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Alterations in trunk bending stiffness following changes in stability and equilibrium demands of a load holding task

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ABSTRACT

The contribution of the trunk neuromuscular system (TNS) to spine stability has been shown in earlier studies by characterizing changes in antagonistic activity of trunk muscles following alterations in stability demands of a task. Whether and/or how much such changes in the response of TNS to alteration in stability demand of the task alter spinal stiffness remains unclear. To address this research gap, a repeated measure study was conducted on twenty gender-balanced asymptomatic individuals to evaluate changes in trunk bending stiffness throughout the lumbar spine's range of flexion following alterations in both stability and equilibrium demands of a load holding task. Trunk bending stiffness was determined using trunk stiffness tests in upright posture on a rigid metal frame under different equilibrium and stability demands on the lower back. Increasing the stability demand by increasing the height of lifted load ~30 cm only increased trunk bending stiffness (~39%) over the lower range of lumbar flexion and under the low equilibrium demand condition. Similarly, increasing the equilibrium demand of the task by increasing the weight of lifted load by 3.5 kg only increased trunk bending stiffness (55%) over the low range of lumbar flexion and under the low stability demand condition. Our results suggest a non-linear relationship between changes in stability and equilibrium demands of a task and the contribution of TNS to trunk bending stiffness. Specifically, alterations in TNS response to changes in stability and equilibrium demand of a given task will increase stiffness of the trunk only if the background stiffness is low.

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1. Introduction

Equilibrium and stability of the human spine during daily activities are primarily provided by the trunk neuromuscular system (TNS). While the contribution of TNS to spine equilibrium is directly reflected in an individual's ability to perform an activity (e.g., holding a given trunk posture or moving the trunk in the space as desired), its contribution to spine stability is less clear. Granata and Orishimo (2001) demonstrated the contribution of TNS to spine stability by characterizing changes in antagonistic activity of trunk muscles following alterations in stability demands of a load holding task. Specifically, subjects were instructed to hold a load (4.5 or 9.0 kg) between two vertical guide-bars at different heights, so that the equilibrium demand of the task on the lower

back was nearly unchanged given the constant horizontal distance between the load and the lower back, whereas the stability demand of the task was altered by changing the load height (Granata and Orishimo, 2001). Although higher levels of antagonistic muscle activity were found with increasing stability demands, it remained unclear whether and/or how the observed changes in the response of TNS altered spinal stability.

Spinal stability, in a biomechanical sense, is defined as the capacity of the system that provides spinal equilibrium to sustain the equilibrium in the presence of mechanical perturbations. Therefore, spinal stability can partially be assessed through measures of trunk bending stiffness. Increased activity of trunk muscles in recumbent posture has been shown to increase trunk bending stiffness throughout the lumbar spine's range of flexion (Beach et al., 2005; Brown and McGill, 2008, 2010; Lee and McGill, 2015). Similarly, trunk bending stiffness in neutral standing posture was found to increase with increases in activity of trunk muscles (Cholewicki et al., 2000; Gardner-Morse and Stokes, 2001; Stokes and Gardner-Morse, 2003). The main limitation of these

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earlier studies in the assessment of TNS contribution to spinal stability is that in all cases the increase in the activity of trunk muscles was achieved through either changes in the equilibrium requirements of the task (e.g., pre-activation efforts) or intentionally recruiting trunk flexor muscles while maintaining an upright posture (Brown and McGill, 2010; Lee et al., 2006). Therefore, it remains unclear how alterations in TNS following changes in stability requirement of a task, as reported by Granata and Orishimo (2001), affect trunk bending stiffness and spinal stability.

We have developed a new experimental device that enables assessment of trunk bending stiffness in an upright posture throughout the lumbar spine's range of flexion. The objective of this study was set to evaluate changes in trunk bending stiffness throughout the range of flexion following alterations in both stability and equilibrium demands of a load holding task. It was hypothesized that with increasing each of the stability and equilibrium demands of the task, trunk bending stiffness would increase. Considering our recent finding on the effects of gender and lumbar flexion angle on trunk bending stiffness (Shojaei et al., 2016), we further hypothesized that increases in trunk bending stiffness with increases in stability and equilibrium demands will be affected by gender differences and by the passive contribution of trunk tissues to spine equilibrium (i.e., increased contribution under larger lumbar flexion angles). To test our hypotheses, a repeated measure study design similar to that of Granata and Orishimo (2001) was used wherein changes in stability and equilibrium demands of the task were achieved by changing, respectively, the weight and height of the lifted load.

2. Methods

2.1. Participants

Twenty gender-balanced asymptomatic individuals between 18 and 30 years old were recruited from the University of Kentucky's student population. Exclusion criteria were previous history of back pain, evidence of neuromuscular disorders, history of working in physically demanding occupations, involvement in excessive levels of physical activity that might significantly impact the neuromuscular behavior, and a body mass index (BMI) outside the 20–30 kg/m² interval. Prior to data collection, all participants com-

pleted an informed consent procedure approved by the University of Kentucky Institutional Review Board. The mean (SD) values of stature, body mass, and BMI were respectively 178.0 cm (6.2 cm), 78.9 kg (12.0 kg), and 24.8 (3.5) for males and 164.7 cm (5.1 cm), 67.1 kg (7.0 kg), and 24.7 (3.8) for females.

2.2. Experimental procedures

Each participant completed one experimental session comprising of six trunk stiffness tests in upright posture under different equilibrium and stability demands. Prior to these trunk stiffness tests, each participant conducted a trunk bending–return test, to obtain his/her lumbar spine's range of flexion (Fig. 1). For the trunk bending–return test, participants were instructed to bend their trunk forward from an upright posture to their maximum comfortable bending posture and then to return to their original upright posture. Participants were instructed to repeat the trunk forward bending and backward return three times with a self-selected slow pace. Wireless Inertial Measurement Units (IMUs; Xsens Technologies, Enschede, Netherlands) superficial to the T10 vertebral process and the sacrum (S1) (Fig. 1) were used to measure rotations of the thorax and pelvis as rigid bodies.

Trunk stiffness tests were conducted on a rigid metal frame (Fig. 2), wherein the participant's pelvis was constrained using straps and the upper body was kept upright throughout the experiment using a harness-connecting rigid rod assembly. The stiffness tests were conducted within this frame by rotating the participant's legs (and pelvis as it was constrained and isolated from the upper body) around his/her lower back using an actuated platform. The height of platform was adjusted for each participant such that the platform's axis of rotation coincided with ~ the S1 spinal level (Fig. 2). Since the lower extremities and the pelvis of participants were constrained to the platform and the thorax was fixed in space, it was assumed that the amount of lumbar flexion was the same as the amount of rotation of the platform. The test started with the participant in standing posture, followed by rotation of the legs and pelvis at a constant angular velocity of ~3 deg/s (dictated by the platform's actuator), to achieve a lumbar flexion equal to 70% of the lumbar range of flexion, and then returning them back into the initial standing posture on the frame. The selection of a sub-maximal (i.e., 70%) lumbar flexion for these tests was

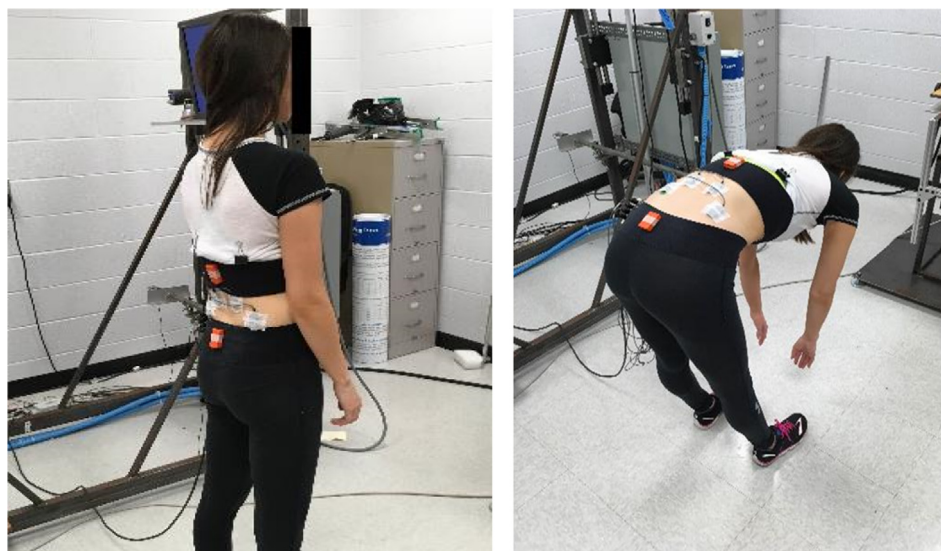


Fig. 1. Wireless Inertial Measurement Units superficial to the T10 vertebral process and the sacrum (S1) as well as surface sensors for collecting electromyography activity of selected back and abdominal muscles (left). The maximum flexed posture during the trunk bending–return test to obtain lower back range of flexion (right).

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