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The effect of a lower extremity kinematic constraint on lifting biomechanics

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ABSTRACT

Leaning against a stationary barrier during manual materials handling tasks is observed in many industrial environments, but the effects of this kinematic constraint on low back mechanics are unknown. Thirteen participants performed two-handed lifting tasks using both a leaning posture and no leaning posture while trunk kinematics, muscle activity and ground reaction force were monitored. Results revealed that lifting with the leaning posture required significantly less activity in erector spinae (26% vs. 36% MVC) and latissimus dorsi (8% vs. 14% MVC), and less passive tissue moment compared with the no leaning posture. Peak sagittal accelerations were lower when leaning, but the leaning posture also had significantly higher slip potential as measured by required coefficient of friction (0.05 vs. 0.36). The results suggested that the leaning lifting strategy provides reduced low back stress, but does so at the cost of increased slip potential.

1. Introduction

Industrial manual materials handling tasks often require lifting a load over a static barrier such as a railing or the side of a storage bin. The constraint that this barrier places on the kinematics of the lower extremities has a direct impact on the postures of the torso and it is believed that this will influence lifting biomechanics and lumbar stress. A review of the literature revealed that prior studies on this topic have focused on an alternative strategy wherein lifters used their off hand to support the weight of the upper body on the barrier while the dominant hand lifts the load (Ferguson et al., 2002; Kingma and van Dieën, 2004). Both studies illustrated the superiority of this strategy in terms of reduced trunk moment, reduced spine compression and reduced anterior–posterior shear force on low back. While this approach is shown to be effective at reducing spinal loads, this option is not available during two-handed lifts and so the uncertainty of the biomechanical effects of two-handed lifting over a barrier persists.

The two-handed lifting over a barrier are commonly observed in lifting task of crab fishermen in North Carolina wherein the LBP was shown as the highest cause of work impairment, holding 17.7% (Lipscomb et al., 2004). Mirka et al. (2005) evaluated biomechanical stresses placed on lumbar spine during the work activities of crab fishing by employing continuous assessment of back stress (CABS) methodology, which characterizes the stress on the low back throughout the workday, expressed in terms of time-weighted histograms (Mirka et al., 2000). The results of this study showed that the workers pulling the crab pots from the water or side of the boat up into the sorting table (using two hands) deserve attention in terms of a risk of LBP (Kucera and McDonald, 2010; Mirka et al., 2005). The crab pots used by fishermen in the estuary waters of North Carolina are big and heavy, 60 cm × 60 cm × 60 cm cages made of chicken wire and framed with rebar, weighing between 3 and 12 kgf (depending on catch) and are lifted at a rate of one lift per minute. These pots are typically pulled up to the side of the boat by a mechanized “pot-puller” and then the fishermen reach over the side of the boat and lift the pot into the boat. A common lifting strategy observed in small-boat crab fishing operations is to lean against the side of the boat (washboard) with one or both thighs to handle big and heavy crab pots when lifting the crab pots from the water. If the fishermen choose not to lean against the washboard, hyper-flexion of trunk and/or asymmetric lifting are typically observed. If the fishermen choose to lean against the washboard, they are not able to use their legs to help with the lifting motion because the knee and ankle degrees of freedom in the kinematic chain have been lost. In addition, the horizontal external force provided by the interaction between the thighs and the washboard generates additional anterior-posterior ground reaction forces that can increase the slip potential on the slippery deck surface. However, from the opposite point of view, the leaning on a barrier could increase the stability of the entire body by providing additional contact points between body and stationary objects where

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the support provided by additional contact could reduce the rocking motion on the boat. These observations make the exploration of the biomechanics of these kinematically constrained leaning postures worthy of further exploration.

One previous study considered the effect of a shin-level kinematic constraint on low back biomechanics during lifting. Shu et al. (2007) evaluated the differences in activation levels of trunk extensor muscles while kneeling on a knee support (i.e. loss of the degree of freedom of the ankle joint). In this study the participants were asked to maintain a designated trunk flexion angle and then receive and hold a weight that was released into their hands by the experimenter. The kinematic constraint eliminated the motion of the ankle joint but allowed participation of the knee joint in supporting this load. Their results showed that the loss of the degree of freedom at the ankle joint had little effect on the activation level of latissimus dorsi and multifidus muscles during this task. While this previous study provided some information regarding the effect of a kinematic constraint, it was somewhat limited in that it only considered the constraint on the ankle joint – a joint with relatively limited direct impact on low back function. It was felt that limiting the participation of the knee joints through a kinematic constraint may be much more impactful on the function of the low back. The goal of current study was to investigate the effect of a thigh-level kinematic constraint by leaning against the barrier on trunk muscle activation and lifting kinematics.

2. Methods

2.1. Overview of the study design

The lower extremity kinematic constraint employed in this study was a thigh-level railing simulating a washboard on the side of a small fishing boat (Fig. 1). This constraint led to the loss of two degrees of freedom in the kinematic chain (ankle and knee joints). There were two phases in this study: a static phase that involved static weight-holding tasks and a dynamic phase that involved free dynamic lifting tasks. The static trials were designed to understand how the muscles of the lumbar region function under leaning and no leaning conditions. The dynamic trials were designed to quantify the trunk kinematics and ground reaction force used to calculate the required coefficient of friction (RCOF) of the floor during the leaning and no leaning conditions.

2.2. Participants

Thirteen male participants were recruited from the university undergraduate and graduate student population of Iowa State University. They did not report any chronic problems or current pain in the low back or lower extremities. Each participant provided written informed consent prior to participation. The average and standard deviation of age, stature and whole body mass of participants were 28.1 yr (4.0), 172.5 cm (2.7), and 71.5 kg (7.2), respectively.

2.3. Experimental apparatus

The experimental setup was designed to simulate a boat with 82 cm height rail, which served as the lower extremity kinematic constraint during leaning conditions. The height of rail was selected based on measurements of boats in a field study of North Carolina crab fisherman. The load was a common 60 cm (L) × 60 cm (W) × 35 cm (H), 9 kg crab pot used by commercial crab fisherman.

2.4. Experimental equipment

During the static phase, surface electromyography was used to capture the activities of the ten sampled muscles (Model DE-2.1, Bagnoli™, Delsys, Boston, MA) (data collected at 1024 Hz), and a magnetic-based motion analysis system was used to capture the instantaneous lumbar curvature (The MotionMonitor™, Innovative Sports Training, Chicago, IL) (data collected at 102.4 Hz).

During the dynamic phase, the lumbar motion monitor (LMM) (Chattanooga Group Inc., Chattanooga, TN) was used to capture the three-dimensional trunk kinematics (data collected at 60 Hz). A Bertec force platform (Bertec, Columbus, OH) was used to capture ground reaction forces (data collected at 60 Hz) used to calculate the RCOF.

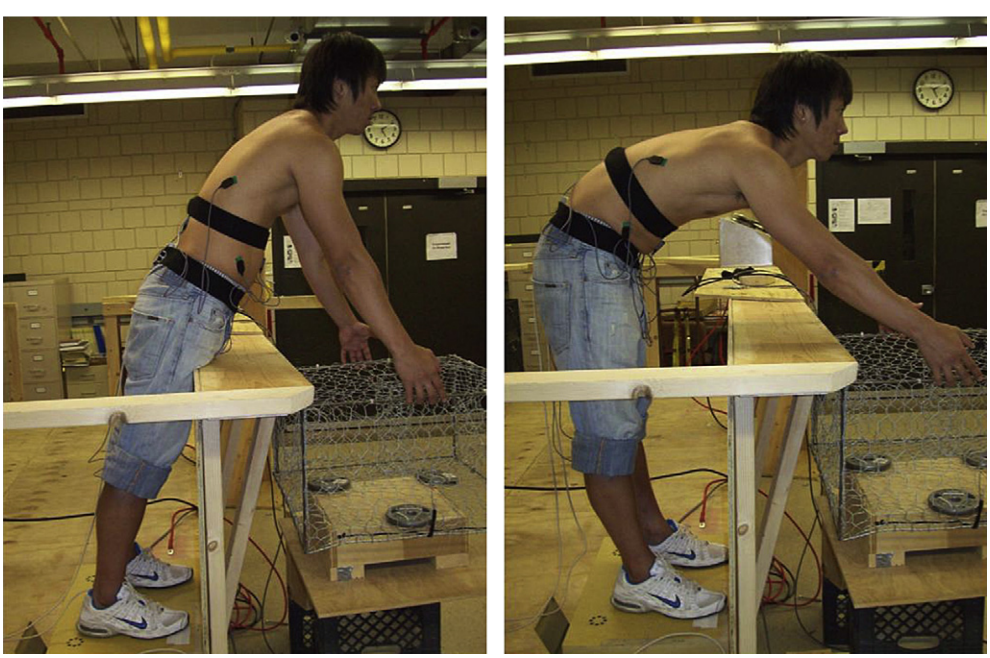

Fig. 1. Experimental task: comparison of two lifting postures. Left: leaning, 70 cm height, Right: no leaning, 70 cm height.