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Kinematics and muscle activities of the lumbar spine during and after working in stooped postures

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ABSTRACT

Existing biomechanical evidence suggests mechanisms of low back injuries and disorders associated with prolonged stooping. However, no research has tested realistic and more natural stooped work conditions with human subjects in the investigation of the biomechanical responses of the low back in prolonged stooping. The current study was aimed to explore various biomechanical responses of the low back in more realistic and work-related loading and posture conditions of prolonged stooping. Twenty two subjects performed stooped work tasks for 7 min with periodic micro-breaks in upright standing, and various measures for assessing biomechanical responses of the low back were obtained before, during and immediately after the stooped work period. Study results found significant increases ($p < 0.05$) in the range of lumbar flexion and myoelectric activation of the low back muscles after the stooped work period. During stooped work, the low back extensor muscles did not show flexion–relaxation. It could be concluded that the natural and unrestricted stooped work conditions produced similar viscoelastic responses of the low back to what more severe stooping conditions with posture restrictions did in previous research, but could be more fatigue-prone due to low but consistent activation of the low back extensor muscles during stooped work activities.

1. Introduction

Low back disorder (LBD) is one of the most common disorders that has caused substantial economic burden to society. One of major physical risk factors that have been related to the occurrence of low back pain or disorders is frequent exposures to static upper body deep flexion postures or prolonged stooping (Bernard, 1997; Shin et al., 2009).

Occupational tasks that require workers to work at or below knee height for extended periods of time (e.g. landscaping and horticultural services, roofing work and concrete work) have reported relatively high incidence rates of LBDs compared to industry average (BLS, 2008), and construction and farm workers have ranked the prolonged stooping posture as one of the most problematic work postures for their work-related LBDs (Goldsheyder et al., 2002; Rogers and Granata, 2006). Although the mechanism of injury is still under investigation, it is commonly accepted that frequent exposure to prolonged stooping is one of major risk factors for LBDs (Fathallah et al., 2008).

In recent efforts in the investigation of injury mechanism and the development of prevention strategies, researchers have assessed the risk of injury associated with stooping by quantitatively evaluating the development of micro-tissue damage in the supporting passive tissues of the lumbar spine (Solomonow et al., 2003a), increases in the range of lumbar flexion in upper body full flexion trials (McGill and Brown, 1992; Rogers and Granata, 2006; Shin et al., 2009), delayed occurrence of flexion–relaxation in upper body flexion movements (Solomonow et al., 2003b; Shin et al., 2009), changes in the perturbation response behaviors of paraspinal muscles (Rogers and Granata, 2006; Bazrgari et al., 2011), and increased myoelectric (EMG) activity of lumbar erector spinae muscles (Shin and Mirka, 2007) after prolonged or repeated exposures to stooped postures. These physiologic or behavioral responses of the lumbar spine have been recognized as indicators of mechanical instability of the lumbar spine, and researchers have suggested an association between stooping and the occurrence of spinal laxity and instability as an injury mechanism (Adams and Dolan, 1996; Solomonow, 2006; Shin et al., 2009).

While previous research has consistently shown evidence that suggests the association between stooped postures and LBDs, there is a need for further research with more work-related postures or loading conditions of prolonged stooping. Previously, changes in the lumbar spine musculature of human subjects associated with prolonged stooping have been quantified under controlled and restricted postural conditions such as maintaining an upper body forward flexion posture at the end of voluntary flexion range or a

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passively hanged (relaxed) upper body posture for up to 20 consecutive minutes in sitting or in quiet standing, with the pelvis and lower extremities restrained to a fixture to isolate the sagittal plane motion of the upper body to those anatomical structures superior to the pelvis (McGill and Brown, 1992; Rogers and Granata, 2006; Shin and Mirka, 2007). No study has yet experimentally confirmed the occurrence of the above-mentioned biomechanical responses of the lumbar spine of human subjects in more work-related and unrestricted prolonged stooped posture conditions, and it has been frequently addressed as a limitation in previous research.

Although the restricted and somewhat extreme loading conditions (e.g. static full flexion for 20 consecutive minutes) could improve study sensitivity, the lack of empirical data that show the occurrence of similar biomechanical responses of the low back in unrestricted loading conditions could limit the utility of existing knowledge on the injury mechanism. To address this limitation, the current study was aimed to quantitatively assess the effects of prolonged stooping on viscoelastic responses of the low back with more work-related and unrestricted stooped work posture and loading conditions. Two different stooping scenarios were tested for each subject with different micro-break schedules to cover wider scope of work-related stooping conditions. The two micro-break schedules were specifically chosen not only to represent realistic break schedules but also to compare efficiency of different micro-break schedules in mitigating cumulative effects of prolonged stooped postures while maintaining overall task duration.

2. Methods

2.1. Subjects

Twenty two subjects (12 females and 10 males) who had no chronic or current low back problems participated in the experiment. Prior to participation, each subject provided informed consent on a protocol approved by the institutional review board. Their mean age was 23 yrs (standard deviation, SD: 2 yrs), and mean height and weight were 1.66 m (SD: 0.09 m) and 62.7 kg (SD: 14 kg), respectively.

2.2. Experimental variables

Various biomechanical measures were quantified before, during and immediately after 7-min work in a stooped posture with periodic micro-breaks to determine the occurrence of stooping-related changes in the lumbar spine musculature. First, the limits of voluntary lumbar flexion and pelvic forward rotation in upper body full flexion trials were obtained before and after the 7-min work, and increments in the peak angles were evaluated as an indicator of viscoelastic and poroelastic changes of passive spinal tissues (Solomonow et al., 2003b; Rogers and Granata, 2006). Second, EMG amplitudes of lumbar erector spinae muscles and external oblique muscles in weight holding trials were measured before and after the work period, and increments in the amplitudes were interpreted as the compensatory response of the muscles to the reduced moment generating capacity of the passive spinal tissues (Shin and Mirka, 2007; Shin and D'Souza, 2010). Third, median frequency of the EMG signals from the weight holding trials were compared before and after the work period, and the shift of the median frequency towards lower frequencies was considered as an indication of muscle fatigue development. Finally, range of lumbar flexion variation (maximum, minimum, mean) and mean amplitudes of the lumbar spine erector spinae muscles were collected at the beginning and periodically during the work period to determine whether the lumbar spine was maintained near full flexion postures and whether the extensor muscles exhibited myoelectric silence (Shin et al., 2009) while maintaining the stooped posture.

The above dependent variables were collected in two work sessions of different schedules for micro-breaks (session 'A' and 'B'). Between the two work sessions, the overall duration of maintaining a stooped posture was kept consistent while the duration and frequency of the micro-breaks varied. Each subject experienced both sessions on the same experiment day. In session 'A', subjects stood up from a stooped posture every 30 s and took a micro-break for 6 s in upright standing before returning to the stooped posture. In session 'B', subjects took a 12-s micro-break every 60 s during the 7-min work period (Fig. 1). For both sessions, the total duration of stooped posture was 6 min, while the total duration of break was slightly longer for session 'A' (66 s). The order of two sessions was randomized and balanced between subjects, and sufficient rest break was provided between the two for each subject.

2.3. Data collection

Prior to the beginning of each session, the subject conducted a weight holding trial and a full upper body forward flexion trial in series. For the weight holding, the subject held a weighted object, which was equivalent to 40% of the subject's maximum lifting capacity, for 5 s in a forward flexed standing posture with both wrists at the height of knee joints. The subject was asked to keep their legs and arms straight, and minimize the forward rounding of the upper back during the weigh holding. The weight of the hand-held object was determined from a simple static biomechanical model that considered the upper body posture, estimated upper body mass, and posture-specific maximum trunk extension moment that occurred during the maximum voluntary contraction tests.

Immediately after the weight holding trial, the subject returned to an upright standing posture and began a full upper body forward flexion trial towards the voluntary end of upper body flexion. The subject was asked to reach the voluntary limit of flexion in 5 s with both legs kept straight. The speed of flexion was trained prior to the beginning of the experiment and controlled by an auditory feedback (verbal counting of seconds) during data collection. The weight holding and the full flexion trials were conducted again immediately after the 7-min work session.

During the work period in a stooped posture, the subject was asked to simulate work-related stooped postures by repeating a set of ground touching and walking-in-place motions in a forward flexed posture. Each set consisted of touching the ground four times in 3 s with switching hands and walking four steps in place in 3 s while keeping their hands between the ground and the knee (Fig. 2). No other postural restrictions were imposed. The pace of ground touching and walking was practiced prior to the experiment so a single set (ground touching four times + walking four steps in place) could be finished approximately in 6 s. A short break

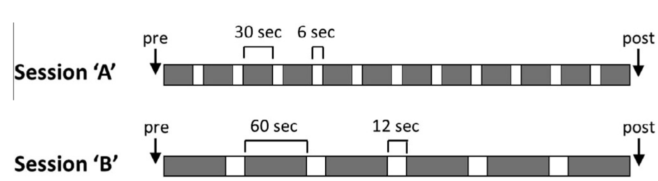

Fig. 1. Two experimental conditions. Gray boxes indicate periods of stooped posture, and white boxes indicate micro-break periods. Big arrows show timing of pre- and post-session data collection trials (weight holding + full flexion).