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Compensatory strategy between trunk-hip kinematics and reaction time following slip perturbation between subjects with and without chronic low back pain

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ABSTRACT

Compensatory trunk and hip motions following slip perturbations may compromise the control of lumbopelvic movement. However, it is unclear how postural integration of the trunk and hips can be transferred to treadmill-induced slip perturbations in subjects with chronic low back pain (LBP). The purpose of this study was to investigate trunk reaction times and three-dimensional trunk-hip angle changes following a slip perturbation (duration: 0.12 sec, velocity: 1.37 m/sec, displacement: 8.22 cm) with a handheld task between subjects with and without chronic LBP. There were 23 subjects with LBP and 33 control subjects who participated in the study. The trunk reaction time was not significantly different between groups. However, the three-dimensional trunk-hip angle changes were significantly different following the perturbation. There were significant interactions between the body regions and three-dimensional angles between groups. There was a negative correlation between reaction time and trunk flexion in the LBP group. Overall, the LBP group demonstrated significantly reduced trunk flexion, which might be associated with reduced adaptability or a possible fear of avoidance strategy. Clinicians need to consider compensatory strategies to improve trunk flexibility following slip perturbations in subjects with chronic LBP.

Mini abstract: Trunk reaction time and three-dimensional trunk-hip motions were compared between subjects with and without chronic low back pain (LBP). The control group demonstrated greater trunk flexion; however, the LBP group reduced trunk flexion to protect against further injuries following the novelty of the slip perturbation.

1. Introduction

Low back pain (LBP) is the most common musculoskeletal condition affecting the adult population, with a prevalence of up to 84% (Balague et al., 2012). Although LBP resolves in the majority of patients in approximately 6 weeks, at least 5% of patients develop chronic LBP after the initial episode (Manchikanti et al., 2014). This pain syndrome lasts for at least 3 months, and chronic LBP represents the second leading cause of disability (Allegri et al., 2016; Macedo et al., 2012b).

It has been reported that LBP groups demonstrate a trunk stiffening strategy to control their posture during standing and rely on ankle proprioception (Brumagne et al., 2008b). In addition, subjects with LBP demonstrate postural sway, which is not related to reduced spine motion, but might be linked to an increase in muscular active tension (Hamaoui et al., 2004). However, the changes in motor cortical representation related to neuromuscular mechanisms might restore postural control.

The trunk stiffness through co-contraction could explain delays in muscle response time since postural disturbances may cause a slower deviation of trunk posture (Maaswinkel et al., 2016; van Dieen and Cholewicki, 2003). One study reported the awareness of potential slip risk to cause protective changes to human gait by using a motion capture system during walking in healthy young adults (Yang et al., 2016). Although their results could provide insights into dynamic stability control when individuals anticipate potential slip risk during treadmill walking, their study reported only sagittal plane data rather than three-dimensional trunk changes.

In response to sudden perturbations during walking, subjects with LBP demonstrated delayed muscle onset, inadequate postural and neuromuscular control, and variability as a response to sudden trunk

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loading in comparison to healthy control subjects (Mueller et al., 2017; Sung et al., 2018a). Although subjects with LBP implemented specific compensation strategies for destabilized postural control, they typically demonstrated increased postural sway (Caffaro et al., 2014). Individuals with chronic LBP tend to have less hip medial rotation, either unilaterally or bilaterally; whereas, the control group does not display these deficits (Hoffman et al., 2011; Murray et al., 2009). These altered motions might disrupt trunk and hip coordination; however, there is a lack of recovery investigation following slip perturbations.

Recent systematic reviews support the finding that individuals with LBP have reduced lumbar motion and proprioception and move more slowly compared to control subjects (Laird et al., 2014; Tong et al., 2017). These factors contribute to the stability of the trunk since unexpected loading of the spine is a risk factor for LBP (Cholewicki et al., 2005, 2000; Radebold et al., 2000; Shahvarpour et al., 2014). It has been confirmed that impaired postural control of the lumbar spine is associated with delayed muscle response times in subjects with chronic LBP (Radebold et al., 2001). In addition, trunk-hip responses are likely influenced by perturbations as well as individual neuromuscular control from fear of avoidance. However, it is unclear whether these results maintain validity during treadmill-induced slip perturbations with a handheld task.

Previous kinematic analyses indicated that a contribution of lumbar motion relative to the hip region was reduced in the LBP group (Shum et al., 2005). The interaction between lumbar spine and hip movements vary as a result of variations in measurement methods, loading conditions, or the pathology contribution to pain. A recent study reported that subjects with LBP demonstrated impaired muscle response times and trunk posture, especially in the sagittal and transverse planes (Mueller et al., 2017). These perturbation results could indicate reduced trunk stability and higher loading during walking. Other results reported greater lumbar motion and velocity during the initial phase of extension from the fully flexed position in the LBP group (McClure et al., 1997).

It is evident that external perturbations can differentiate local dynamic stability in fall-prone healthy adults (Lockhart and Li, 2008). Specifically, repeated-slip exposure might be effective in a rapid adaptation to slips across functional activities (Pai et al., 2010). However, there is limited investigations that utilize valid measurements of kinematic consequences following specific perturbations and recovery. For example, improper utilization of the ankle compensation strategy following slips might lead to increased fall risk in subjects with LBP. If trunk and hip motions are properly controlled, the compensatory strategies to avoid pain recurrence might result in kinematic integration. It would be beneficial to compare trunk reaction time with three-dimensional kinematic analyses to understand balance deficits between subjects with and without LBP.

Three-dimensional trunk and hip motions might provide balance recovery before and after the perturbations to prevent further injuries. The purpose of this study was to compare trunk reaction time and three-dimensional trunk-hip kinematics following treadmill-induced slips between subjects with and without LBP during a handheld task. It was hypothesized that the LBP group would demonstrate significantly longer trunk reaction times and decreased trunk flexion relative to hip motions following the perturbation.

2. Methods

2.1. Participants

Subjects were recruited from the University community through advertisement, and those subjects who met the study's inclusion criteria received information regarding the study design and signed a copy of the Institutional Review Board approved consent form. Subjects with LBP were eligible to participate if they: (1) were between 20 years and 45 years of age and right limb dominant, (2) had a current episode of LBP with or without leg pain for at least a 3 month duration prior to data collection, (3) had no serious pathology, such as nerve root compromise, at the time of data collection, and (4) had no conditions which would prevent them from standing without impaired balance (e.g., central nervous system disorder, vestibular disorder, diabetes, etc.).

Subjects were excluded from participation if they: (1) had a diagnosed psychological illness that might interfere with the study protocol, (2) had overt neurological signs (sensory deficits or motor paralysis), and/or (3) were pregnant. The control group was recruited based on the age and body mass index (BMI) of the LBP group, which ranged from 18.5 to 29.9.

2.2. Experimental procedures

Upon arrival to the Motion Analysis Center, each subject completed a health questionnaire form, which included demographic information. A visual analog scale (VAS) was also utilized for the assessment of variations in intensity of pain in the LBP group. The scale was comprised of a 100 mm horizontal line labeled with scale anchors at each end (Huskisson, 1983). The two ends of the VAS scale were explained to subjects as being "no pain" and "pain as bad as it could be," and the scores ranged from 0 to 100 (mm). The reliability and concurrent validity of this scale in chronic pain patients is moderate to good (Boonstra et al., 2008).

The level of disability for all participants was evaluated by the Oswestry Disability Index (ODI), which is one of the most frequently used tools for measuring chronic disability related to LBP (Ciccone et al., 1996). A sum is calculated and presented as a percentage, where 0% represents no disability and 100% represents the worst possible disability. The ODI has been a worthwhile outcome measure with high validity and reliability (Fairbank et al., 1980, 2000).

The subjects were barefoot during the study. Prior to actual data collection, the subjects walked one trial at a speed of 1.7 m/sec for 1 min without perturbation on the ActiveStep® treadmill (Simbex, Lebanon, NH) to be familiar with the device. The subjects were instructed to stand on the treadmill while holding a tray, and they were informed that they may or may not experience a slip at any time in order to produce real-life trunk reactions to the treadmill-induced slips.

The participants were instructed to hold a 2.2-pound tray with an empty cup on it to mimic a task similar to a functional activity. This weight was chosen as we previously investigated functional tasks with trunk rotation and sudden perturbations (Sung and Danial, 2017; Sung and Ham, 2010). If a slip occurred, subjects attempted to correct their posture and to recover a standing position while holding the tray and not letting the cup fall off the tray. During the test, all subjects wore a full-body safety harness system, which protected them from any potential injuries.

The treadmill has a two-ply belt consisting of a black polyurethane top-layer and an under-layer made of a nylon-polyester weave. The actual belt speed and displacement were also registered by the treadmill controller. The belt was free to slide forward on top of a low-friction metal frame embedded on the treadmill. Fig. 1A indicates the experimental setup for inducing slips in standing while holding a tray. The treadmill-induced slip perturbation included the following parameters based on the functional trials from previous studies: duration: 0.12 sec, velocity: 1.37 m/sec, and displacement: 8.22 cm (Kajrolkar et al., 2014; Pai et al., 2014). Fig. 1B and C includes a comparison of the kinematic changes between subjects with and without chronic LBP.

2.3. Data collection

The kinematic data measured three-dimensional trunk and hip motions during the entire profile by the motion capture system, which consists of 12 infrared cameras (Vicon MX, Oxford, UK), sampling at 120 Hz. A total of 34 reflective markers (12 mm diameter) were attached to each subject's anterior superior iliac spines (ASIS), posterior