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The assessment of material handling strategies in dealing with sudden loading: The effects of load handling position on trunk biomechanics

Xiaopeng Ning [a,*], Jie Zhou [a,1], Boyi Dai [b,2], Majid Jaridi [a,3]

[a] Department of Industrial and Management Systems Engineering, West Virginia University, Morgantown, WV 26506, USA
[b] Division of Kinesiology and Health, University of Wyoming, Laramie, WY 82071, USA

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ABSTRACT

Back injury caused by sudden loading is a significant risk among workers that perform manual handling tasks. The present study investigated the effects of load handling position on trunk biomechanics (flexion angle, L5/S1 joint moment and compression force) during sudden loading. Eleven subjects were exposed to a 6.8 kg sudden loading while standing upright, facing forward and holding load at three different vertical heights in the sagittal plane or 45° left to the sagittal plane (created by arm rotation). Results showed that the increase of load holding height significantly elevated the peak L5/S1 joint compression force and reduced the magnitude of trunk flexion. Further, experiencing sudden loading from an asymmetric direction resulted in significantly smaller peak L5/S1 joint compression force, trunk flexion angle and L5/S1 joint moment than a symmetric posture. These findings suggest that handling loads in a lower position could work as a protective strategy during sudden loading.

1. Introduction

Each year in the United States, work-related back injury causes over one hundred million lost work days (Guo et al., 1999) and billions of dollars of direct (e.g. medical) and indirect (e.g. lost productive time) costs (Frymoyer and Cats-Baril, 1991; Maetzel and Li, 2002; Stewart et al., 2003; Yelin and Callahan, 1995). According to the United States national data, back injury accounts for 42% of all reported occupational musculoskeletal disorders with even higher rates reported from occupations that involve manual handling tasks such as nurses (53%), nursing aides (55%), and laborers (44%) (BLS, 2012).

During the performance of manual handling tasks, sudden loading due to loss of control or external impact can cause back injuries (Manning et al., 1984; McCoy et al., 1997; Omino and Hayashi, 1992). When the human trunk experiences sudden loading, both reflexive and voluntary muscle contractions are initiated to increase stability and regain balance (Cholewicki et al., 1997). However, such instantaneous muscle reactions elevate spinal compression (Granata and Marras, 2000) especially when the load is unexpected (Marras et al., 1987). Previous studies have reported that the magnitude of mechanical loading on spine (such as spinal compression and shear forces) is directly associated with the risk of back injuries (Bakker et al., 2007; Norman et al., 1998). When such loading exceeds the tolerance limit, tissue damage may occur (Marras, 2000). Therefore, to mitigate the risk of back injury during manual handling, it is critical to develop load coping strategies that can reduce the biomechanical impacts to the spine caused by sudden loading.

A number of protective strategies have been previously investigated. Studies have shown that the presence of warning signals prior to a sudden loading event significantly reduced the average muscle activation level by 49.8% (Lavender et al., 1989), reduced the spinal compression force by 16% (Lavender and Marras, 1995), and increased spinal stability (Mawston et al., 2007). In addition, appropriate training practices and increased experience helped reduce spinal compression force by 29% and peak L5/S1 joint moment by 25% (Lavender et al., 1993; Lawrence et al., 2005). A

* Corresponding author. Industrial and Management Systems Engineering, P.O. Box 6070, West Virginia University, Morgantown, WV 26506, USA. Tel.: +1 304 293 9436; fax: +1 304 293 4970.

E-mail addresses: xiaopeng.ning@mail.wvu.edu (X. Ning), jizhou@mix.wvu.edu (J. Zhou), bdai@uwyo.edu (B. Dai), majid.jaridi@mail.wvu.edu (M. Jaridi).

[1] The Ergonomics Lab, Industrial and Management Systems Engineering, West Virginia University, Morgantown, WV 26506, USA. Tel.: +1 304 435 9777; fax: +1 304 293 4970.

[2] Division of Kinesiology and Health, University of Wyoming, 1000E University Ave, Laramie, WY 82071, USA. Tel.: +1 307 766 5423; fax: +1 307 766 4098.

[3] Industrial and Management Systems Engineering, P.O. Box 6070 West Virginia University, Morgantown, WV 26506, USA. Tel.: +1 304 435 9437; fax: +1 304 293 4970.

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recent study discovered that maintaining a staggered foot stance during the impact of sudden loading could significantly reduce trunk flexion angle by 4.1° and L5/S1 joint moment by 6.6 Nm compare to parallel stance (Zhou et al., 2013). Although the above methods have been explored to develop protective strategies to cope with sudden loading, the effect of load handling position on trunk biomechanics has not been investigated.

Granata and colleagues discovered elevated trunk muscle co-activation with an increase of load vertical height when performing static weight holding tasks (Granata and Orishimo, 2001). Such an increase of trunk muscle activity enhances trunk stiffness and stability; however, it also increases spinal loading and the associated risk of back injury (Lavender et al., 1993). Another study explored the impact of sudden loading on trunk biomechanical responses during stoop lifting. Results of that study discovered significantly larger postural disturbance and spinal loading when the subject experienced sudden loading in more flexed trunk postures (i.e. lower load height) (Chow et al., 2003).

Furthermore, asymmetric lifting has been shown to elevate the risk of LBP due to increased torsional and spinal shear loadings caused by axial trunk rotation and lateral bending (Waters et al., 1993). However, much less is known regarding the biomechanical impact of a sudden loading from an asymmetric direction. One study investigated the effect of load dropping direction (symmetric or asymmetric) on trunk muscle activity and found 37% increase and 55% decrease in muscle activation levels of contralateral and ipsilateral trunk extensor muscles respectively when load was dropped from an asymmetric direction (Lavender et al., 1989). However, in that study the dropping load had a larger moment arm in the asymmetric condition and spinal loading was not estimated. A recent study investigated the impact of an asymmetrically released hand load on the biomechanical responses of human trunk when standing still and facing forward (i.e. without trunk rotation) (Zhou et al., 2013). Interestingly, the results of this study demonstrated that when trunk rotation is eliminated and load moment arm is controlled, an asymmetrically released load caused smaller trunk flexion and L5/S1 joint moment in comparison to load released from a symmetric position. Despite the previous evidence, however, the potential interaction effect between the load releasing height and horizontal position (i.e. asymmetry) on trunk biomechanical responses during sudden loading has not been investigated.

The present study was designed to understand whether load handling position can be used in the design of protective strategies against back injuries caused by sudden loading. More specifically, the objective of the current study was to investigate the effects of load handling height and load asymmetry (created by arm rotation but not trunk rotation) on trunk biomechanical responses when experiencing sudden loading. According to the previous findings, we hypothesized that one will experience greater spinal compression force, but smaller postural perturbation when a load is handled at a higher position and released suddenly. As suggested by previous research (Zhou et al., 2013), we expect to observe smaller trunk flexion when the load is handled and suddenly released from an asymmetrical position than in a symmetrical position.

2. Method

2.1. Subjects

Eleven male subjects with mean (SD) height, mass, and age of 176.6 (3.4) cm, 71.2 (6.5) kg, and 26.7 (2.0) years respectively volunteered to participate in this study. Subjects with no previous training or working experience in manual material handling were recruited from the student population of West Virginia University, and none reported a previous history of low back pain or upper/lower limb injuries. The experimental procedure was approved by the university's Research Integrity and Compliance Committee.

2.2. Experimental design

Two independent variables were involved in the current experimental design: vertical load handling position (HEIGHT, three levels) and transverse load handling position (ASYM, two levels). These two independent variables collectively describe the location of both hands and the load (the load was always in the hands (Fig. 1) before the sudden releasing event). In all testing conditions, trunk remained forward facing. The three HEIGHT levels were defined with respect to participants' anthropometry: 'High' (eyebrow level: the initial holding height of the load aligns with the height of eyebrows), 'Middle' (shoulder level: the initial holding height of the load aligns with the height of clavicle bone), and 'Low' (umbilicus level: the initial holding height of the load aligns with the height of umbilicus). The two ASYM load positions were: 'Symmetry' (in the midsagittal plane) and 'Asymmetry' (45° leftward to the midsagittal plane). The effect of transverse load handling location has been previously investigated (Zhou et al., 2013). In the current study the interaction between HEIGHT and ASYM was explored. The combination of the two independent

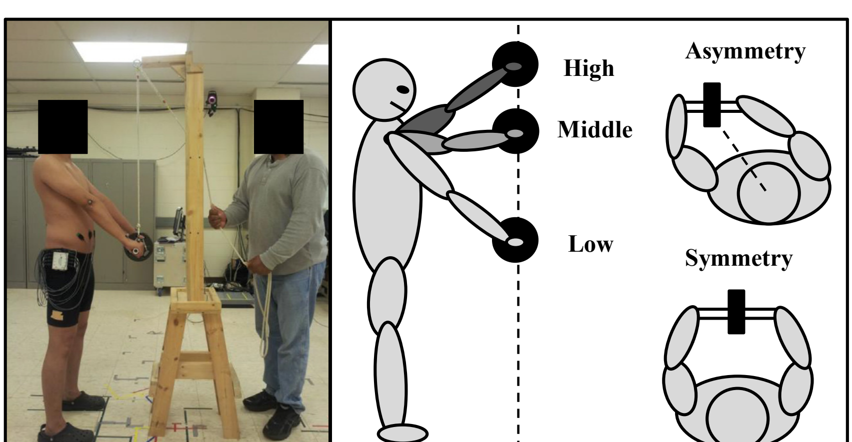

Fig. 1. A side view of the experiment setup (left panel) and a demonstration of different load handling positions (right panel).

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