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Disturbance and recovery of trunk mechanical and neuromuscular behaviors following repeated static trunk flexion: Influences of duration and duty cycle on creep-induced effects

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ABSTRACT

Occupations involving frequent trunk flexion are associated with a higher incidence of low back pain. To investigate the effects of repeated static flexion on trunk behaviors, 12 participants completed six combinations of three static flexion durations (1, 2, and 4 min), and two flexion duty cycles (33% and 50%). Trunk mechanical and neuromuscular behaviors were obtained pre- and post-exposure and during recovery using sudden perturbations. A longer duration of static flexion and a higher duty cycle increased the magnitude of decrements in intrinsic stiffness. Increasing duty cycle caused larger decreases in reflexive muscle responses, and females had substantially larger decreases in reflexive responses following exposure. Patterns of recovery for intrinsic trunk stiffness and reflexive responses were consistent across conditions and genders, and none of these measures returned to pre-exposure values after 20 min of recovery. Reflexive responses may not provide a compensatory mechanism to offset decreases in intrinsic trunk stiffness following repetitive static trunk flexion. A prolonged recovery duration may lead to trunk instability and a higher risk of low back injury.

1. Introduction

Low back pain (LBP) remains the most prevalent musculoskeletal disorder around the world and involves a substantial economic burden (Baldwin, 2004; Dagenais et al., 2008; Jeffrey, 2006; Loney and Stratford, 1999; Luo et al., 2004; Manchikanti et al., 2009). An increased risk of LBP is associated with occupational tasks that involve repetitive lifting and prolonged trunk flexion (BLS, 2009; Hoogendoorn et al., 2000; Manchikanti, 2000; Marras, 2000). Although some disagreement remains regarding the level to which causality has been demonstrated (Kuijer et al., 2011; Wai et al., 2010), several studies have identified potential underlying mechanisms linking flexed working postures to the onset of LBP. Flexed postures can alter trunk passive mechanical properties and compromise active neuromuscular control of the spinal column as a consequence of decreased trunk proprioception (Gade and Wilson, 2007; Wilson and Granata, 2003). These alterations may adversely affect the mechanics of the spinal column, potentially leading to excessive spinal load and/or spinal instability, and increasing the risk for low back injury (Panjabi, 1992a, 1992b).

Recent studies indicate that a single period of exposure to static trunk flexion causes viscoelastic deformation of trunk soft tissues (e.g., muscles, discs, ligaments, and joint capsules) and alters trunk mechanical behaviors as indicated by reductions in intrinsic trunk stiffness (Bazrgari et al., 2011; Hendershot et al., 2011; Little and Khalsa, 2005; McGill and Brown, 1992; Solomonow et al., 2003b). Reductions in intrinsic trunk stiffness require active neuromuscular compensation to maintain mechanical equilibrium and stability of the spine (Bazrgari et al., 2011; Hendershot et al., 2011). However, static trunk flexion also alters the active neuromuscular behavior in that it reduces muscle force-generating capacity (Fowles et al., 2000; Weir et al., 2005), diminishes muscle spindle excitability (Avela et al., 1999; Solomonow, 2012), and may alter the ligament-muscle reflexive response (Le et al., 2009; Solomonow, 2009).

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Decreases in both intrinsic trunk stiffness and active neuromuscular behavior induced by trunk flexion may therefore increase the risk of developing LBP due to spinal instability.

Disturbances to trunk passive mechanical and active neuromuscular behaviors induced by trunk flexion can require a longer time for recovery than the initial exposure duration (Adams et al., 1990; Bazrgari et al., 2011; Ekström et al., 1996; Hedman and Fernie, 1995; Hendershot et al., 2011; Keller et al., 1988; McGill and Brown, 1992). Static flexion that is repeated (e.g., as in agricultural and construction tasks) could therefore result in an accumulation of disturbances to trunk mechanical and neuromuscular behaviors due to incomplete recovery upon initiation of subsequent tasks. Hence, quantifying the acute changes in trunk passive mechanical and active neuromuscular behaviors following repeated trunk flexion is important for better understanding LBP etiology, and may aid in improving work design (e.g., work–rest cycles) in occupations involving frequent and/or repetitive flexed postures. At present, there is limited evidence regarding the effects of cyclic flexion tasks on passive mechanical and active neuromuscular behaviors of the human spine. Existing literature on repeated flexion has examined different aspects of spine biomechanics, different task designs, and/or different models. For example, work by Lu et al. (2004), Solomonow (2012), Solomonow et al. (2000, 1999) investigated the effect of repetitive loading on the spine using feline models. Shin and D'Souza (2010) reported on spinal muscle activity following cyclic loading, but didn't assess passive and active stiffness as investigated here. Therefore, the present study aimed to contribute new evidence regarding this topic.

The objective of the present study was to quantify the effects of static flexion duration and duty cycle on trunk passive mechanical and active neuromuscular behaviors following cycles of repeated trunk flexion and recovery. Previous studies have confirmed that a longer duration of prolonged static flexion increases neuromuscular disturbances in the lumbar spine (Bazrgari et al., 2011; Hendershot et al., 2011; LaBry et al., 2004). In studies using a feline model, short rest periods between flexion events have also been shown to have adverse effects (Courville et al., 2005; Sbriccoli et al., 2007). We hypothesized that the severity of changes in trunk behaviors following repeated static flexion would increase with both static flexion duration and duty cycle. We also expected that changes in passive mechanical behaviors following repeated flexion would not be adequately compensated by the active neuromuscular system, and that recovery would be prolonged and contingent on the severity of changes.

2. Methods

2.1. Participants

Twelve participants completed the study, and all were healthy adults with no self-reported history of low-back pain or current medical conditions that might have influenced the results. Participants included six males with mean (SD) age, stature, and body mass of 23.3 (1.9) yr, 177.9 (3.7) cm, and 71.6 (8.4) kg, respectively; corresponding values for the six females were 24.5 (2.3) yr, 162 (4.4) cm, and 56.7 (3.3) kg. A relatively young group of participants was included to avoid potential influences related to age. Prior to any data collection, each participant completed informed consent procedures approved by the Virginia Tech Institutional Review Board.

2.2. Experimental design and procedures

A repeated measures design was used, in which several measures of trunk mechanical and neuromuscular behaviors were obtained prior to and following exposures to repeated static trunk flexion. Participants completed six experimental sessions involving exposure to all combinations of three static flexion durations (FD) and two flexion duty cycles (DC). Each session was conducted at a similar time on separate days, and with a minimum of two days between consecutive sessions. To minimize inter-session variation, the same trained experimenters used a standardized experimental protocol. This protocol included ensuring consistent electrode placements (measuring and recording the position of each collection site), confirming participants' health status in each session, and performing consistent measurements throughout the sessions. To reduce the potential for order-related confounding effects, the order of conditions was specified using balanced Latin Squares (i.e., two 6 $\times$ 6 squares, one for each gender group). During the experiment, participants stood in a rigid metal frame designed to restrain the pelvis and lower limbs in a fixed, but comfortable posture (Fig. 1).

Participants were exposed to one of the six combinations of three static flexion durations (1, 2, and 4 min) and two duty cycles (33% and 50%). Static flexion involved participants flexing their trunk forward as far as possible while relaxing their muscles, minimizing potential confounding effects of muscle fatigue. This flexion–rest–flexion sequence was repeated continuously for 48 min, with the number of total cycles dependent on the FD and DC (Fig. 2). Concurrent with a differing number of total cycles, this study design resulted in two different total flexion exposure durations (TE). These TE durations were determined by DC, specifically 24 min for the 50% DC and 16 min for the 33% DC. Different TEs are inherent when testing different level of DC given a fixed exposure period (here, 48 min). Thus, the specific values of FD and DC determine TE, as well as the rest period between exposures in successive cycles. Both aspects (FD and DC) were expected to influence trunk passive mechanical and active neuromuscular behaviors, and which were of interest in this study. Note that an alternative design approach could have kept TE consistent and manipulated DC with a variable exposure period. However, a fixed exposure period was considered more relevant, since most occupational work has a set working period (e.g., an 8 h shift or 2 h exposure in a rotation plan). The 48-min exposure period was selected to allow for completion of full cycles of flexion exposure, yet avoid adverse outcomes among participants (i.e., pilot work

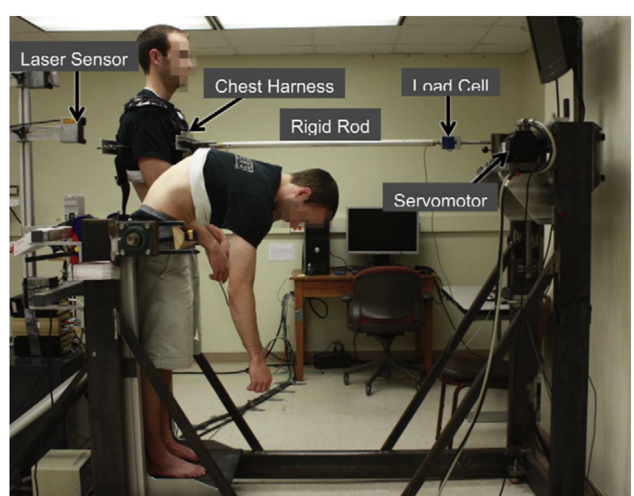

Fig. 1. Experimental set-up demonstrating a participant during trunk mechanical and neuromuscular measurement superimposed with a picture of the same participant in static flexion.