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The effects of operator position, pallet orientation, and palletizing condition on low back loads in manual bag palletizing operations

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ABSTRACT

Many mining commodities are packaged and shipped using bags. Small bags are typically loaded onto pallets for transport and require a significant amount of manual handling by workers. This specific task of manual bag handling has been associated with the development of musculoskeletal disorders (MSDs), especially low back disorders. This study evaluates the biomechanical demands of different work layouts when performing manual palletizing of small bags, and evaluates the biomechanical stresses associated with different stacking techniques. Results indicate that peak forward bending moments as well as spinal compression and shear forces are higher when the pallet is situated at the side of the conveyor as opposed to the end of the conveyor. At low levels of the pallet, controlled bag placement results in higher peak forward bending moments than stacking at higher levels and when dropping the bag to lower levels. The results of this study will be used to inform the development of an audit tool for bagging operations in the mining industry.

Relevance to industry: In many cases for workers loading small bags, compression forces exceed the NIOSH criterion of 3400 N. Orientation of the pallet has a significant impact on spinal compression, and positioning the pallet at the end of the conveyor reduces the estimated compressive loading on the lumbar spine by approximately 800 N.

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1. Introduction

Many mining commodities are packaged and shipped using bags. These may be small bags that are manually handled or bulk bags that may weigh several hundred kilograms (kg). Small bags (typically weighing 23 kg but with weights up to 46 kg) are usually loaded onto pallets for transport and require a significant amount of manual handling by workers. While the loading of small bags onto pallets has been automated in some loading facilities, at many operations the repetitive job of loading small bags onto pallets is still performed manually. Manual handling is associated with the development of musculoskeletal disorders (MSDs), especially low back sprains and strains (Dempsey and Hashemi, 1999). This is particularly true if the workplace layout is poorly designed and/or appropriate lifting aids (such as lift tables) are not provided (Keyserling et al., 1988).

In the United States, the Mine Safety and Health Administration (MSHA) requires all mines to report all injuries, illnesses, and fatalities. These data are in the public domain, and are provided in statistical analysis software format (IBM SPSS, Somers, NY) by the National Institute for Occupational Safety and Health (http://www.cdc.gov/niosh/mining/data/default.html). For this study, accident, injury, and illness reports from MSHA were obtained for the calendar years 2007–2011. After filtering for cases that occurred only in mills and preparation plants and that were considered non-fatal injuries with days lost, the MSHA database contains 217 injuries that can be classified as occurring during bag palletizing. The number of days lost and restricted activity days due to palletizing-related injuries over this time period was 10,047, with a median of 17 days per injury. Overwhelmingly, the specific mineworker activity at the time of injury was handling material or rock, accounting for over 88% of all accidents. The predominant nature of injury was sprains and strains (68%), with a few scattered contusions and fracture cases. Overexertion was the predominant

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accident type (70%). The back was the part of body most frequently injured when handling bags (34% of cases), followed by shoulders (15%), and hands/fingers (11%).

To begin to address the worker safety concerns revealed by these numbers, this study evaluated the biomechanical demands of different work layouts when performing manual palletizing of small bags. Specifically, investigators observed during field visits that manual palletizing operations in which bags were delivered via conveyor were typically performed by workers stacking bags onto two different pallet orientations relative to the conveyor: pallet at the end of the conveyor, or pallet at the side of the conveyor. Thus, one purpose of this study was to evaluate the biomechanical stresses on workers performing bag palletizing tasks with the pallets in these two orientations. Furthermore, field visits revealed that some workers maintained their grasp on the bag through the final placement on the pallet, while others would drop the bag into place, particularly at the lower layers of the pallet. A secondary purpose of the study was to evaluate the biomechanical stresses associated with these techniques. Finally, the effects of the lift destination height and worker position (left or right side) with respect to the pallet were investigated.

One of the issues of interest in this study was the influence of pallet positioning on spinal loading during palletizing tasks. Spinal compression is traditionally assumed to be the principal biomechanical mechanism associated with occupationally related low back disorder (LBD) (Granata and Marras, 1999; Waters et al., 1993). However, Granata and Marras (1999) found that the biomechanical sources of low back pain (LBP) are dynamic, multifaceted, and multidimensional, with spinal shear and torsion loading also playing roles. Occupational low back injury prevention research has focused on the effects of reducing extreme torso flexion and the external moment, with little emphasis on torso twisting and lateral bending (Jorgensen et al., 2005). Torso twisting has also been identified as a risk factor for occupational LBP (Hoogendoorn et al., 2000; Kelsey et al., 1984; National Institute for Occupational Safety and Health, 1997; National Research Council, 2001; Punnett et al., 1991).

Though previous studies have examined the torso kinematics and biomechanical loading associated with changes in pallet position with loading boxes, no studies have looked at these factors with respect to positioning of workers at the side versus the end of the conveyor when palletizing bags. Thus, this study examined the effect of operator position relative to the conveyor on lumbar loading, and also evaluated the effects of control of the load during lifting (dropping versus controlled placement) and lift destinations (high vs low levels of pallet) on loading of the lumbar spine.

2. Methods

2.1. Experimental design

A split-split-split plot experimental design was employed to evaluate the physical demands of lifting bags off a conveyor and placing them onto a pallet. Ground reaction force and kinematic data were used to drive a biomechanical model that estimated joint forces and moments and low back compression experienced during the lifting task.

This study evaluated torso twisting in two different conveyor configurations. From the motion analysis data collected in this experiment, the spinal compression and shear can be estimated and compared with the dynamic lifting components.

2.2. Study population and participant inclusion criteria

Eight male participants from the National Institute for Occupational Safety and Health (NIOSH) in Pittsburgh, PA, participated in this study. The average ± standard deviation of the age and weight were 33 ± 5.3 years and 88.6 kg ± 10.5 kg, respectively. Two participants were left-handed and six were right-handed. Participants were healthy with no symptoms for cardiovascular disease and no history of hand, wrist, arm, back, and neck or shoulder injuries. Before participating, each participant read and signed an informed consent form approved by the NIOSH Human Subjects Review Board.

2.3. Independent variables

Several independent variables were examined in this study (Table 1). First, the orientation of the pallet relative to the conveyor (variable name of pallet orientation with values *End* versus *Side*) was of interest. Pallet orientation is directly related to the location of the operator. When the pallet is on the *Side*, the operator removes the bags from the side of the conveyor. When the pallet is on the *End*, the operator removes the bags from the end of the conveyor. There were two operator positions: *Position1*, in which the operator is on right of pallet and needs to move to his left to place bag on pallet, and *Position2*, in which the operator is on left of pallet and needs to move to his right to place bag on pallet. Examples of these different scenarios can be seen in Fig. 1. Next, three levels of bags were stacked on the pallet in each trial (see Fig. 2): *Level1* (the bottom three bags), *Level2* (two bags, laid on top of and in a perpendicular orientation to *Level1*), and *Level3* (three bags, laid on top of *Level2*, placed as in *Level1*). Bags were stacked in one column at the part of the pallet closest to the operator. Additionally, three palletizing conditions were examined: a lower pallet level (*Level1* 6″ above floor level) with controlled bag placement (*LPLcontrol*), a lower pallet level while dropping the bag into place on the pallet (*LPLdrop*), Fig. 2A, and an upper pallet level (*Level1* 30″ above the floor) with controlled bag placement (*UPLcontrol*), Fig. 2B. Finally, bag destination (which is horizontal lifting distance) for the closest and farthest bag from the conveyor for each level (with values *Near* or *Far*), was an independent variable. For this variable, the middle bags of *Level1* and *Level3* were omitted from the analysis.

2.4. Dependent variables

Moments calculated about L5-S1 were the primary dependent variables in the study. These included the Peak Forward Bending (PFB) moment, Peak Left Lateral Bending (PLLB) moment, Peak Right Lateral Bending (PRLB) moment, Peak Left Twisting (PLT) moment, and Peak Right Twisting (PRT) moment. Estimates of the Compression and A–P Shear Forces acting about L5-S1 were obtained through the use of a regression equation developed by Van Dieen and Kingma (2005) which are based on the value of the net L5-S1 moment. Data from each operator position (*Position1* and *Position2*) were analyzed separately, as bending and twisting moments would be occurring in opposite directions in these two positions.

2.5. Data collection procedure

Participants were positioned on two force plates and then performed twelve lifting tasks (two pallet orientations [*Side* or *End*], three palletizing conditions [*UPLcontrol*, *LPLcontrol*, *LDLdrop*], and two operator positions [*Position1* or *Position2*]) in a completely randomized order.

Each task consisted of 8 lifts of 11.3-kg (25-lb.) bags off of a conveyor and onto a pallet. The bag weight of 11.3 kg was used due to NIOSH Human Subjects Review Board restrictions. The bags were obtained from a mining company and dimensions were 22″

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