however, that has explored this response as a function of the combined effect of both PTE and MF, which is often seen in occupational settings. Twelve participants performed three experimental protocols on three different days to achieve (1) PTE, (2) MF and (3) PTE&MF (combined). Trunk kinematics and muscle activities were monitored to assess the effects of these protocols on the peak lumbar flexion angle and the lumbar angle of the flexion-relaxation of the trunk extensor muscles. Results showed responses to the uni-dimensional stresses (PTE and MF) consistent with those seen in the previous literature, while the combined protocol elicited responses that more closely matched the PTE protocol.

1. Introduction

Load sharing between the active tissues (i.e., muscles) and the passive viscoelastic tissues (e.g., ligaments, tendons, intervertebral discs, etc.) of the low back has been clearly documented during trunk flexion and extension motions. As trunk flexion angle increases from an upright posture, the low back muscle activity gradually increases in order to compensate for increased external moment from the mass of the torso. As the trunk continues to flex, however, the passive tissues of the spine are elongated to the point where they begin to exert a passive extensor moment. As the trunk continues in flexion, these passive tissues increase their contribution to the extensor moment to a point, at near full trunk flexion, when the load is transferred completely to the passive tissues and there is no muscle activity in the paraspinal muscles – known as the flexion-relaxation phenomenon (FRP). A variable of particular importance in this process is the lumbar angle at which this myoelectric silence commences, as this angle is affected by low back disorders and can contribute to our understanding of the fundamental control mechanism of the low back system under normal or abnormal low back conditions (Descarreaux et al., 2008; Rogers and Granata, 2006; Solomonow et al., 2003a, 2003b).

Many of the studies that have explored the FRP have focused on the effect of passive tissue elongation (PTE) on the FRP response, or they have focused on the effect of fatigue of the low back musculature on the FRP response. Focusing on the effects of PTE, Solomonow et al. (2003a) asked participants to hold a ten-minute static trunk full-flexion posture while seated on a physical therapy mat. Comparing the pre-PTE to the post-PTE, they showed a similar FRP response in both men and women participants. For men, the lumbar flexion angle at which FRP occurred was 46.1° pre-PTE and grew to 50.5° post-PTE, while for women the values were 49.8° and 52.5°. These results demonstrated that the extensor moment generating capacity of the passive tissues was compromised with PTE and resulted in the extensor musculature remaining active deeper into the flexion motion. Rogers and Granata (2016) studied the reflexes of the paraspinals muscles during 16 min of full-flexion stooping. Recognizing that these reflexes are controlled by receptors in the spinal ligaments, these authors hypothesized that a decrease in the spinal reflex could be attributed to the laxity of the passive tissues of the low back during these prolonged stooping activities. This, in turn, would decrease the sensitivity of these mechanoreceptors thereby causing errors in the neuromuscular reflex. In summary, the changes in FRP with prolonged trunk flexion revealed laxity in the passive tissues that could be a significant indication of spinal instability and elevate the risk of spinal buckling (Solomonow et al., 2003b, 2003c).

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Other researchers have explored the effects of extensor musculature fatigue (MF) on the FRP. Descarreaux et al. (2008) used the Sorenson technique to generate fatigue in the lumbar extensors and evaluated the effect of this fatigue on the trunk flexion angle at the onset of the FRP. They showed that FRP was initiated earlier in the flexion motion when the extensor muscles were fatigued. Using trunk angle as the dependent variable (as compared to lumbar angle in the Solomonow studies cited above), these authors showed that the fatigue in the extensor muscles decreased the trunk angle at which the FRP was initiated for the erector spinae from 74.7° to 70.4°. The authors suggested that low back muscle fatigue limits force generation capacity of the muscles providing insufficient stabilization to the spinal column, so the fresh passive tissues are charged earlier to compensate for the decreased force generation ability of low back muscles. In a follow-up study, this group (Descarreaux et al., 2010) found similar results and went on to hypothesize that greater lumbar flexion in earlier phase of trunk flexion-extension, caused by a fatigue-initiated change in the lumbopelvic rhythm, could result in the earlier initiation of the FRP and would explain the results from their earlier study.

There have been a few studies that have considered the combined effects of muscle fatigue and passive tissue fatigue. Dickey et al. (2003) conducted a study wherein participants executed 100 trunk flexion-extension motions (4.5 s trunk flexion, 2 s holding full flexion "hanging", and 4.5 s trunk extension) in which both passive and active tissue fatigue were initiated. The results revealed a shortened silence period with deeper maximum flexion angle after the protocol – results that are consistent with studies that explored prolonged stooping postures designed to create passive tissue fatigue. On the other hand, Olson et al. (2004) conducted a study requiring cyclic lumbar flexion-extension (5 s trunk flexion and 5 s trunk extension) for 9 min, and showed earlier cessation of EMG during flexion and delayed activation of EMG during extension. They showed no change in maximum trunk flexion angle. These results are more consistent with a muscle fatigue protocol. The main difference between these two studies was the number of cyclic flexion-extension (100 in Dickey's study and 56 in Olson's study) and the existence of holding time at the full flexion posture.

In summary, the previous studies of the effects of PTE and MF on the FRP of the trunk extensor muscles have demonstrated significant, but opposing, effects. MF appears to cause the FRP to occur earlier in the flexion motion, while PTE appears to delay the onset of FRP in the flexion motion. The two studies noted above in which both PTE and MF were expected did not indicate any clear tendency of the combined effect. Exploring the effects of the combination of MF and PTE in a single experimental protocol is important because in industrial settings, workers performing manual materials handling tasks not only stoop (thereby elongating the passive tissues) but also perform physically demanding lifting tasks (thereby creating muscle fatigue.). The tension between these opposing effects is worthy not only for purely scientific reasons, but may also have direct impact on estimates of spine loading during occupational tasks. The goal of this study was to explore the FRP response to three different low back stressing protocols: 1) extensor muscle fatigue protocol, 2) passive tissue elongation protocol and, 3) a protocol with the combined effect of extensor muscle fatigue and passive tissue elongation.

2. Methods

2.1. Participants

Twelve male participants were recruited from the university undergraduate and graduate student population of Iowa State University. The average and standard deviation of age, stature and whole body mass of participants were 28.3 yr (4.7 yr), 175.9 cm (2.7 cm), and 73.5 kg (6.6 kg), respectively. Participants did not report any chronic problems or current pain in the low back or lower extremities. Each participant provided written informed consent prior to participation, using a form approved by the institutional review board (IRB) at Iowa State University.

2.2. Apparatus

Surface electromyography data were collected at 1024 Hz from eight trunk muscles including the right and left pairs of: L4 paraspinals, L3 paraspinals, rectus abdominis, external oblique (Model DE-2.1, Bagnoli™, Delsys, Boston, MA). Trunk kinematic data were collected at 102.4 Hz from magnetic sensors placed over the S1 and T12 vertebrae (Ascension Technology Corporation, Shelburne, VT). The sagittal plane angle of each of these sensors was collected continuously. An electrical metronome set the pace for the flexion-hold-extension motion.

The experimental trials were conducted on a platform that could be set up for the two different conditions. In those trials designated as "free stooping", the participants simply stood on the platform and stooped with locked knees to the full flexion position but motion of the pelvis was allowed. In the trials designated as "restricted stooping", the participants' legs and pelvis were strapped to a vertical stable structure thereby maintaining verticality of the lower extremity as participants stooped to the full flexion posture (i.e. no horizontal motion of pelvis) (Fig. 1). Straps were used to secure the thighs and pelvis to this rigid structure but were not cinched so tightly so as to eliminate pelvic rotation. The two stooping techniques were employed to test the role of lower extremity during trunk flexion-extension under the three conditions. These two data sets (free vs. restricted) were analysed separately in the statistical analysis.

2.3. Experimental design

There was one independent variable, PROTOCOL, with three levels: A) passive tissue elongation (PTE), B) extensor muscle fatigue (MF), and C) the combination (PTE&MF). There were three kinematic dependent variables in this study and they reflected the

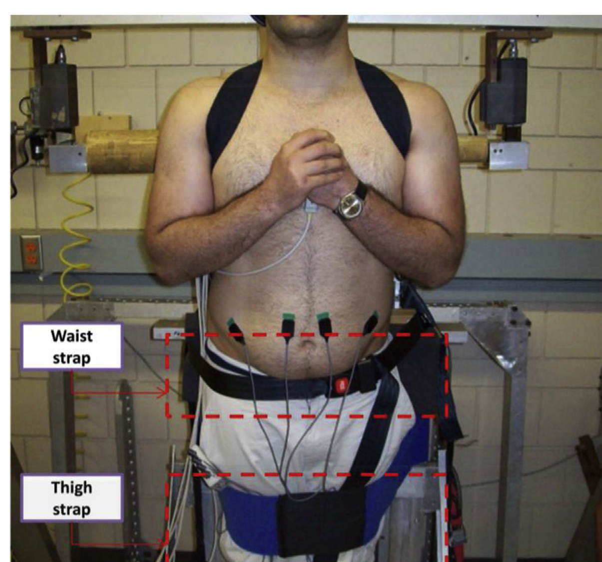

Fig. 1. Upright standing with lower extremity constraints in place.