University of Cincinnati

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I, Todd R. Ramsey, hereby submit this original work as part of the requirements for the degree of Master of Science in Occupational Safety and Ergonomics.

It is entitled:
The Effects of Load-Positioning Material Handling Equipment on Spinal Loading During Manual Handling of Bulk Bags

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The Effects of Load-Positioning Material Handling Equipment on Spinal Loading During Manual Handling of Bulk Bags

A thesis submitted to the
Graduate School
of the University of Cincinnati
in partial fulfillment of the
requirements for the degree of

Master of Science

in the College of Medicine, Department of Environmental Health,
Division of Environmental and Occupational Hygiene

by

Todd Ramsey

B.S., Marshall University, 2008

Committee Chair: K.G. Davis, Ph.D.
Abstract:

Low back disorders among workers in manual materials handling industries are very prevalent and represent a large proportion of worker’s compensation costs in the United States. A potentially significant source for LBD risk in these industries is manual palletizing operations. Previous studies investigating biomechanical loading of the spine for manual palletizing have identified load location on the pallet as one of the primary drivers for potential injury. However, evidence on the effectiveness of ergonomic interventions is limited, with no research investigating interventions that focus on modifying load location. The objective of this study was to evaluate the effectiveness to control LBD risk and spine loading of two interventions: a self-leveling pallet carousel designed to position the loads vertically and horizontally at the lift origin and an adjustable cart designed to raise loads vertically at the lift destination. Thirteen trained males (aged 18-40 years) participated in a simulated order selecting task. Spine loads that were predicted by an EMG-assisted model, LBD risk index, and perceived exertion were quantified for each intervention condition (e.g. carousel to traditional cart, pallet to traditional cart, pallet to adjustable cart, and carousel to adjustable cart). The results showed that combining both devices results in reduction in LBD risk (7%), spine compression (61%), anterior-posterior shear (72%), and lateral shear (63%). Individually, the carousel was responsible for the greatest reductions, but the lowest values were typically achieved by combining adjustable cart and carousel. The results from this study show that these, and similar devices may have the potential to reduce low back injuries in workplaces where palletizing and order selecting operations occur frequently. Further investigation into real-world feasibility and long term use effects is still needed to provide a more complete picture of the benefits of these load positioning devices.
Acknowledgments:

I would like to acknowledge many individuals who contributed to the completion of this project. First, I would like to thank my advisor, Dr. Kermit Davis for his guidance and support through the entire process as well as providing the laboratory resources to collect the data. I would also like to thank Dr. Vern P. Anderson and the National Institute for Occupational Safety and Health (NIOSH) for the opportunity to work on a summer internship which ultimately led to the idea for this research and providing partial support for this project, specifically funding for participant incentives and supplies. In addition, I would like to thank James Galante and Southworth Ergonomic Equipment for lending carousel and adjustable cart that was evaluated in the study. Additionally, I would like to thank all the students who took time out of their busy schedules to assist with data collection. These contributions were essential to the completion of this project. Lastly, I would like to acknowledge my thesis committee: Drs. Vern P. Anderson, Kermit Davis, Susan Kotowski, and Thomas Waters for their valuable insight and time. Their expert guidance and insight bolstered the development of this research while enriching my learning experience and professional development. To everyone involved with this project, I am sincerely grateful, thank you.
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1. Introduction:

Low back disorders (LBDs) are prevalent and represent a very costly problem to many physically demanding workplaces. Each year, the estimated 600,000 back injuries in the United States cost industry between 10 to 14 billion dollars in workers’ compensation costs and up to 149 million workdays annually [1]. The literature indicates that back injuries are more costly than other types of occupational injury; even though low back pain claims represent 16%-19% of all workers’ compensation claims, they account for 33-41% of all claim costs [2]. Industrial jobs that require manual materials handling (MMH), especially lifting, have an increased incidence of back injury cases [3]. Dempsey et al. [3] found that claims associated with MMH represent the single largest source of claims and costs. Although a variety of injury types are prevalent in MMH, lower back strain accounted for the highest percentage of claims and claims cost. Their conclusion is that overexertion is the primary source MMH losses.

Overexertion injuries in industries that require manual lifting are due in large part to the biomechanical lifting factors that have been shown to contribute to low back disorder [2]. Workers are typically exposed to well-established workplace lifting risk factors such as lifting heavy and/or bulky objects, lifting objects near the floor, and high lifting frequently [4]. These workers may also be required to assume bad lifting postures such as extreme and prolonged torso flexion as well as trunk twisting [3,5,6], which have been shown to increase the risk of occupationally-related LBD [7]. Additionally, when lifting large heavy objects far from the body, workers may be subjected to large load moments (the product of load weight and the distance of that load from the worker’s center of mass), another well-established risk factor for work-related low back disorder (LBD) [2,7].

One job that is particularly risky for LBD is order selectors in warehouses and distribution centers where workers continuously lift while product is transferred from pallet to pallet or carts. Palletizing/de-palletizing is a widespread and universal format for handling a multitude of different goods, yet there are surprisingly few studies investigating the biomechanical risk to workers who perform repeated lifting from pallets. Manual palletizing, that is the transfer of products to or from a pallet, represents about half of the MMH tasks in the manufacturing, service sector, warehousing, and food industries [8]. One
major factor influencing the biomechanics of the lift is the position on the pallet [8]. The load’s vertical and horizontal position relative to the worker has a major influence on the loading of the spine and the risk of occupationally-related LBD [8]. Marras et al. [8] evaluated spine loading and risk of LBD for experienced material handlers when de-palletizing boxes of different weights (18, 23, and 27 kg) from six different regions of the pallet(front-top, back-top, front-middle, back-middle, front-bottom, and back-bottom). This study found that load position, regardless of weight, impacted sagittal flexion, lateral velocity, maximum load moment, and LBD risk. Trunk motion (posture and velocity), external load moment, and LBD risk probability were greatest when lifting from the lowest and farthest back regions of the pallet. Spinal loading also responded in a similar fashion to load position on the pallet. Predicted spinal compression and shear forces were highest when lifting from the bottom layers and in the back positions of the pallet. One conclusion of this study was that the location of the load on the pallet was much more important than the weight of the load when estimating LBD risk and spinal loading [8]. One could conclude from these findings that lifting risk could be reduced by avoiding lifts from the lower and more distant regions of the pallet.

A study by Jorgensen et al. [9] looked at the effects of pallet distance on torso kinematics and LBD risk. In this study, subjects lifted boxes from a fixed lift origin to two pallet destinations at two distances: a “close” location and a “far” location. Box position on the pallet was divided into 6 regions: top-front, top-back, middle-front, middle-back, and low-front, low-back. The general trend was that as the distance between the two pallets increased, the trunk kinematics and overall LBD risk probability increased. In addition, increased kinematics and LBD risk resulted when lifting from the top front to the low-back regions of the pallet, which again shows the impact of load position on potential LBD risk factors. The Jorgensen study [9] investigated distance between pallets as a potential modifier of the risk of LBD during palletizing but had limited investigation into the effect of pallet region.

A second very similar study by Jorgensen and associates [2] investigated LBD risk as a function of pallet orientation. Subjects lifted boxes from a fixed origin to a destination pallet at two pallet orientations—90° adjacent and 180° behind respectively. The 90° adjacent position reduced torso
kinematics and overall LBD risk when compared to the 180° position. Again, torso kinematics and LBD risk varied significantly with changes in load position on the pallet. Generally, the low regions and back regions (more horizontally distant) resulted in increased torso kinematics (more awkward postures and faster motions) as well as increased LBD risk. Based on these results, this study recommended keeping the pallet at a 90° position, raising the lowest level of the pallet, and keeping the pallet position close to the lift origin. This study also concluded there is a lack of scientific investigations into feasible interventions to reduce worker exposure to biomechanical risk factors inherent in MMH tasks, such as palletizing [2].

The above studies [2, 8, 9] found that load position, irrespective of load weight, or pallet distance and orientation, had a significant impact on spinal loading and LBD risk probability. Based on these studies, an effective manual palletizing intervention will raise the height at the origin and destination (load position at waist level) as well as reduce the moment arm (e.g. place the product close to the body).

While load positioning devices have been specifically designed for use in manual palletizing tasks, biomechanical research to support their effectiveness is virtually non-existent. One such device, the self-leveling pallet carousel uses either springs or pneumatic air bladders to automatically raise the pallet so that the low regions are eliminated as well as a carousel feature that allows the worker to rotate the pallet 360 degrees, thereby positioning the load close to the body, reducing the horizontal load moment.

An additional device designed to reduce lifting risk, referred to as an “ergo cart” by Davis and associates [10], was evaluated in an unpublished research demonstration project. The ergo cart is an adjustable load positioning cart that uses springs to automatically adjust the platform height to waist level based on the weight of the product placed on it. This cart was compared to a flat cart when palletizing and de-palletizing of product in a grocery store warehouse. Fifteen males employed as shelf stockers volunteered and were monitored with the lumbar motion monitor while selecting product using ergo cart and flat cart. The ergo cart was found to reduce trunk flexion and lateral bending, but
increased trunk twist when compared to the flat cart. This increase in twist kinematics when lifting loads from higher vertical positions agrees with the results of Jorgensen et.al. [2], which found twist angle and velocity increased with higher vertical load position. The ergo cart reduced horizontal load moment by about 6% and the overall LBD Risk Index was reduced by about 3% as compared to the flat cart[10]. While these results indicate that use of an adjustable cart for the activities described could be beneficial, the study lacks a spinal loading assessment that would provide a more comprehensive evaluation of the intervention. Further, this intervention does not affect load position on the pallet.

The following hypotheses were tested in this study:

**Hypothesis 1:** The adjustable cart and self-leveling carousel individually reduce awkward postures, spinal loading, LBD risk probability, and perceived exertion ratings compared to traditional methods.

**Hypothesis 2:** The synergistic effect of the adjustable cart and self-leveling carousel will produce the maximum reduction of adverse LBD outcome variables.

The objectives of this study are to identify what impact each device has on the spine loading and LBD risk, and to explore whether or not these devices are compatible with traditional methods for palletizing. That is, will the combined effects of load positioners and traditional equipment result in increased risk to workers, or will this combination allow for improved load positioning and decreased lifting risk. Both the adjustable cart and self-leveling pallet carousel may benefit workers in manual material handling jobs, specifically those workers involved in manual palletizing tasks. Although evidence is very limited, these devices may reduce awkward lifting postures, trunk motions, and load moments, as well as the resulting spine forces and LBD risk. By positioning loads closer to the worker horizontally and raising the lowest level of the pallet, the pallet carousel mitigates risk factors at the lift origin, while the adjustable cart raises the vertical position of loads at the lift destination.

Thus, this study investigated the effects of an adjustable cart and self-leveling carousel on the trunk kinematics, spinal loading, LBD risk index, and perceived exertion levels as subjects transferred bags of concrete mix from a pallet to a cart. Each intervention was evaluated individually (e.g. carousel and flat cart; pallet on floor and adjustable cart) as well together (e.g. carousel and adjustable cart). This allowed
the researcher to evaluate the ergonomic benefits and/or drawbacks of the interventions with respect to one another and with respect to traditional methods currently employed in workplace palletizing operations.
2. Methods:

2.1 Study Overview

This ergonomic intervention study used a within-subjects design to evaluate differences in trunk kinematics, spinal loading, LBD risk, and perceived exertion as a function of four de-palletizing tasks: 1) pallet on the floor to flat cart, 2) pallet on the floor to adjustable cart, 3) pallet on the self-leveling carousel to flat cart, and 4) pallet on self-leveling carousel to the adjustable cart (see Figures 1A-D). The tasks simulated a manual de-palletizing task of bulk items in large home building product retail facilities.

2.2 Subjects

Thirteen volunteers were recruited in person using a flyer (Appendix 1.). Subjects were healthy males between the ages of 18 and 40, mean age 22.6 years, who passed a standard medical screening questionnaire (Appendix 2.) and reported no history of back disorders or pain in the past 6 months. Eleven of the participants were from two large home improvement retail chains in the greater Cincinnati area, one was working as a landscaper, and one was employed in construction trades. While it is not certain that workers in landscaping and construction trades regularly engage in palletizing, they were accustomed to lifting heavy and awkward loads frequently, and therefore would be considered conditioned lifters.

2.3 Study Design

2.3.1 Independent variables

There are three independent variables in this study: 1) palletizing intervention condition, 2) pallet layer, and 3) load position. Four different intervention conditions were evaluated: pallet on floor to flat cart, pallet on floor to adjustable cart, carousel to flat cart, and carousel to adjustable cart. Pallet layer corresponded to the height at the origin and had three heights: top, middle, and lower. The load position consisted of 9 positions on each layer: front-left, front-middle, front-right, middle-left, middle-middle, middle-right, back-left, back-middle, and back-right.
Figure 1. Palletizing Intervention Conditions:
Floor-Flat (A), Floor-Adjustable (B), Carousel-Flat (C), Carousel-Adjustable (D).
2.3.2 Dependent variables

There are five dependent variables measured: 1) trunk kinematics as measured by the Lumbar Motion Monitor (LMM), including the peak three-dimensional sagittal, lateral, and axial position and velocity, 2) LBD risk index—probability of “High Risk” group membership, 3) muscle activity—expressed as a percentage of the normalized maximum exertion, 4) spine loading—compression, lateral shear and anterior-posterior shear forces as predicted by an EMG-Assisted Spinal Loading Model, and 5) Borg Rating of perceived exertion (RPE)—subjective rating of the effort required to lift, assessed immediately after the completion of one layer of bags.

Muscle activity was recorded from ten muscles: left and right pairs of the latissimus dorsi, erector spinae, internal obliques, external obliques, and rectus abdominis. Peak values during each lift were determined as a percentage of the maximum exertions (%MVC). Trunk kinematics were recorded by the lumbar motion monitor with peak values of the three-dimensional position and velocities identified by the software.

The LBD risk index was calculated by utilizing the peak sagittal flexion, average twist velocity, peak lateral velocity, static load moment (horizontal moment arm multiplied by the weight), and lift rate. LBD risk index was computed by utilizing the multiple logistic regression model developed by Marras and associates [7, 11] which is based on the evaluation of 403 industrial jobs in 48 manufacturing companies. The regression model predicts how much a task resembles a “high risk” job (e.g. at least 12 injuries per 200,000 hours). The LBD risk index has been used to evaluate the effectiveness of ergonomic interventions in the workplace [11] and in laboratory studies evaluating palletizing tasks [2,8,9].

Spine loading was predicted by an EMG-assisted biomechanical model developed in the Biodynamics Laboratory at the Ohio State University. This model, which has been well-validated in a wide variety of manual material handling conditions [12,13,14,15,16,17,18,19,20], predicts the peak and cumulative spinal compression, lateral shear, and anterior-posterior shear at the L5-S1 level. These spinal loading estimates are valuable for assessing lifting risk, especially when compared to benchmarks for strength tolerance limits such as 3400 N for compression [21], and 1000 N for shear [22].
Rating of perceived exertion (RPE) was also collected from the subjects using the Borg RPE scale [23]. The ratings were recorded after the completion of each layer of bags (3 ratings per condition). This perceptual effort rating scale has been shown to correlate strongly with heart rate, and integrates sensory information from muscles and joints, central cardiovascular and respiratory functions, and the central nervous system to yield a perceived exertion rating that is comparable between subjects [24,25,26,27,28,29]. The Borg RPE scale has been widely used to study the perception of exertion in laboratory, clinical, and occupational settings, and by ergonomist evaluating work tasks [24].

2.4 Experimental Set-Up

Two oak pallets (W:122 cm x D:102 cm x H:13 cm) were staged in the laboratory—one on the floor and one on the self-leveling pallet carousel. Tape on the floor marked the edge of the pallet so they could be reset after each trial if they moved. The loads to be lifted were twenty seven 18 kg bags of dry concrete mix (measuring 41 cm x 28 cm x 9 cm), which were wrapped in duct tape for reinforcement. The added weight from the duct tape was verified by a scale to be negligible. The bags were arranged on the pallets in a 3 x 3 x 3 matrix, corresponding to nine positions, with 3 vertical layers on the pallet. Calibration of the self-leveling pallet carousel followed manufacturer instructions, based on the 490 kg of total weight, to obtain a vertical height at the top-most layer of bags that was roughly 81 cm.

Load vertical height and travel distance are shown in tables 1A, B. The vertical height of each bag was measured from the bag’s center to the floor for each experimental device. Since the heights of the bags on the floor pallet and the flat cart do not vary within layers, the heights of all bags in top, middle, and bottom layers were 38 cm, 28 cm, and 18 cm on the pallet and 46 cm, 65 cm, and 86 cm on the cart, respectively. The heights of bags on the pallet carousel and adjustable cart changed after each bag was lifted therefore mean heights for the top, middle, and bottom layers, are given as 80 cm, 82 cm, and 84 cm on the carousel and 82 cm, 75 cm, and 91 cm on the adjustable cart respectively (see fig. 2). Mean vertical travel distances from origin to destination for bags in the top, middle, and bottom layers were 8 cm, 37 cm, and 68 cm for the floor-flat, 43 cm, 47 cm, and 73 cm for pallet on floor-adjustable, -34 cm, -17 cm, and 2 cm for carousel-flat, and 1 cm, -7 cm, and 7 cm for the carousel-adjustable conditions.
respectively (positive value indicate upward movement while negative is downward), (see fig. 3). Note that these vertical height values were obtained during a simulated lifting session but are a representative estimate of the actual heights.

Table 1 A. Bag distance from floor

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Layer 3 Mean: 18 84 91 86

Device Mean: 27.9 81.8 82.1 65.5

Table 1 B. Bag vertical travel distance from origin to destination

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Layer 2 Mean: 37 47 -17 -7

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Layer 3 Mean: 18 84 91 86

Device Mean: 27.9 81.8 82.1 65.5

Condition Mean: 37.5 54.2 -16.3 0.4
Figure 2. Mean load height by device and layer

Figure 3. Mean load travel distance as a function of intervention condition and layer
The two carts (flat and adjustable) were positioned parallel to the front of the pallets. The flat cart had a platform measuring 122 cm x 71 cm with a height from the floor of 28 cm. The adjustable cart had a platform with dimensions 122 cm x 86 cm, and a height ranging from 38 cm to 80 cm depending upon the weight placed on the platform. The adjustable cart’s spring resistance was calibrated prior to the study to achieve full range of motion of the cart while keeping top-layer bags near 81 cm. The platform surface of both carts was marked with tape to create four standardized lift destination locations. The distance from the leading edge of these marked locations to the leading edge of the pallets was held constant at 64 cm. Each destination was designated with a number (e.g. 1, 2, 3, and 4). The orientation and distance between pallet and cart is similar to the 180° behind orientation, and far pallet location of the studies by Jorgensen and colleagues [2, 9]. The decision to place the carts 180° behind the subjects as opposed to 90° adjacent was made based on the assumption that this orientation is more commonly utilized in industry. Further, based on the previous study by Jorgensen et al. [2], this orientation of the cart to pallet represents the riskiest position where the trunk kinematics and LBD risk is greatest.

2.5 Experimental Procedures

All participants read and signed an informed consent form that was approved by the University of Cincinnati Institutional Review Board prior to participating in the study. Subjects were introduced to the lab staff, thoroughly briefed on the lifting tasks they would be asked to complete and provided limited instructions about lifting. Anthropometric measurements of each subject were acquired and recorded (Table 2).

<table>
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<td><strong>Height (cm)</strong></td>
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<td><strong>Weight (kg)</strong></td>
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<tr>
<td><strong>BMI</strong></td>
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</table>
Subjects were instructed to lift and transfer the full complement of bags from the pallet to the cart under the 4 different device combinations, which were completed in random order. Subjects were instructed to deposit each bag on the carts in one of the four marked destination locations and then stacked them in a repeated sequence until all bags were transferred. The pace of lifting was dictated by a computer-generated beep every 10 seconds (lifting frequency = 6 lifts/min). The lift rate corresponded to the lift rates commonly found in industry [7,12] and has been used in other studies [8].

EMG electrodes were placed on the skin utilizing proper and standardized procedures [30]. A set of static maximum exertions (MVC) were performed to normalize the muscle activity data and included: trunk flexion, trunk extension, lateral bend left, lateral bend right, twist left, twist right, latissimus dorsi pull-down left, and latissimus dorsi pull-down right. Subjects were verbally motivated by the investigator and lab staff to perform as close to a real maximum exertion as possible [15,30]. Upon completion of the MVC conditions, the LMM was positioned on the body and the subject stood in the calibration system. A neutral condition was collected to obtain baseline positions of the data collection devices [15,31]. A set of sagittal lifts were completed to set the muscle gain for “open loop” conditions. This allowed the model to predict accurate estimates without needing to have feet stationary on the force plate [8,32,33,34,35,36,37].

Subjects were provided the following instructions: lift at the beep but do not anticipate it, start each lift in an upright standing posture, do not toss or throw bags (maintain significant control), lift one bag at a time in any order you choose, and lift one layer at a time. Lifting style was left up to each subject and was not controlled. Bags were de-palletized in a semi-random fashion; subjects were allowed to lift the bags one at a time in any order from the origin pallet for a given layer. An entire layer was de-palletized before a short pause for the perceived exertion rating and continuation to the next layer until all three layers are completed. Upon completion of unloading the pallet, subjects were given a rest period of at least five minutes between palletizing intervention conditions. During this break period, lab staff set up the next condition by staging the bags back onto the respective pallet and positioning the appropriate
cart parallel to the front of that pallet, using tape marks on the floor to aid in proper spacing. After completion of the conditions, a second set of calibration exertions were collected.

LMM trunk kinematics data and EMG data were collected and analyzed by the software simultaneously and in real time during each lift. The load moment arm for each lift was measured horizontally from the midpoint between the ankles to the midpoint between the hands of the subject at the point when the bag was the farthest from the subject (worst case) using a tape measure. These values were recorded by lab staff on the data collection sheet for use in analysis (Appendix 3).

Subjects were asked to rate their level of exertion immediately after each layer was completed using the Borg scale (6—minimal effort to 20—maximal effort) [23]. A large poster showing the exertion rating scale from 6 to 20 was displayed on a wall nearby as a visual aid to the subjects (see Fig. 4). Their verbal rating was recorded by lab staff using the data collection sheet.

![Figure 4. Borg Rating of Perceived Exertion poster](image)
Each lift cycle started with the subject in a neutral standing position, and ended after the bag of their choosing from the specified layer had been placed with significant control into its destination location and the subject returned to an upright neutral position. Data collection occurred during this lift cycle from when the computer beep sounded to the time the subject returned to a neutral standing posture. Upon completion of the study, all subjects were monetarily compensated for their time.

2.6 Apparatus:

3.6.1 Electromyographical system

Electromyography data were collected using bipolar Ag-AgCl surface electrodes spaced approximately 3cm apart and positioned over the belly of left and right sides of these five pairs of muscles: latissimus dorsi, erector spinae, internal obliques, external obliques, and rectus abdominus, using standard placement procedures [15,30] (see figure 5A,B). The signals from these electrodes were recorded from a Grass Instruments electromyographic system and converted to a PC computer via analogue-to-digital board. These signals were rectified, smoothed using a high pass filter at 30 Hz and a low pass filter at 1000 Hz, elimination of electrical noise with a notch filter at 60 Hz, and integrated using a 40 millisecond rolling smoothing filter.

2.6.2 Lumbar Motion Monitor:

Subjects were then fitted with the Lumbar Motion Monitor (LMM), which was developed by Marras and associates [7,38,39] and has been widely utilized and validated for biomechanical low back assessments in the field and laboratory. The LMM is a tri-axial electrogoniometer that is worn on the back, and measures instantaneous trunk position, velocity, and acceleration in the sagittal, lateral, and axial planes. This device can be worn comfortably by the subject and does not interfere with trunk motion during lifting (see Fig. 5A).
Figure 5A. Electrode Placement (Back) & Lumbar Motion Monitor
2.6.3 *Calibration System:*

A calibration system that included a force plate (Bertec model 4060) and an electrogoniometric system translated and rotated ground reaction forces and moments to the L5/S1 vertebral level. The system consisted of a pelvic angle monitor and moment arm monitor that has previously been described by Fathallah et al [31]. This system was used in conjunction with the EMG assisted model to determine the “open loop” gain to predict spine loads (see Fig. 6).
Figure 6. Open-Loop Lifting Calibration
2.7 Statistical Analysis:

Means and standard deviations were calculated for all dependent variables as a function of independent variables. Univariate descriptive statistics were performed on all dependent variables to identify outliers, which were subsequently excluded. SAS statistical analysis software was used to compute repeated analysis of variation (ANOVA) to identify significant main effects and interactions. Subjects were used as a random blocking factor to account for variation due to inherent individual differences. Standardized Tukey post-hoc tests were used to determine the sources of significant effects.
4. Results:

3.1 Analysis of Variance:

Results for the analysis of variance indicated several significant main and interaction effects for trunk kinematics, trunk muscle activity, spine load estimates, LBD risk probability, and Borg RPE. Table 3 shows which main and interaction effects were significant (shaded in grey). All of the dependent variables were significantly affected by intervention condition. As expected, layer and position significantly influenced the majority of independent variables. The combined effect of device condition and pallet layer was found to be significant for all of the spine force estimates, all of the agonistic trunk muscles, sagittal and lateral flexion and velocity, and LBD risk. The device condition-load position combined affects were significant for only a few dependent variables: right and left erector spinae, right abdominals, right and left internal obliques, and sagittal flexion. None of the dependent variables were significantly affected by interaction of layer by position or condition by layer by position.

Table 3: Results of the Analysis of Variance tests: p-values reported with significant effects being shaded grey

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<td>Sagittal velocity</td>
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3.2 LBD Risk:

LBD risk probability as a function of both condition and layer can be seen in figure 7. LBD risk under the floor-flat cart condition for the top, middle, and bottom layers was 47.2%, 47.7%, and 49.0% respectively. LBD risk for the floor-adjustable cart condition for the top, middle, and bottom layers was 45.3%, 47.0%, and 48.4% respectively. LBD risk for the carousel-flat cart condition for the top, middle, and bottom layers was 47.4%, 44.0%, and 39.5%, respectively. LBD risk under the carousel-adjustable cart condition for the top, middle, and bottom layers was 43.6%, 41.9%, and 37.4% respectively. The trend for LBD risk by layer for conditions using the pallet on the floor is one of increasing risk from the top layer to the bottom layer, with relatively small increases in risk from one layer to the next. An opposite trend in LBD risk is seen by layer under conditions using the self-leveling pallet carousel. Here, the risk decreases from the top to the bottom layers, this time in slightly larger increments. LBD risk probability as a function of the overall impact of the palletizing intervention condition is shown in figure 8. The pallet on the floor to the flat cart condition resulted in the highest LBD risk probability of 48%. Risk probability was reduced by 1.1% when transferring bags from the floor pallet to the adjustable cart, by 4.4% when transferring from the self leveling carousel to the flat cart, and by 7.0% when de-palletizing bags from the pallet carousel to the adjustable cart for a LBD risk probability of 41%.

Mean load moment arm data are shown in figure 9. The largest mean moment arm, 63.98 cm was measured under the floor-flat cart condition. This was reduced by 0.27% to 63.80 cm under the floor-adjustable cart condition, by 4.88% to 60.85 cm under the carousel-flat cart condition, and by 2.56% to 62.34 cm under the carousel-adjustable cart condition.

3.3 Peak Spine Loading

Effects on mean peak spinal loading from the condition and layer interaction can be seen in figures 10, 11, 12. Mean peak compression under the floor-flat cart condition was 4710 N for the top layer, 5793 N for the middle layer, and 5840 N for the bottom layer. Under the floor-adjustable cart condition, it was 4870 N, 5253 N, and 5550 N for the top, middle, and bottom layers respectively. Under the
Figure 7. Probability of High Group Membership (LBD Risk) as a function of intervention condition and layer

Figure 8. Probability of High Group Membership (LBD Risk) as a function of intervention condition (Different alpha characters indicate significant difference)
carousel-flat cart condition, it was 3149 N, 2096 N, and 1786 N for the top, middle, and bottom layers respectively. Finally, mean peak compression under the carousel-adjustable cart condition was 2231 N, 1966 N, and 1195 N for the top, middle, and bottom layers respectively.

Mean peak A-P shear under the floor-flat cart condition was estimated to be 1707 N, 2129 N, and 2330 N for the top, middle, and bottom layers respectively. Under the floor-adjustable cart condition, the A-P shear force was estimated at 1717 N, 1973 N, and 2100 N for the top, middle, and bottom layers respectively. Under the carousel-flat cart condition, A-P shear force was found to be 836 N, 507 N, and 442 N for the top, middle, and bottom layers, respectively, and for the carousel-adjustable cart condition it was 592 N, 529 N, and 596 N for the top, middle, and bottom layers respectively.

Mean peak lateral shear was estimated to be 488 N, 619 N, and 762 N for the top, middle, and bottom layers respectively under the floor-flat cart condition while the floor-adjustable cart condition resulted in 449 N, 506 N, and 583 N for the top, middle, and bottom layers respectively. Under the carousel-flat cart condition, the lateral shear forces were 317 N, 201 N, and 185 N for the top, middle,
Figure 10. Mean peak compression as a function of intervention condition and layer

Figure 11. Mean peak anterior-posterior shear as a function of intervention condition and layer
and bottom layers, respectively while the carousel-adjustable cart condition resulted in similar shear forces of 326 N, 266 N, and 298 N, respectively.

The overall effects of intervention condition on mean peak spinal loading are seen in Figures 13 thru 15. Compressive loading was the highest, 5346 N, for bag transfers from the floor pallet to the flat cart and were only reduced by 122 N, or 2.3% when just the adjustable cart was used (floor-adjustable condition). Larger reductions were seen when the carousel pallet was utilized with a reduction of 3003 N or 56% when utilized with flat cart (carousel-flat cart condition) and 3283N or 61% when used in combination with adjustable cart (carousel-adjustable condition).

Mean peak anterior-posterior (A-P) shear was highest, 2054.7 N, for the floor-flat condition but was slightly reduced when using the adjustable cart (by 125 N or 6%). A large reduction was seen for the carousel conditions with1460 N or 71% reduction for the carousel-flat condition and 1483 N or 72% reduction for the carousel-adjustable conditions. Similar results were found for mean peak lateral shear where the largest loads were found for the floor pallet to the flat cart condition (622 N). Small reductions were found when using the adjustable cart only (110 N or 18% lower lateral shear force).
Figure 13. Mean peak compression as a function of intervention condition (Different alpha characters indicate significant difference)

Figure 14. Mean peak Anterior-Posterior shear as a function of intervention condition (Different alpha characters indicate significant difference)
Lateral shear forces were reduced by more than half when using the carousel system with the flat cart, reducing the shear forces by 390 N or 63% and the carousel-adjustable cart condition reducing the shear forces 326 N or 52%.

### 3.4 Cumulative Spine Loading

Interaction effects of condition and layer on cumulative spinal loading are shown in Figure 16 to 18.

Cumulative compression under the floor-flat cart condition was 1263 KiloNewton seconds (KNS), 1265 KNS, and 1301 KNS for the top, middle and bottom layers, respectively. Lower values of cumulative compression were found for the floor-adjustable cart condition to the levels of 1099 KNS, 1154 KNS, and 1208 KNS for the top, middle, and bottom layers, respectively. Even lower cumulative compression values were found for carousel conditions with 917 KNS, 733 KNS, and 642 KNS for the top, middle, and bottom layers, respectively for the carousel-flat cart condition and 763 KNS, 700 KNS, and 675 KNS for the top, middle, and bottom layers, respectively for the carousel-adjustable cart condition.

Cumulative A-P shear was found to be 341 KNS, 371 KNS, and 411 KNS for the top, middle, and bottom layers, respectively under the floor-flat cart condition. Slightly lower but not biomechanically
meaningful A-P shear values were found for the floor adjustable cart condition with 320 KNS, 339 KNS, and 363 KNS for the top, middle and bottom layers, respectively. A-P shear loads were about 220 KNS for all layers when utilizing carousel system, independent of type of cart.

Cumulative lateral shear was estimated to be 94 KNS, 103 KNS, and 123 KNS for the top, middle, and bottom layers, respectively under the floor-flat cart condition. Slightly lower values were found for the floor-adjustable cart conditions with 69 KNS, 75 KNS, and 83 KNS for the top, middle, and bottom layers, respectively. Again, the lateral shear values were in the ballpark of 50 KNS for all layers when using the carousel, independent of cart condition.

![Figure 16. Cumulative compression as a function of intervention condition and layer](chart.png)
Figure 17. Cumulative anterior-posterior shear as a function of intervention condition and layer

Figure 18. Cumulative lateral shear as a function of intervention condition and layer
The effects of intervention condition on cumulative spinal loading are shown in Figures 19-21.

Cumulative compression was greatest for the floor-flat cart condition at 1276 KNS, with lower values for the other conditions: floor-adjustable cart condition at 1153 KNS, carousel-flat cart condition at 764 KNS, and carousel-adjustable cart condition at 713 KNS. A-P shear was greatest for the floor-flat cart condition (374 KNS), followed by floor-adjustable cart condition (340 KNS), carousel-flat cart condition (223 KNS), and carousel-adjustable cart condition (229 KNS). A similar result was found for lateral shear where the floor-flat condition had the highest cumulative lateral shear (106 KNS) followed by floor-adjustable cart (76 KNS) and carousel condition with adjustable cart at 49 KNS and flat cart at 39 KNS.

Figure 19. Cumulative compression as a function of palletizing intervention condition (Different alpha characters indicate significant difference)
Figure 20. Cumulative anterior-posterior shear as a function of palletizing intervention condition (Different alpha characters indicate significant difference)

Figure 21. Cumulative lateral shear as a function of palletizing intervention condition (Different alpha characters indicate significant difference)
3.5 Ratings of Perceived Exertion:

Differences in mean RPE were significant between all conditions except for carousel-flat and carousel-adjustable (see Figure 22). The highest rating was reported for the floor pallet to flat cart condition at 12.44. The floor pallet to adjustable cart condition resulted in a rating to drop to 11.99, a 0.45 point decrease. The mean ratings of perceived exertion were 9.95 and 9.59 for the carousel to flat and carousel to adjustable cart conditions respectively, a reduction of 2.49 and 2.85 respectively.

![Figure 22. Mean rating of perceived exertion by intervention condition (Different alpha characters indicate significant difference)](image)

3.6 Muscle Activity:

Agonistic muscle activity as a function of condition is shown in Figure 23. Activity of the latissimus dorsi muscle group was highest, 39% for the left side and 49% for right side under the floor-adjustable cart condition, followed by floor-flat at 38% and 49%, then carousel-flat cart at 33% and 39%, and finally
carousel-adjustable cart at 29% and 38%. Within each condition, the right side of this muscle group was more active than the left. Left and right side erector spinae activity was highest under the floor-adjustable cart condition at 106% and 89%, followed by floor-flat cart at 102% and 88%. This activity was further reduced under the carousel-flat cart at 65% and 56%, and by the carousel-adjustable cart condition at 66% and 55% for the left and right sides respectively. Activity of the left and right side internal oblique muscle group was highest for the floor-adjustable cart condition at 100% and 97%, followed by floor-flat cart at 97% and 96%, then carousel-flat cart at 62% and 58%, and finally carousel-adjustable cart at 59% and 57%.

Antagonistic muscle activity as a function of condition is shown in Figure 24. Left and right side rectus abdominus activity was greatest under the floor-adjustable cart condition at 32% and 33%, followed by floor-flat cart at 31% and 29%, then carousel-adjustable cart at 30% and 27%, and finally carousel-flat cart at 25% and 23. External oblique activity was also highest under the floor-adjustable cart condition at 25% for the left side and 29% for the right, followed by floor-flat cart at 25% and 27%, then carousel-adjustable cart at 21% and 25%, and finally carousel-flat cart at 19% and 20%.
Figure 23. Mean peak muscle activity of agonistic muscle groups as a function of intervention condition

Figure 24. Mean peak muscle activity of antagonistic muscle groups as a function of intervention condition
3.7 Trunk Kinematics:

Mean peak sagittal, lateral, and axial trunk position as a function of condition are shown in Figure 25. Sagittal flexion was the highest for the floor-flat cart condition at 63°. It was reduced, although not significantly by 2.3% to 62° for the floor-adjustable cart condition, by 39%, to 38.8° for the carousel-flat cart condition, and by 54%, to 29.3° for the carousel-adjustable cart condition. Trunk lateral flexion was also greatest under the floor-flat cart condition at 27.3°. It was reduced by 18% (to 22.5°) for the floor-adjustable cart condition and by 44% (to 15.2°) under both carousel conditions. Trunk axial position did not follow the same trend as sagittal and lateral values. Axial twist was greatest under the carousel-adjustable condition at 35°, and was reduced by 11%, 15%, and 21% for the floor-flat cart, floor-adjustable cart, and carousel-flat cart conditions respectively. The only significant difference in twist existed under the carousel-adjustable condition.

Mean peak sagittal, lateral, and axial trunk velocity as a function of condition is shown in Figure 26. Sagittal velocity was greatest under the floor-flat cart condition at 101°/sec. was reduced, but not significantly, by 6.3%, to 95°/sec under the floor-adjustable cart condition. A significant reduction was found for the two carousel conditions: with flat cart 40% (61°/sec) while for the adjustable cart reductions were 49% (to 52°/sec). Trunk lateral velocity was highest for the floor-flat cart condition at 45°/sec. It was reduced, although not significantly, by 19%, to 37°/sec under the floor-adjustable cart, 26%, to 33.4°/sec. under the carousel-flat cart, and by 28%, to 33°/sec. under the carousel-adjustable cart conditions respectively. Axial twist velocity was highest for the carousel-adjustable condition at 77°/sec. significantly reduced nearly equally under the remaining three conditions by approximately 11%, to 68°/sec.
Figure 25. Mean peak trunk position as a function of intervention condition

Figure 26. Mean peak trunk velocity as a function of intervention condition
4. Discussion:

In this study the single most beneficial device for reducing lifting risk was the self leveling carousel. LBD risk was reduced significantly with the introduction of this device (3.3%), and drastic reductions in peak spine loading were seen; 56% for compression, 71% for A-P shear, and 63% for lateral shear. Comparatively, the adjustable cart produced additional but minimal reductions; 1.1% for LBD risk, 2.3% for compression, 6% for A-P shear, and 18% for lateral shear peak spine loads. The best case for LBD risk reduction was found when combining intervention devices (7% reduction), and the worst case was found when using neither of them (floor-flat condition).

Although mean LBD risk never exceeded the “high risk” benchmark of 60% (level at which high risk group membership is virtually assured) [40] under any of the conditions, analysis of individual lifts shows that high risk lifts did occur and that load positioning devices reduced their frequency. Figure 27 shows the proportion of lifts under each intervention condition that exceed the “high risk” LBD index benchmark value. The floor-flat cart condition had the most high risk lifts at 14.9%, followed by floor-adjustable at 8.8%, carousel-adjustable at 4%, and finally carousel-flat at 3.7%. Mean peak spine loads in excess of the spine tolerance values of 3400 N for compression and 1000 N for shear given by McGill et al [22] were estimated for both floor-flat and floor-adjustable conditions, whereas both the carousel-flat and carousel adjustable conditions yielded mean peak loads well below those levels. Figure 28 illustrates the proportion of lifts under each condition that exceed these threshold levels. Conditions without the carousel have a very high proportion of lifts; 96.6%, and 95.4% (compression) resulting in excessive spine loads, while conditions with the carousel have a much lower proportion; 28.5% (compression), and 16% (A-P shear).

LBD risk increased from the top layer to the bottom layer, which agrees with the findings of Marras et Al. [8], except under conditions using the self-leveling carousel; here the risk decreased from top to bottom. Due to this divergent trend, it is the bottom layer of the pallet that contributes most to the LBD risk decrease seen with the load positing devices. This trend may be a result primarily of differences in sagittal flexion: increasing sagittal flexion from top layers to the bottom layers, which is experienced in
traditional palletizing [8], but with the pallet carousel these effects are nullified. Additionally, with the carousel-flat cart condition the increasing load destination height results in less sagittal flexion from the top layer to the bottom. Description of this trend for the carousel-adjustable cart condition is perhaps the most complex as a result of changes in vertical positions between origin and destination and the resulting changes in sagittal flexion and trunk twist. In this case sagittal flexion position and velocity decrease from top to bottom layer, while twist position increases and velocity decreases, so sagittal flexion drives the trend.

Spine loading followed a very similar trend in that the load estimates where highest for the bottom layers of the pallet, except when the carousel was used, and the smallest loads were attained when utilizing both load positioning devices together, except for mean peak lateral shear, which increased significantly under the carousel-adjustable condition.

Figure 27. Proportion of lifts that exceed “high risk” LBD benchmark by intervention condition
Figure 28. Proportion of lifts exceeding spine loading benchmarks by intervention condition (spine tolerance values of 3400 N for compression and 1000 N for shear given by McGill et al [22])

Differences in muscle activity and trunk kinematics arising from varying load positions appear to account for a large part of the changes in LBD risk and spine loading between the intervention conditions. There is a consistent trend in muscle activity showing reduced magnitude under conditions using the self leveling carousel. There are, however some small increases where the adjustable cart is used in conjunction with the pallet on the floor: latissimus dorsi, right erector spinae, rectus abdominis, external obliques, and internal obliques. This may be due to the deep sagittal flexion still required to reach the bags at the origin, and a greater load travel distance in a positive direction i.e. more raising than lowering in the transfer of bags from the low pallet to the higher cart. This increased load travel distance may have impacted the subjects’ anticipation, resulting in greater muscle activation at the start of each lift. The effects on spine loads from these increases is somewhat counterintuitive since the spine loads estimates are decreasing, however the postural improvements created by the adjustable cart at the lift destination likely offset the muscle activity increase. Another small increase in muscle activity is
seen between the carousel-flat cart and the carousel-adjustable cart conditions. This time the difference may result from the greater negative load travel distance, or lowering transfer motion achieved when moving the bag from the higher carousel to the lower flat cart, and the increase in trunk twisting seen in the carousel-adjustable condition.

Reduced trunk motion and horizontal load moment also resulted from improved load positioning, which drove down LBD risk probability as well as three-dimensional spine loading. Horizontal load moment was significantly reduced with the addition of the self leveling carousel. This reduction resulted from subjects utilizing the rotating carousel feature to position bags closer to their bodies for each lift. Although a small decrease in load moment is seen when using the adjustable cart with the pallet on the floor, a significant increase is seen from the carousel-adjustable cart condition compared to the carousel-flat cart condition. This may be a result of subjects keeping their feet stationary for the carousel-adjustable cart transfer, while they may have taken steps to get into position for the carousel-flat cart transfer. Lateral velocity and sagittal trunk angle are consistently reduced when using load positioners. Changes in sagittal flexion appear to be the primary driver for LBD risk reduction as this parameter underwent the more significant reductions. These reductions likely resulted from the loads being raised vertically by the intervention devices. Trunk twist velocity on the other hand remained mostly unaffected by each intervention device independently. However when the carousel and adjustable cart were combined a significant increase in twist was recorded. This response in twist counteracts the general trend seen with other LBD risk parameters, and likely reduced the protective effects of the load positioning devices. This result agrees with the findings of Davis et al [10], who experienced similar increases in twist when instituting an adjustable cart for load transfers.

The subjects’ rating of perceived exertion trends similarly with LBD risk and spine loading, except for the floor-adjustable condition, which received the highest RPE. The perception of the carousel-adjustable cart combination was the lowest and it therefore would be anticipated that its adoption into MMH workplaces would well-received by workers.
5. Limitations:

The addition of the adjustable cart reduced LBD risk and spine loading, but these effects are not as strong as those of the carousel, thus giving the impression that the adjustable cart does not contribute to reduced risk to the same extent as the carousel. One potential reason for this may be the height of the flat cart used. The platform height of the flat cart was 30 cm, which, when compared to many carts used in MMH, is quite high. This higher-than-typical cart platform requires much less trunk flexion during the lift, and as a result LBD risk index is reduced, and the values for conditions using the flat cart appear truncated.

All the subjects used in this study were young healthy males, therefore the effects of load positioning equipment on other demographics may be different. From this study, it is not known how this equipment might affect older populations, females, or those individuals with health conditions. This study also used a relatively small group of subjects, and the anthropometric diversity of this group of 13 individuals could have been greater. Since the effects of load positions will cause different trunk motions and muscle activities for individuals of varying anthropometric dimensions, the results could change significantly if the subjects were very short, very tall, or very obese. It could be anticipated that the equipment would be more protective for extremely tall people, since the bags have been raised from the floor and may require less trunk flexion. This raised bag position may have similar but reduced effects on the trunk flexion of extremely short people. Therefore greater differences in LBD risk and spine loads between intervention conditions with load positioners and without may have been observed for the tallest individuals, whereas a smaller difference may have been seen for shorter individuals. Increases in horizontal load moment could result for very obese individuals due to their large body size prohibiting the bags from being held closer to the trunk. This potential effect would cause LBD risk and spine loading to increase. An analysis of anthropometric effects on outcome variables could be conducted, but might not prove to be statically important in a small study group such as this one.
This study is a simulation in a controlled environment, and as such it could not account for real world factors which could change the effects of the equipment. The most significant factor may be that the bags were all uniform in size, shape, and weight. Using these two load positioning devices for mixed pallets like those occurring regularly in industry may yield very different results. However, even if loads vary in size and shape, and the effective load height for a given article of freight may change in industry, this equipment still raises it from floor level to a height that will require less trunk bending. Further, loads of different weights should make very little difference in the effects of load positioners, since it was found by Marras et al [8] that load position plays a more important role in palletizing risk than weight does. Also from a real world perspective, it may be easier to change the position of an item than to change the item’s weight, potentially making load positioner more viable as an intervention. Additionally, to reduce strain on subjects, only a partial pallet of concrete bags was simulated as opposed to a full pallet. While using a full pallet of bags may more accurately represent real world conditions, this workload (80 bags in 8 layers and a total weight of 1452 kg) was considered too risky for the subjects. Furthermore, the region of the pallet targeted here (bottom layers) is responsible for the greatest lifting risk [2,7,9] and is the pallet region most likely to benefit from intervention.

This study was only a short term evaluation of intervention effects, not a long term prospective study. While the immediate effects of these load positioning devices can clearly be seen as protective, it cannot predict the long term effects of continuous use of such devices in a real workplace. It would be anticipated, however, that since immediate effects are protective, that long term effects would be similar. More research into the effects of prolonged use of these devices in the workplace is needed rule out adverse long term effects, as well as potential logistical challenges with real workplace implementation.
6. Conclusion:

This study showed that the self leveling pallet carousel was highly effective at reducing LBD risk and spine loading for the simulated de-palletizing task. Since the individual benefits of the carousel outweigh those of the adjustable cart, it is recommended that in situations where only one device can be implemented that the self leveling pallet carousel should be used. While the combination of carousel and adjustable cart yielded the greatest reduction in LBD risk (7%), RPE (2.8 points), spine compression (61%) and A-P shear (72%), the effects weren’t much better than the carousel alone. The relative weakness of the adjustable cart likely arose from increases in trunk twist and load moment that accompanied its combination with the carousel, as well increased agonistic and antagonistic muscle activity caused by its implementation. Overall the results of this study show that load positioning devices such as these have the potential to reduce lifting related injuries in palletizing, evidenced by the reductions in LBD risk and spine loading experienced herein, however more research is needed to investigate long term use effects.
7. References:


Volunteers Needed For
A Research Study

Subject Population:
Healthy Males
Between the ages of 18 and 40
Must have no history of back problems

Study Duration:
One visit, approximately 4 hours

Subject Involvement:
Subjects will complete 4 trails involving lifting and moving 40 pound bags of concrete from a pallet to a cart.

Subjects will be compensated for their involvement

If you would like more information about the study please contact Todd Ramsey at 513-658-6880 or Ramseyte@mail.uc.edu
II. Medical screening questionnaire:

Screening Questionnaire for Participation in the Study:
The effect of load-positioning material handling equipment on spinal loading during manual handling of bulk bags

A. Your name: ____________________________  B. Today’s Date: ____________

C. Your age (to nearest year): ____________  D. Sex (circle one): Male / Female

E. Your height: ______ ft. _______ in.  F. Your weight: _________ lbs.

G. Phone number where you can be reached if clarification of the information on the questionnaire is required: ____________________________

H. Emergency Contact: Name ____________________________ Phone number ____________

The following questions will help us determine your overall level of health. Please answer ALL questions.

1. Have you ever or do you currently have any of the following conditions?

   a. Seizures ..........................................................  NO YES
   b. Diabetes ...........................................................  NO YES
   c. Asthma or wheezing ............................................  NO YES
   d. Chest or left arm pain or discomfort with exercising or physical activity  NO YES
   e. Heart Disease or a Heart Condition, including a Heart Attack, Irregular Heart beat or Heart Failure ...........................................................  NO YES
   f. Stroke or Cerebrovascular Accident (CVA) ...........................................................  NO YES
   g. Transient Ischemic Attack (TIA) or “mini-stroke” ............................................  NO YES
   h. Blackouts or Fainting ...........................................................  NO YES
   i. Swelling in your legs or feet ...........................................................  NO YES
   j. High Blood Pressure ...........................................................  NO YES
   k. Shortness of Breath more than others your age ............................................  NO YES
   l. Hernias ...........................................................  NO YES

2. Do you have any other significant health condition(s)?  No Yes If yes, please describe below.

3. Have you been hospitalized in the past year?  No Yes If yes, please describe below.

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Received & Approved - Date: 5/25/11

By: ____________________________
Chairperson/Designee
Institutional Review Board

UNIVERSITY OF
Cincinnati
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