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# The effects of transfer distance on spine kinematics when placing boxes at different heights

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ABSTRACT

Twisting and lateral bending motions in repetitive lifting tasks are associated with occupational low back injuries and can be challenging to reduce with engineering controls. This study tested the hypothesis that twisting and lateral bending can be reduced by changing the transfer distance. Eighteen males, with no material handling experience lifted 10.9 kg boxes from 0.9 m above the floor and placed the boxes at a destination located 0.50, 0.75, 1.00, 1.25, 1.50, or 1.75 m away and at heights of 0.5 m, 0.9 m, and 1.3 m above the floor. Overall, twisting and forward bending decreased with increased transfer distance when placing the box. Conversely, the lateral bending when lifting and placing the box increased with increasing transfer distance. In short, having a transfer distance between 1 and 1.25 m when performing palletizing tasks to different heights may optimally balance spine kinematics, back injury risk, and productivity measures.



## 1. Introduction

Manual material handling tasks in industry that result in lateral bending and twisting motions of the spine have been associated with the onset of low back injuries (Kelsey et al., 1984; Marras et al., 1993; Punnett et al., 1991). Twisting and lateral bending movement velocities associated with asymmetric spine motions have been identified as two of the five risk factors in the Lumbar Motion Monitor risk model (Marras et al., 1993; Marras and Granata, 1995). The challenge faced by ergonomists attempting to prevent injuries in repetitive lifting tasks, that cannot be eliminated or automated, is how to control or limit the range and speed of these spine postural deviations. While spine motions and moments in the sagittal plane (forward flexion) can be reduced by raising lift origins and destinations (Davis and Marras, 2005; Lavender et al., 2003), controlling the postural deviations in the frontal plane (lateral bending) and the transverse plane (twisting) poses a greater challenge to industrial ergonomists. Some would argue that the exposure to lateral bending and twisting motions could be controlled through training on better lifting techniques. Lavender et al. (1995) reported that when instructed to step during an asymmetric lifting task, participants significantly reduced the amount of spine twisting and lateral bending. Unfortunately, the studies investigating the effectiveness of training on lifting techniques have shown few people actually adopt the techniques and there is little change in reported low back pain (Daltroy et al., 1997; Lavender et al., 2007; van Poppel et al., 1998).

Alternatively, Marras and Allread (2006) advocated that asymmetric spine motions can be controlled through adjustment to workplace layout, for example, separating the lifts origin and destination. Jorgensen et al. (2005), however, reported that manipulating the transfer distance had limited effectiveness when trying to control spine kinematics. In our prior work, we found that separating the lift origin and destination by 1 m to be effective in reducing the degree to which participants twisted or laterally bent their backs (Lavender and Johnson, 2009) when lifting boxes with handles from and to conveyors 0.76 m above the floor. Additionally, when transferring boxes without handles from 0.5 m, 0.9 m, and 1.3 m above the floor to a conveyor 0.9 m above the floor, a task similar to that experienced when de-palletizing materials, Mehta et al. (in press) reported transfer distances between 1 and 1.25 m provided a balance between several spine kinematic variables. The present study, using a similar paradigm, investigated if the relationships between transfer distance and spine kinematic measures persist when transferring boxes without handles from near hip level to three different levels representative of a palletizing

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task. Specifically, this study tested the hypotheses that (1) changing the transfer distance between a lift's origin and destination affects the amount of twisting and lateral bending and the speed of these motions, and that (2) the relationship between the spine kinematics and the transfer distance depends upon the height to which boxes are placed.

## 2. Methods

### *2.1. Participants*

Eighteen healthy male students with an average age of 20 years (SD = 2.5 years) with no previous material handling experience and no prior history of musculoskeletal disorders of the shoulder and torso participated in this study. The mean height and weight of the participants were 1.82 m (SD = 0.06 m) and 75.5 kg (SD = 12 kg). All participants signed an informed consent document approved by The Ohio State University Institutional Review Board.

### *2.2. Apparatus*

Two passive conveyors were constructed from Creform™ materials. The conveyors frames were fitted tightly on top of large scales, which were used to identify the timing of each lift's initiation and termination in the data stream. The frame of the destination conveyor was placed on a movable dolly, so that the transfer distance between the two conveyors could be adjusted. The boxes (0.4 m × 0.3 m × 0.25 m) were made of cardboard (without handles) and filled with paper to achieve the desired weight. Fig. 1 shows a schematic of the experimental setup.

Three dimensional spine kinematic data were obtained with a magnetic motion capture system (The Motion Monitor™) using the LiftTrainer™ program which sampled the kinematic and force scale data at 120 Hz. This system provided data on the movement of each lower and upper arm, the head, and the spine (between T1 and S1) and associated movement velocities. The spine data used the local coordinate system of the sensor on the sacrum.

### *2.3. Experimental design*

The experimental design investigated two independent variables: the transfer distance (6 levels) and the final height at which the boxes were placed (3 levels). The participants performed a simulated material handling task in which they moved three 10.9 kg boxes, one at a time, from an origin conveyor (fixed at 0.9 m above the floor) to a destination conveyor positioned 0.5 m, 0.9 m, and 1.3 m above the floor. These heights were selected to represent palletizing work performed at low, medium, and high levels, respectively. The transfer distances between the lift origin and destination were 0.5, 0.75, 1.0, 1.25, 1.5, and 1.75 m. For analysis purposes, the lifting tasks were broken down into three phases: picking (initial lift), carrying, and placing (termination of the transfer). Given that the lateral bending and twisting postures peak during the picking and placing phases (Lavender and Johnson, 2009), only the data from these two phases were used. The picking and placing phases were analyzed separately to determine whether the hypothesized changes in spine postural deviations and associated movement velocities due to transfer distance were limited to one or the other of these phases in the box transfer process. The dependent variables were the peak angular displacements in the sagittal plane (degree of forward bending), the transverse plane (degree of twisting) and the coronal plane (degree of lateral bending), along with the peak three-dimensional angular velocities of the spine (from T1 to S1) while picking up and placing the boxes.

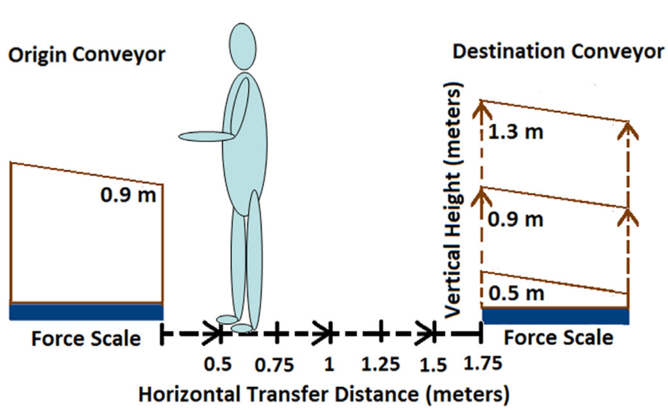


**Fig. 1.** The experimental task consisted of moving a series of three boxes between two conveyors. The destination conveyor (right side of picture) was moveable and was used to manipulate the transfer distance and lift height.

### *2.4. Procedures*

After signing an informed consent document, anthropometric measures (height and weight) were obtained from each participant. Seven motion capture system sensors were then placed on the subject: on the back of the head, at the top of the thoracic spine (T1), over the top of the sacrum (S1), and bilaterally on the upper and lower arms using Velcro straps and medical tape.

The participants were instructed to simulate a work within a fast-paced distribution environment as they move the three boxes from the origin conveyor to the destination conveyor within 15 s. The participants were free to choose their style of lifting and no instructions were provided regarding how to lift or handle the boxes. However, due to the cables running to the motion sensors, participants could only turn to their left while transferring the boxes. Before the start of data collection process, the participants were asked to practice the lifting task so that they could pace themselves and complete the set of three lifts within the specified time window.

The sequence of destination heights was counter-balanced across subjects. Within each height condition, the sequence of transfer distance conditions was randomized. Participants performed two replications of the task for each combination of destination height and transfer distance. A 1-min break was provided after each set of three box transfers and a 5-min break was provided after each block of conditions at a given destination height was performed to minimize fatigue development.

### *2.5. Data analysis*

Given that the present study was designed to emulate a continual work flow in a fast-paced distribution environment, where people are lifting materials more or less continuously throughout the work periods, only second and third lifts in the sequence were analyzed as the initial lift in the sequence was not representative of a continual work flow. Out of 18 subjects, 2 subject's data were excluded due to unexpected errors in the data collection program. The picking, carrying, and placing phases of each lift were based upon the data from the force scales under the origin and destination conveyors. However, the selection of each phase needed to be preformed manually to accommodate variability in the subject's lifting styles. The time points for each phase were picked based on the orientation of the participants with respect to the conveyor and change in force scale levels. For example, the picking phase was initiated when the participant reached for the box and terminated when the participant initiated the turn. Likewise, the placing phase was initiated when the participant