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Short communication

Evidence for an exposure-response relationship between trunk flexion and impairments in trunk postural control

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ABSTRACT

Prolonged trunk flexion alters passive and active trunk tissue behaviors, and exposure-response relationships between the magnitude of trunk flexion exposure and changes in these behaviors have been reported. This study assessed whether similar exposure-response relationships exist between such exposures and impairments in trunk postural control. Twelve participants (6 M, 6 F) were exposed to three distinct trunk flexion conditions (and a no-flexion control condition), involving different flexion durations with/without an external load, and which induced differing levels of passive tissue creep. Trunk postural control was assessed prior to and immediately following trunk flexion exposures, and during 10 min of standing recovery, by tracking center of pressure (COP) movements during a seated balance task. All COP-based sway measures increased following each flexion exposure. In the anteroposterior direction, these increases were larger with increasing exposure magnitude, whereas such a relationship was not evident for mediolateral sway measures. All measures were fully recovered following 10 min of standing. The present results provide evidence for an exposure-response relationship between trunk flexion exposures and impairments in trunk postural control; specifically, larger impairments following increased exposures (i.e., longer flexion duration and presence of external load). Such impairments in trunk postural control may result from some combination of reduced passive trunk stiffness and altered/delayed trunk reflex responses, and are generally consistent with prior evidence of exposure-dependent alterations in trunk mechanical and neuromuscular behaviors assessed using positional trunk perturbations. Such evidence suggests potential mechanistic pathways through which trunk flexion exposures may contribute to low-back injury risk.

1. Introduction

Occupational tasks involving trunk flexion are associated with an increased risk for low back pain (BLS, 2009; Hoogendoorn et al., 2000). Experimental studies indicate that prolonged trunk flexion reduces passive support of the spine (McGill and Brown, 1992; Toosizadeh et al., 2012) and alters trunk neuromuscular responses (Fowles et al., 2000; Shin and Mirka, 2007). Recently, disturbances in passive and active trunk tissue responses to external trunk perturbations have been shown to be dependent upon the magnitude of trunk flexion exposure (Bazrgari et al., 2011; Hendershot et al., 2011). Disturbances in these behaviors have also been related to reductions in trunk postural control during an unstable seated balance task in patients with low back pain (Radebold et al., 2001). Such a task challenges the neuromuscular system to maintain spinal stability, exclusive of responses from the lower-extremities, and has been used as an alternative method to assess trunk sensorimotor and neuromuscular function by tracking center of pressure (COP) movements vs. discrete responses to positional perturbations (Leitner et al., 2009; Preuss et al., 2005). It is presently unclear whether similar exposure-dependent disturbances in trunk postural control during seated balance occur following different magnitudes of trunk flexion exposures. The aim of this study was, therefore, to evaluate the effects of several trunk flexion exposures on trunk postural control during an unstable seated balance task. We hypothesized that the magnitude of changes in trunk postural control would increase with increasing trunk flexion exposure, as evidenced by increases in COP-based sway measures. As a secondary aim, we also explored the patterns of recovery in trunk postural control following such exposures.

2. Methods

2.1. Participants

Twelve young adults (6 male, 6 female) participated after completing informed consent procedures approved by the Virginia Tech Institutional Review Board.

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Mean (SD) age, stature, and body mass for six males were 23.3 (2.0) yr, 185.2 (4.3) cm, and 77.7 (4.0) kg, respectively; corresponding values for the six females were 24.5 (3.0) yr, 162.0 (5.3) cm, and 60.8 (3.7) kg. All participants reported being free of current or recent injuries, illnesses, musculoskeletal disorders, and other health-related aspects that may have influenced the results.

2.2. Experimental design and procedures

Participants were exposed to three distinct conditions involving prolonged static trunk flexion of different durations and with/without an external load (29 N; ~3 lbs strapped to each wrist): 2 min with no load ("2NL"), 4 min with load ("4L"), and 10 min with load ("10L"). A control condition ("CTRL") was also included, during which participants stood in an upright posture for 4 min (without load). Each of the four conditions was completed in a randomized order and at similar times on different days separated by at least 72 h. These three flexion conditions were intended to control the magnitude of flexion exposure using occupationally-relevant factors (i.e., flexion duration and with/without a small load in the hands), and which induced different levels of passive tissue creep (though we did not control these). A full-factorial combination of factors was not used to minimize the number of sessions, and since our primary interest was to identify an exposure-response relationship between different magnitudes of trunk flexion exposure and trunk postural control during a seated balance task.

Creep deformation of posterior trunk tissues was induced by having participants flex their trunk forward to a full, relaxed position while standing in a rigid metal frame with the pelvis and lower limbs restrained using straps (see Bazrgari et al., 2011 for additional details and an image of a participant in the flexed posture). Participants slowly (~3 s) flexed forward from an upright standing posture and remained in full, passive flexion for the designated duration with their head facing down and arms hanging vertically. Lumbar kinematics were monitored (100 Hz) using a triaxial 6DOF inertial measurement unit (IMU: Xsens Technologies, XM-B-XB3, Enschede, The Netherlands) affixed over the T12 spinous process using double-sided tape.

Pre- and post-exposure (to trunk flexion or after the control condition) measures of trunk postural control were obtained while participants maintained seated balance on an unstable chair for 60 s (see Lee and Granata, 2008 and Slota et al., 2008 for detailed images of the device). Briefly, adjustments to the seat allowed the participant's center of mass to be centered over a central pivot. The positions of four springs, located in each cardinal direction, were adjusted (relative to the gravitation gradient, ∇G, for each participant+chair assembly) such that the difficulty of the task was similar across participants. Task difficulty (i.e., spring positions) was standardized to 60% ∇G for all four springs. During seated balance trials, participants were instructed to keep the chair surface as level as possible, while sitting with an upright posture, eyes open and looking straight ahead, with their arms folded across their chest and with the hips and knees flexed at ~90° angles.

In each experimental session, participants first completed six pre-exposure seated balance trials with 2 min of rest between each. Seated balance trials were also completed immediately after exposure to each of the four conditions, and at additional intervals of 2.5, 5, and 10 min afterwards to assess recovery. The typical delay between the end of a flexion exposure and the first post-exposure measurement was ~30 s, and resulted from having to move participants from the rigid frame to the unstable chair. During recovery, participants returned to an upright standing posture between seated balance trials to minimize potential confounding by the seated posture itself, since prolonged sitting can induce viscoelastic deformation of the spine (Howarth et al., 2013).

During all seated balance trials, triaxial reaction forces and moments were recorded (1000 Hz) using a force platform (AMTI, OR6-7-1000, Watertown, MA, USA) located beneath the chair-spring assembly. These were low-pass filtered (second-order, bidirectional, Butterworth, 10 Hz cut-off frequency), and processed to obtain COP time series in the anteroposterior (AP) and mediolateral (ML) directions.

2.3. Dependent measures and statistical analyses

Creep deformation throughout each flexion period was characterized by changes in the trunk flexion angle, measured by the IMU. For all seated balance trials, the first and final 5 s of each trial were removed, and all COP data were de-meaned prior to analyses. Trunk postural control was quantified using several reliable and relatively independent measures of sway (Larivière et al., 2013; Prieto et al., 1996; van Dieën et al., 2010) derived from COP time series: root-mean-square (RMS) distance (cm), mean sway velocity (cm/s), and the short-term diffusion coefficient (Ds; cm^2/s). Ds is determined from the linear slope of mean square COP displacement vs. increasing time intervals, and represents the magnitude of short-term movements in COP (Collins and De Luca, 1993).

Statistical analyses were performed using JMP (Version 10, SAS Institute Inc., Cary, NC, USA), and significance was determined when $p < 0.05$. Initially, multivariate analyses of variance (MANOVA) were used to assess the six replications of pre-exposure seated balance trials for evidence of learning/practice effects. Such effects (decreases across replications) were significant in the first four replications. Thus, the mean of the final two (5th and 6th) pre-exposure trials was used in subsequent analyses to represent the pre-exposure value. Paired t-tests were used to assess changes in these measures across all conditions (except CTRL) immediately following the exposure period. Subsequently, change scores were obtained by normalizing all post-exposure measures to pre-exposure values [(post-pre)/pre]. Acute effects of exposure condition and gender on these normalized changes were assessed using mixed-factor ANOVAs. Where relevant, post-hoc paired comparisons were made using Tukey's Honestly Significant Difference (HSD) test. For dependent measures with significant post-exposure effects of condition from the ANOVAs, repeated measures MANOVAs were used to assess the effects of these same factors over the 10-minute recovery period. Where sphericity violations were found in MANOVAs, the Geisser-Greenhouse correction was used. Data from one condition of one participant (female, 4L) were excluded from these analyses due to measurement errors. Summary values are reported as means (SD).

3. Results

Creep deformation across all conditions (except CTRL) was 5.8 (4.9)°, and was similar (p=0.61) between males [6.7 (5.2)°] and females [5.6 (4.6)°]. Creep deformation increased ($p < 0.001$) with increasing exposure (Fig. 1).

3.1. Immediate post-exposure changes

COP-based measures of trunk postural control increased following flexion exposure (Table 1), and all AP sway measures increased with increasing flexion exposures (Fig. 1). Gender differences were not significant for any dependent measure (Table 1), and there were no significant ($p > 0.08$) gender x exposure condition interaction effects.

3.2. Recovery

Comparisons between initial (pre-exposure) and final (post-recovery) values indicated no differences ($p > 0.19$) in any of the sway measures following 10 min of standing, regardless of condition or gender, and implying full recovery. Further, no significant differences ($p > 0.11$) in recovery patterns were found between exposure conditions (Fig. 2).

4. Discussion

Larger creep deformations found here with increasing flexion exposure (duration and/or load) are consistent with prior work (Bazrgari et al., 2011). Post-exposure increases in RMS distance and sway velocity, coupled with larger short-term COP amplitudes (Ds), suggest reduced trunk postural control (van Dieën et al., 2010). These post-exposure reductions in trunk postural control

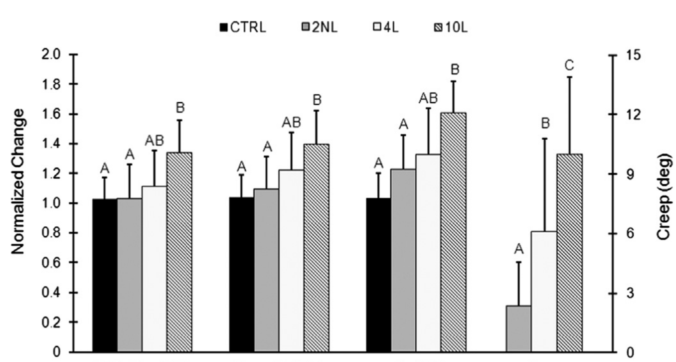

Fig. 1. Primary axis (left) indicates effects of exposure condition on RMS distance (AP), mean velocity (AP), short-term diffusion coefficient, Ds (AP). Normalized changes are illustrated (e.g., 1.5 indicates a 50% increase from pre-exposure values). Secondary axis (right) indicates creep deformation induced by trunk flexion exposures. Error bars indicate standard deviations, and results from post hoc pairwise comparisons (within each measure) are indicated by letters.