Assessment of a Transfer Pick Pallet on Lower Back Biomechanics

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Occupations that require regular manual material handling have been shown to have a high prevalence of low back disorders. Previous research has shown that risk factors associated with low back disorders (LBD) include load moment, lateral velocity, twisting velocity, lifting frequency, and sagittal trunk angle. These risk factors are present during pallet loading and unloading tasks, in which a worker is required to bend to pick up boxes close to the ground as well as stretch across a pallet to reach boxes with large horizontal distances. In an attempt to address the harmful risk factors present during palletizing tasks, the current study assessed the potential benefits of a transfer pick pallet, which allows the worker to slide the back rows of the pallet to the front of the pallet, decreasing the horizontal distance to unload the boxes. Five experienced warehouse workers (i.e., order pickers) participated in an experiment assessing a full crossing of pallet type (standard vs. transfer) and box weight (light vs. heavy). Dependent variables collected were task completion time, NIOSH lift index (LI), and average probability of LBD risk (using measurements from a lumbar motion monitor). The results suggest that the transfer pallet significantly reduced the LI and reduced the probability of LBD while not significantly increasing the task completion time.

**Practitioner Summary:** The use of a transfer pallet in a pallet-unloading task significantly decreased the risk of low back disorders (as assessed with a lumbar motion monitor) and decreased the lift index calculated from the NIOSH lifting equation while not increasing the total completion time required to unload a pallet containing 36 boxes.

**Keywords:** Manual material handling, low back biomechanics, palletizing.

1 Introduction

There is a very high prevalence of low back disorders (LBDs) among warehouse workers, particularly those whose jobs require a great deal of manual material handling (MMH). Dempsey and Hashemi (1999) examined the nature of injuries associated with MMH as well as the body parts most frequently affected in workers' compensation claims between 1990 and 1995. They found that 36% of all workers' compensation claims were related to MMH. Low back injuries composed 29.5% of all MMH claims, which is almost 3 times as many as the second-most frequently affected body part (fingers, 10.8%). Furthermore, low back injuries composed 41.6% of MMH claims costs, which is almost 4 times as much as the second-highest percentage of claims costs (upper arm- 10.9%). Similarly, Dunning et al. (2010), who collected workers' compensation data from Ohio between 1999 and 2004, found that lumbar spine injuries were associated with the highest median cost per claim at $8,750. For the number of incidents resulting in 7 or more days away from work, lumbar spine injuries was the leading category with 34.1% of incidents, followed by shoulder injuries at 30.6%. Furthermore, 25.1% of the claims came from the manufacturing sector. Taken together, these studies highlight the importance of implementing engineering and/or management controls to reduce worker risk of developing LBDs.

1.1 Biomechanical Issues with Pallet Picking

Many studies have identified the physical load and motion factors that predict risk of LBDs. In a study conducted by Marras et al. (1993), the objective was to determine whether dynamic trunk motions along with other risk factors could predict the risk of LBD in MMH tasks. They performed a cross-sectional study of 403 jobs from 58 manufacturing companies (124 jobs were classified as high risk, while 111 were classified as low risk). Multiple logistic regression analysis found 5 measures that reliably estimated the probability of LBD, including maximum load moment, maximum sagittal trunk angle, twisting velocity, lifting frequency, and
maximum sagittal trunk angle. In a similar study, Norman et al. (1998) sought to identify biomechanical risk factors related to the reporting of lower back pain by workers in an automobile assembly company. A logistic regression analysis found peak lumbar shear force, peak torso flexion velocity, cumulative lumbar moment, and average hand force could predict whether a worker would report experiencing lower back pain. Finally, Granata and Marras (1999) found that the mechanisms of spinal injury required a combination of multiple factors. They found that they could accurately classify risk of LBD by simply measuring spinal compression.

Trunk flexion has been repeatedly demonstrated to increase a worker’s risk of developing a LBD. Punnett et al. (1991) investigated the relationship between non-neutral trunk postures of workers in an automobile assembly plant and the risk of musculoskeletal back disorders reported to the medical department. The authors found that the probability of reporting back pain increased with increasing exposure to mild (between 21 and 45 degrees) and severe trunk flexion (greater than 45 degrees). Similarly, Hoogendoorn et al. (2000) collected worker posture data from workers in 34 companies in the Netherlands and then sent the workers a series of questionnaires 3 years after observation. The results showed that trunk flexion and lifting at work were associated with a higher occurrence of lower back pain. The authors also showed that the incidence of higher back pain had a positive correlation with the degree of trunk flexion. Finally, Burgess-Limerick and Abernathy (1998) examined the effect of manipulating the placement of the feet relative to the load and found that the distance between the ankles and the load had a much larger effect on posture than the mass of the load itself.

Palletizing tasks, which consist of loading or unloading packages or boxes on or off a pallet (see Figure 1), require lifting of sometimes-heavy loads as well as extreme trunk flexion. Therefore, as expected, many studies have shown that there is a high risk of LBDs associated with loading and unloading packages off of pallets. Marras et al. (1997) observed increased spinal loading and the risk of occupationally-related LBD as workers lifted objects of different weights from different locations on a pallet. They found that the bottom layer yielded larger horizontal moments and the back-bottom region of the pallet increased trunk flexion moment by 25% compared to the front-top region. The authors concluded that the location of the box on a pallet is a far greater determinant of spinal loading than the weight of the packages alone. Jorgensen et al. (2005) found similar results to Marras and colleagues, concluding that pallet region had a significant effect on the maximum trunk flexion and LBD risk, with lower regions and horizontally farther regions increasing maximum flexion and LBD risk. Finally, Elfeituri and Hammouda (2012) reported that the effect of layer height on shear force on the lumbar spine is significant, with increased shear force associated with layers closer to the ground. They also reported that lumbar spine compression force also generally increased for loads closer to the ground, although this was not the case when workers bent their knees to unload the boxes closest to the ground.

Figure 1. Example of a pallet containing eight packages.
1.2 Previous Interventions in Palletizing Tasks
Given the trunk flexion and shear forces associated with palletizing tasks, previous literature has investigated various ergonomic interventions to alleviate the stress that the task places on the lumbar spine. Research investigating the addition of handles to the packages found heart rate and completion time benefits, but negligible benefits regarding trunk movements (Kumar et al., 1993; Davis, Marras, and Waters, 1998; Marras et al., 1999). Marras et al. (2000), in a before-after observational study, found that lift tables (which brought the pallets higher off the ground) reduced LBD by 7.42 per 100 full time employees (FTE) while lift aids (which provided mechanical assistance in moving products) reduced LBD by 6.18 per 100 FTE. In a more high-tech intervention, Lavendar, Ko, and Sommerich (2011) investigated the effects of a lift aid called the Eco-Pick Lift Assist, a type of overhead lift assist device. The authors reported a significant reduction in the 50th percentile electromyographic (EMG) muscle activations in the deltoids, biceps, lattisimus dorsi, and erector spinae, with the erector spinae muscles having the largest decrease in activation. Finally, Ramsey, Davis, and Kotowski (2013) and Davis and Anes (2014) investigated the effects of an adjustable cart on which the height adjusted automatically based on the number of vertical levels of the pallet remained to be picked. It was found that the cart resulted in significantly less sagittal flexion, but increased twisting position and reduced LBD risk by 2.4%.

1.3 Problem Statement
A multitude of research has found that there is a significant risk of LBD in manufacturing workers, particularly for those who are required to regularly load and unload packages from pallets. The trunk flexion and associated compressive and shear forces on the lumbar spine inherent in the task make it necessary to explore engineering interventions to reduce the incidence of LBDs in these workers. Given these findings, the current work assesses the effectiveness of a transfer pallet, which allows the worker to slide the back rows of the pallet to the front of the pallet before removing the packages. The transfer pallet was expected to reduce the trunk flexion, the horizontal reach and resultant load moment required to remove all packages from the pallet, thus reducing the risk of LBD in workers.

2 Method

2.1 Participants
Five experienced warehouse workers, with a mean age of 38.6 years (standard deviation = 5.1 years), participated in the assessment of the transfer pallet.

2.2 Apparatus and Scenario
The experiment was conducted in a warehouse and participants were asked to remove packages from a standard pallet and a transfer pallet, which was located on the second level of a distribution centre storage rack (approximately four feet off the ground). In each trial, participants stood on a forklift donning a safety harness and unloaded boxes of differing weights from the pallet to the forklift platform, where they were immediately removed so that the destination of the boxes remained consistent for each pick. Each pallet contained 36 boxes (3 rows*4 columns*3 vertical layers). Participants wore the Industrial Lumbar Motion Monitor™ (iLMM3™) during the entire experiment, which measured various trunk movements.

2.3 Independent Variables and Experiment Design
Three independent variables were manipulated in the experiment, including pallet type (standard vs. transfer), box weight (heavy vs. light), and box location (1-12). The heavy boxes weighed 18 lb (8.165 kg) while the light boxes weighed 35 lb (15.876 kg). The box locations are displayed in Figure 2. All variables were within-subject, with each participant unloading a full crossing of pallet type and box weight, resulting in four total trials per participant (i.e., the pallets in each trial contained only heavy or only light boxes). The order of administration was randomized for each participant to reduce any potential order effects.
2.4 Dependent Variables

Three dependent variables were collected, including task completion time, average probability of LBD risk, and lift index (LI), which was calculated using the lifting equation developed by the National Institute for Occupational Safety and Health (NIOSH; Waters et al., 1993). The average probability of LBD risk was calculated as the average of five variables—lift rate, maximum moment, maximum trunk flexion, maximum lateral velocity, and average twist velocity—each of which was normalized within participant. The lift rates were monitored as being 175 lifts per hour for the standard pallet and 189 lifts per hour for the transfer pallet; the remaining variables were output by the iLMM3™.

2.5 Procedure

Participants began the experiment by signing an informed consent form and a demographic questionnaire, followed by donning the wireless iLMM3™ with the assistance of the experimenter. Participants then stepped onto a lift truck and were tethered to prevent any falls from the lift truck. During the pallet-unloading task, the participants were asked to remove the boxes from left to right, top to bottom, and front to back. After removing the boxes from the pallet, they were placed at the base of the lift and the experimenter immediately moved the box so that the destination did not change for any boxes. After completion of the task, participants were given adequate rest before beginning the next pallet-unloading task. In total, the experiment lasted approximately 1.5 hours for each participant.

2.6 Hypotheses

It was expected that the transfer pallet would reduce task completion time, reduce the probability of LBD risk, and result in lower NIOSH LI scores due to the reduction in horizontal reach for half of the boxes on the pallet. Furthermore, it was expected that the increases in box weight would increase task completion time and increase the probability of LBD risk.

2.7 Data Analysis

Analysis of Variance (ANOVA) was used to assess the effects of the variables on task time and probability of LBD risk. Factors included in the ANOVA models were participant, trial number, pallet type, box weight, and an interaction between pallet type and box weight. Box location was also included in the ANOVA model for probability of LBD risk. Participant and order were factors used as blocking variables to account for known variability in the model; their significance was not evaluated. Finally, contingency analysis was used to assess the effects of pallet type and box weight on NIOSH LI scores.

3 Results

3.1 Task Completion Time

The analysis of variance (ANOVA) on the log-transformed task completion time revealed a significant effect of box weight (F(1,11)=15.035, p=0.003) on task completion time, but no significant effect of pallet type (F(1,11)=0.032, p=0.862) nor a significant interaction (F(1,11)=1.030, p=0.332). The average completion time was significantly shorter for the light boxes (131.1 sec) compared to the heavy boxes (174.7 sec).
3.2 Average Probability of LBD Risk

A nonparametric ANOVA on the ranked average probability of LBD risk revealed a significant effect of pallet type \( \text{F}(1,698)=102.411, p<0.001 \) and box weight \( \text{F}(1,698)=304.993, p<0.001 \) such that the transfer pallet resulted in a smaller probability of LBD risk (58.6%) compared to the standard pallet (63.8%) and the light boxes had a significantly smaller probability (58.9%) compared to the heavy boxes (65.6%). There was also a significant effect of box location \( \text{F}(11,698)=18.420, p<0.001 \) which exhibited a general trend that as the boxes got lower and further to the back of the pallet, there was a higher probability of LBD risk.

3.3 NIOSH Lift Index

Contingency analyses were performed on the NIOSH LI since many of the horizontal distances in the NIOSH lifting equation exceeded the equation’s maximum allowable distance of 25 in (63 cm). The categories tested in the contingency analyses were \( 1<\text{LI}<2, 2<\text{LI}<3, \) and \( \text{LI}>3 \) (there were no LIs<1). The LI category was significantly different as a function of both pallet type \( (\chi^2=79.656, p<0.001) \) and package weight \( (\chi^2=311.251, p<0.001) \) such that lower LIs were associated with the transfer pallet and the light boxes.

Table 1. Counts for LI groups for pallet type and box weight (the percentage in parenthesis represents the within-row percentages).

<table>
<thead>
<tr>
<th>Independent Variable</th>
<th>Level</th>
<th>1&lt;LI&lt;2 (%)</th>
<th>2&lt;LI&lt;3 (%)</th>
<th>LI&gt;3 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pallet Type</td>
<td>Standard</td>
<td>57 (16%)</td>
<td>33 (9%)</td>
<td>270 (75%)</td>
</tr>
<tr>
<td></td>
<td>Transfer</td>
<td>119 (33%)</td>
<td>87 (24%)</td>
<td>154 (43%)</td>
</tr>
<tr>
<td>Box Weight</td>
<td>Light</td>
<td>176 (49%)</td>
<td>27 (7%)</td>
<td>157 (44%)</td>
</tr>
<tr>
<td></td>
<td>Heavy</td>
<td>0 (0%)</td>
<td>93 (26%)</td>
<td>267 (74%)</td>
</tr>
</tbody>
</table>

4 Discussion

According to the hypotheses, it was expected that the transfer pallet would decrease completion time and that the light boxes would have a smaller completion time than the heavy boxes. The results revealed that the transfer pallet yielded no significant completion time benefit compared to the standard pallet. This was likely due to the extra time it took for the worker to pull the back two rows of the pallet to the front in the transfer pallet. However, results showed that the completion time for the light boxes was significantly shorter than the completion time for the heavy boxes. This corroborates previous results reported by Marras et al. (1997) and suggests that there is a productivity benefit to keeping boxes as light as possible.

It was expected that the transfer pallet would decrease the probability of LBD risk as assessed with the iLMM3™. The results confirmed this expectation, suggesting that the risk factors associated with lifting boxes from the back of the pallet (e.g., load moment, trunk flexion, lateral velocity, twisting velocity) were major contributors to LBD risk and the transfer pallet reduced these risk factors. It was also expected that the light boxes would decrease the probability of LBD risk compared to the heavy boxes and results supported this hypothesis. Granata and Marras (1996) reported that as fatigue increased, the motion of the trunk was reduced, requiring increased pelvic angle to perform the lifting task. Early lifting exertions were dominated by the erector spinae muscles but as fatigue set in, more extensor moment was required from the oblique muscles, resulting in greater shear loading on the spine. Related to this, it is likely that the heavier boxes generated an earlier onset of fatigue, causing the participants to adjust their posture similar to the participants in Granata and Marras (1996).

Finally, It was expected that the transfer pallet would yield a smaller average NIOSH LI than the standard pallet. This was confirmed by the results, as the transfer pallet was associated with significantly more instances of low-LI values and significantly fewer instances of high-LI values. Given these associations, it should be noted that no LIs were less than 1 for either pallet or either box weight, indicating that further controls need to be implemented to make the task safe according to NIOSH lifting equation standards. In this particular scenario, the lowest LI value was 1.1, suggesting that the maximum box weight that could be safely unloaded according to the NIOSH lifting equation was 16.363 lb (7.422 kg).
5 Conclusion

The objective of the experiment was to assess the effectiveness of a transfer pallet on task completion time, probability of LBD risk, and NIOSH LI scores. The results found that the transfer pallet had no significant effect on completion time compared to the standard pallet in a pallet-unloading task, but significantly reduced the probability of LBD risk and the NIOSH LI. Regarding the box weight, increased weight significantly increased task completion time, probability of LBD risk, and NIOSH LI. Finally, the location of the boxes on the pallet revealed a trend that greater horizontal reaches and lower vertical distances resulted in increased risk of LBD.

5.1 Limitations and Future Work

Inherent in the study were various limitations, which may or may not affect the generalizability of the benefits associated with the use of the transfer pallet. First, a small sample size was used (only 5 participants), all of which were experienced male warehouse workers. Furthermore, only the NIOSH LI and LMM LBD risk models were used to assess LBD risk. Other models may reveal different results. Future work should focus on accommodating for the limitations mentioned, including using female warehouse workers, increasing the sample size, and looking at different experience levels of workers (i.e., assess the results on less experienced warehouse workers) or analysing the results with other LBD risk models.

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References


