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Spinal loading when lifting from industrial storage bins

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The study documented three-dimensional spinal loading during lifting from an industrial bin. Two lifting styles and two bin design factors were examined in Phase I. The lifting style measures in Phase I were one hand versus two hand and standing on one foot versus two feet. The bin design variables were region of load in the bin and bin height. The Phase II study examined one-handed lifting styles with and without supporting body weight with the free hand on the bin as well as region and the number of feet. Twelve male and 12 female subjects lifted an 11.3 kg box from the bin. Spinal compression, lateral shear and anterior–posterior shear forces were estimated using a validated EMG-assisted biomechanical model. Phase I results indicated that the bin design factor of region had the greatest impact on spinal loading. The upper front region minimized spinal loading for all lifting styles. Furthermore, the lifting style of two hands and two feet minimized spinal loading. However, comparing Phase I two-handed lifting with Phase II one-handed supported lifting, the one-handed supported lifting techniques had lower compressive and anterior–posterior shear loads in the lower regions as well as the upper back region of the bin. A bin design that facilitates lifting from the upper front region of the bin reduces spinal loading more effectively than specific lifting styles. Furthermore, a bin design with a hand hold may facilitate workers using a supported lifting style that reduces spinal loading.

1. Introduction

A commonly observed task in industry is lifting materials from a bin. However, there are no specific guidelines for the design of the bin or for lifting styles. The National Institute for Occupational Safety and Health (NIOSH) guidelines assume a two-handed sagittally symmetric lift with no obstruction. However, workers are often observed lifting from bins with one hand, leaning on the side of the bin, and standing on one leg while lifting. Differences in lifting techniques may influence spinal loading, thereby influencing the risk of low-back injury. Furthermore, the bin design may influence the kinematics of the lift, resulting in changes in spinal loading. Finally, there may be some combination of these factors that influences spinal loading.

Workers in industry are commonly observed lifting with one hand rather than with two hands. The effects of one- versus two-handed lifting have been investigated.

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Allread (1993) found that one-handed lifting resulted in greater sagittal flexion and higher lateral velocity than two-handed lifting. Marras and Davis (1998) investigated spinal loads during asymmetric lifting using both one- and two-handed lifts. One-hand lifts on the ipsilateral side of the body resulted in compressive loads that were approximately the same as two-handed lifts, and anterior–posterior shear loads decreased whereas lateral shear loads increased. These findings indicated the complex three-dimensional trade-offs that occur in spinal loading between one- and two-handed lifting. However, there is a lack of studies investigating these differences when lifting from a bin.

The second lifting style frequently observed in industry is workers standing on one rather than two feet during lifting tasks. To date, there have been no studies evaluating the kinematics or spinal loading while standing on one leg. It was hypothesized that when workers stand on one leg, sagittal bending would decrease during the lifting tasks, resulting in lower compressive load but a potentially higher shear loading.

The third lifting style found in industry is workers supporting their weight on the side of the bin. This supported lifting style can only occur during one-handed lifting tasks. This type of supported lifting technique has been investigated by Cook *et al.* (1990), who found that one-handed assisted lifting placed less stress on the paraspinal muscles. However, they did not investigate spinal loading.

Among bins found in industry, there are two bin design factors that may influence spinal loading. First, many bins have sides that fold down to raise and lower the height of the side of the bin. The height may influence the kinematics of the lift, thereby changing the spinal loading of the worker. Second, the location of the load in the bin may influence spinal loading. The 1981 NIOSH *Workpractices Guide for Manual Lifting* (NIOSH 1981) as well as the revised NIOSH lifting equation (Waters *et al.* 1993) both have horizontal and vertical discounting factors. Basic mechanics principles dictate that as the horizontal distance increases, the spinal load increases (Ozkaya and Nordin 1999). Marras *et al.* (1997) found that spinal loading was influenced by the region in which the load was placed during palletizing tasks. Spinal loads were significantly greater in the lower compared with the upper regions. The NIOSH guides used compression as one criterion to evaluate the risk of low-back injury due to lifting tasks. However, shear loads may also contribute to the risk of low-back injury and trade-offs between shear and compression should be considered in evaluating overall spinal loading.

As workers pick through a bin, several lifting style and bin design factors may create trade-offs between shear and compressive loading on the spine. There is a void in the epidemiological literature quantifying the risk of low-back injury when lifting from a bin. Furthermore, there is a void in the knowledge quantifying the trade-offs in spinal loading due to lifting style and bin design factors. Therefore, the objective of the study was to quantify spinal loads to determine what trade-offs occur in spinal loading while lifting from a bin using various lifting techniques found in industry, which would permit the recommendation of lifting techniques and bin locations to minimize spinal loads.

2. Materials and methods

2.1. *Approach*

This study quantified three-dimensional spinal loading during several manual material-handling tasks. The study was separated into two phases. Phase I examined two lifting styles and two bin design factors. One lifting style factor in Phase I was one- versus two-handed lifting style. In Phase II, the one-handed lifting style was isolated into lifting with and without support. The study was separated into two phases because the support lifting style was only conducive to specific bin designs. This combination of lifting style and bin design factors allowed the investigation of realistic workplace conditions in the laboratory and the determination of which combinations reduced spinal loads.

2.2. *Subjects*

Twelve male and 12 female college students with no prior history of low-back pain participated in the study. The subjects' ages ranged from 19 to 34 years. The male subjects' mean (SD) weight and height were 74.5 kg (7.8) and 178.4 cm (3.2), respectively. The female subjects' mean (SD) weight and height were 61.2 kg (6.4) and 168.0 cm (6.6), respectively.

2.3. *Experimental design*

Phase I was a four-way, repeated measures, within-subject, completely randomized design. There were two lifting style-independent measures and two bin design-independent variables. The lifting style variables were the number of hands and the number of feet used. The bin design factors were the region of the bin and bin height. The Phase II study was a three-way, repeated measures, within-subject, completely randomized design. Table 1 lists the independent measures and specific conditions for Phases I and II. Figures 1–3 show a two-hand, two-feet lift, a one-handed supported lift on one foot, and a one-handed supported lift on two feet, respectively. The lifts in both Phase I and II were repeated twice for a total of 80 lifts.

The dependent variables in both Phase I and II were spinal loads predicted from an EMG-assisted biomechanical model developed over the past two decades in the Biodynamics Laboratory (Marras and Reilly 1988, Reilly and Marras 1989, Marras and Sommerich 1991a,b, Granata and Marras 1993, 1995a,b, Marras and Granata 1995, 1997, Davis *et al.* 1998). The model has recently been customized to account for gender-specific cross-sectional areas and lines of action of muscles from magnetic resonance imaging (MRI) (Jorgenson *et al.* 2001, Marras *et al.* 2001). The model

Table 1. Independent variables for Phase I and II studies.

Phase I: Independent measures	Phase II: Independent measures
Hands	Support for body with hand
One handed	Support
Two handed	No support
Feet	Feet
One foot	One foot
Two feet	Two feet
Region of bin	Region of bin
Upper front	Upper front
Upper back	Upper back
Lower front	Lower front
Lower back	Lower back
Bin height	
High bin	
Low bin	

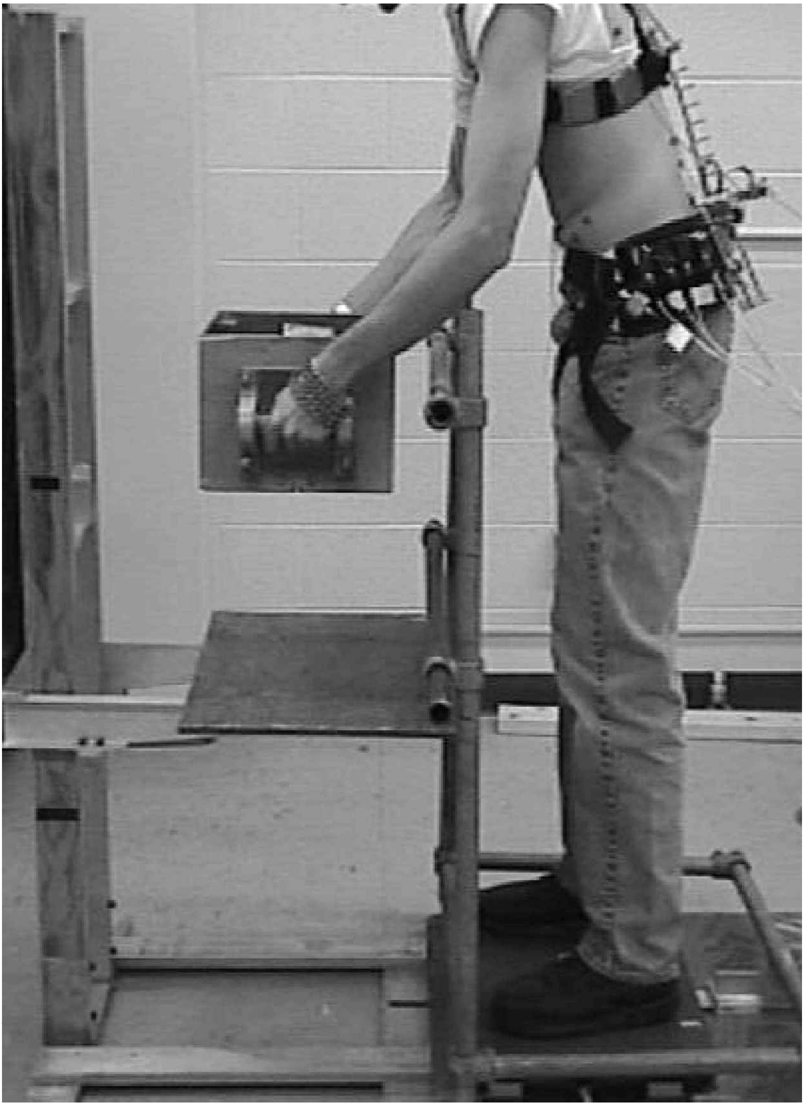

Figure 1. Two hand, two feet lifting condition from the upper front region of bin.

estimated the maximum lateral shears, anterior–posterior shears and compression forces on the lumbosacral joint.

2.4. *Apparatus*

A structure was constructed of steel pipe to simulate the side of a standard bin and was attached to a force plate. This allowed the subjects to apply pressure to the bin, while the force plate measured the kinetic variables. The simulated bin measured $137 \times 112 \times 94$ cm in length, width and height, respectively. It was designed to simulate a typical bin with a fold-down side. A removable pipe was set at 94 cm, while a second bar was 61 cm from the floor to represent the two bin heights.

Figure 2. One-handed supported condition when standing on one foot from lifting the upper front region of bin.

The bin was divided into four regions (figure 4). Regions 1 and 2 were at a height 50.8 cm from the top of the force plate. Regions 3 and 4 were 11.5 cm above the force plate. Regions 1 and 3 were 42 cm directly in front of the subject, while regions 2 and 4 were directly behind the face of the bin. Region 1 was termed the upper back, region 2 the upper front, region 3 the lower back and region 4 the lower front.

A standard box was used as the load for all trials. The box weighed 11.3 kg. It measured 21.6 cm in height, 27.9 cm in depth and 30.5 cm in width, and measured 41.9 cm between the two outside handles. The handles were 10.2 cm from the base of the box. A single handle placed inside the box at the same height was used for all one-handed lifts. Subjects were required to use the handle(s) as appropriate for all lifts in an attempt to minimize the variability in the conditions. In addition, the handles verified

Figure 3. One-handed supported condition when standing on two feet from lifting the upper front region of bin.

that the box was grasped at the same height across all trials. The lifting task origin changed as a function of the experimental condition. The lifting task destination was to position the box directly in front of the person at elbow level for all tasks. Thus, the subject had to lift the box up and over the side of the bin for each task.

The Lumbar Motion Monitor (LMM) collected the trunk motion variables. The LMM is an exoskeleton of the spine and measures instantaneous changes in position. For a detailed description of the calibration and accuracy, see Marras *et al.* (1992). The LMM measures position, velocity and acceleration of the subject's thoraco-lumbar region in all three planes of the body.

Integrated electromyographic (EMG) data was collected using bipolar surface electrodes placed approximately 3 cm apart at the standard locations for 10 trunk

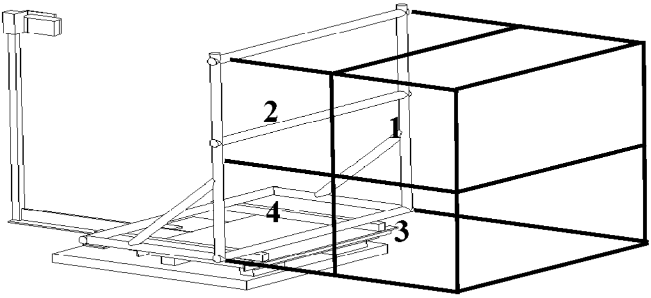

Figure 4. Schematic view of the simulated bin with four regions in which the load could be placed.

muscles, as described in Mirka and Marras (1993). The right and left muscles of interest were: latissimus dorsi, erector spinae, rectus abdominus, external obliques and internal obliques.

A Bertec^{TM} force plate and a set of electrogoniometers measured the external loads and moments relative to the lumbosacral joint during various calibration exertions. The electrogoniometers measured the relative position of the lumbosacral joint with respect to the centre of the force plate as well as the participant's pelvic angle. The forces and moments were translated and rotated from the centre of the force plate to the lumbosacral joint using the measurements from the electrogoniometers, as described in Fathallah *et al.* (1997).

Data were collected simultaneously from all the equipment. The signals were collected at 100 Hz and recorded on a portable computer via an analogue-to-digital board. The data were saved and analysed following each data collection period.

2.5. *Procedure*

Following a brief orientation, subjects read and signed a consent form. Next, they were allowed to practice lifting the box using the various lifting techniques associated with the study. Anthropometric measurements were subsequently collected and EMG electrodes applied using the standard application procedure, as described in Marras (1990). Electrode impedances were verified as < 1 MΩ. Maximum exertions were performed in six directions: sagittal flexion, left and right lateral flexion, and left and right twist, all at 0° of trunk flexion, and sagittal extension at 20° of trunk flexion. Initial voltages were collected for all electrogoniometers, the LMM and the force plate.

2.6. *Data analysis*

All force plate and EMG-electrode data were used as input for the EMG-assisted model. The raw EMG signals were preamplified, high-pass filtered at 30 Hz, low-pass filtered at 1000 Hz, rectified and integrated using the methods discussed by Marras (1990).

2.7. *Statistical analysis*

The means and SD were computed for each dependent variable. Two analyses of variance (ANOVA) were performed using repeated measures design for Phase I and II. The analysis was completed using the SAS 6.4 program. In the Phase I analysis, all two- and three-way interactions were tested for significance. Since there were four levels for the bin region variable, a post-hoc Tukey test was performed. In the Phase II analysis, all the two-way interactions were tested for significance.

3. Results

3.1. *Phase I: Effects of lifting style and bin design on spinal load*

Table 2 is a summary of statistically significant differences found in the Phase I study. It shows the significant findings for the bin design and lifting style effects as well as the significant two- and three-way interactions. The three-way factors that significantly affected spinal loading indicate the complexity of the interaction between bin design and lifting style. This further suggests that ergonomic recommendations may need to be more complex and specific to certain lifting situations than in previously developed guidelines.

Figure 5 shows the influence of the region of the bin hand and feet on lateral shear. The two-hand, two-feet lifting style always had the lowest lateral shear force regardless of the region, and the one-hand, one-foot technique had the highest lateral shear force. The magnitude of the difference changed as a function of the region. There was a 293 N difference between the two-hand, two-feet lifting style and the one-hand, one-foot style in the upper front region, and a 425 N difference between the same two conditions in the lower front region. These trends of lifting style influencing spinal loading within a region were not significant for anterior–posterior shear or compressive loading. Several two- and three-way interactions are listed in the table 2, but the overwhelming factor that influenced spinal loading was the region of the bin. Table 3 lists the means and SD for each condition of hand, feet, bin height and region of the bin. Post-hoc Tukey test results showed a significant difference in compressive loading for each region of the bin, as indicated by the superscript lettering in table 3. The upper front condition had 44% less spinal compression than the upper back condition. The upper back region produced 26% less compressive load than the bottom front condition. The

Table 2. Summary of ANOVA results, showing *p* for the spinal-loading characteristics in Phase I.

Indendent variables	Lateral shear force	Anterior – posterior shear force	Compression force
Hand	0.0001*	0.9900	0.1900
Feet	0.0004*	0.7800	0.0032*
Bin height	0.3900	0.6000	0.2400
Region of bin	0.0001*	0.0001*	0.0001*
Hand*Feet	0.3600	0.2800	0.0500*
Hand*Bin height	0.0009*	0.1700	0.3160
Hand*Region of bin	0.3800	0.0010	0.0800
Feet*Bin height	0.2400	0.0900	0.0067*
Feet*Region of bin	0.0061*	0.3300	0.0005*
Bin height*Region of bin	0.1000	0.1100	0.0007*
Region of bin*Hand*Feet	0.0050*	0.0400*	0.1300
Bin height*Region of bin*Hand	0.3900	0.5600	0.0099*
Bin height*Region of bin*Feet	0.1600	0.0300*	0.8500
Bin height*Hand*Feet	0.5600	0.2200	0.0600

*Significant difference at $\alpha = 0.05$.

bottom back region had the highest compressive load, which was double the compressive load in the upper front region. The lateral and anterior–posterior shear forces nearly doubled in the lower regions compared with the upper regions. However, the shear forces were not significantly different between the front and back within a height. The spinal loads listed in table 3 would change with a different box weight, but the percentage changes and significant trends should remain the same. The one-handed lifting technique created >100% more lateral shear force than the two-handed lifting, but there was no significant difference for anterior–posterior shear or compression force. Standing on one foot during lifting created 32% more lateral shear force and 8% higher compressive load than standing on two feet.

3.2. *Phase II: Supported lifting study results*

The supported lifting study evaluated the main effects of support, region and feet. Table 4 summarizes the ANOVA results. The effect of support was significant for all the spinal loading measures. The effects of the region of the bin and feet were similar to those listed in table 2. The two-way interactions of support and region of the bin, support and feet, and feet and region of the bin all significantly influenced anterior–posterior shear. Compression was significantly influenced by the interaction of support and region of the bin as well as by the interaction of feet and region of the bin.

The supported lifting style had significantly lower spinal loads than the unsupported lifting style. The percent decrease in spinal loading were 15.7%, 17.4% and 15.9% for lateral shear, anterior–posterior shear and compression, respectively. The interaction of feet and supported lifting style influenced anterior–posterior shear. The no support condition had less anterior–posterior shear when standing on both feet, whereas the supported lifting style had less anterior–posterior shear when standing on one foot. Figures 6 and 7 show the interaction of the region

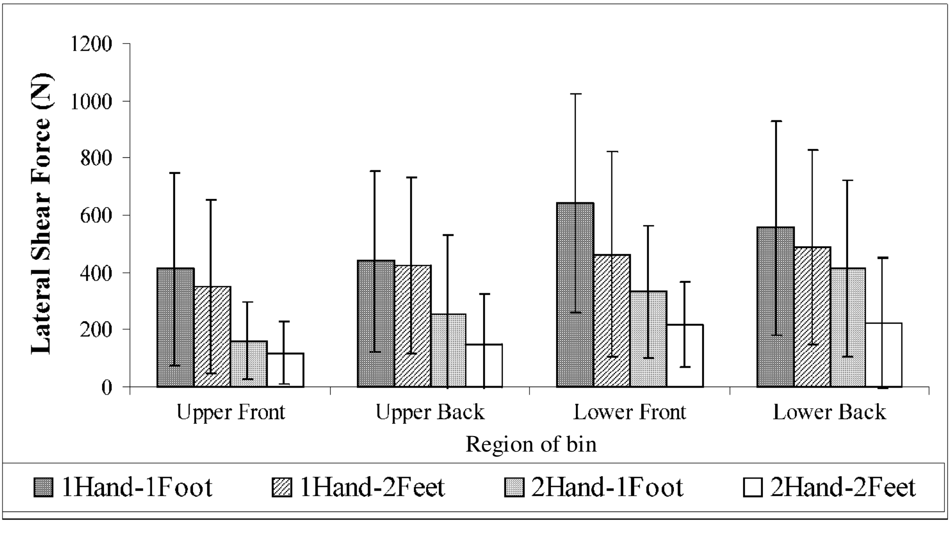

Figure 5. Mean and SD for lateral shear force as a function of the region of bin, number of hands and number of feet.

of the bin and support for compression and anterior–posterior shear, respectively. Both compression and anterior–posterior shear forces had greater reductions due to support in the lower regions of the bin.

4. Discussion

The many significant interactions in the study illustrate the complexity of workplace design and lifting style factors that influence spinal loading. There is an overwhelming influence on spinal loading due to the bin design factor of the region of the bin in which the load is placed. Several researchers have found that box location or region of the lift influences spine loading (Snook *et al.* 1978, Seroussi and Pope 1987, Chaffin and Page 1994, Marras *et al.* 1997, 1999, Davis *et al.* 1998). The present study has shown very similar findings for lifting from industrial bins. Changes in the region factor influence anterior–posterior shear and lateral shear as well as compression. However, the workplace design factor of bin height only influenced spinal loading in combination with the region of the bin or the lifting style factors. The lifting style factor of hands affected only lateral shear and feet influenced both lateral shear and compression. Furthermore, the magnitude of the influence was much greater for the workplace design factor of the region of the bin than for the lifting style factors. Moving from the upper front region to the lower

Table 3. Phase I means (SD) for the spinal-loading characteristics.

Independent variables	Condition	Latereral shear force	Anterior–posterior shear force	Compression force
Hand	one hand	472.2 (350.5)*	1093.3 (854.7)	6033.6 (2981.2)
	two hand	233.8 (216.9)*	1136.9 (964.1)	5742.3 (1712.3)
Feet	one foot	401.7 (335.1)*	1109.4 (856.1)	6138.6 (2957.5)*
	two feet	304.3 (285.1)*	1120.8 (963.3)	5637.3 (2717.9)*
Region of bin	upper front	260.2 (271.7)^a	616.6 (311.1)^a	3765.7 (1452.8)^a
	upper back	317.0 (290.8)^a	738.0 (500.0)^a	5418.1 (2364.2)^b
	lower front	414.4 (335.0)^b	1498.3 (1037.8)^b	6839.8 (2765.4)^c
	lower back	420.4 (329.0)^b	1607.5 (1058.4)^b	7528.2 (2978.4)^d
Bin height	94 cm	361.9 (328)	1089.9 (800.8)	5795.8 (2660.4)
	61 cm	344.1 (301)	1140.3 (1009.1)	5980.2 (3027.4)

*Significant difference at $\alpha = 0.05$.

Region has four experimental conditions, therefore the letters were used to indicate which regions were significantly different from one another at $\alpha = 0.05$.

Table 4. Summary of ANOVA results having *p* for the spinal-loading characteristics in Phase II.

Independent variables	Lateral shear force	Anterior–posterior shear force	Compression force
Support	0.0023*	0.0001*	0.0001*
Region of bin	0.0020*	0.0001*	0.0001*
Feet	0.0090*	0.8700	0.1200
Support*region of bin	0.3600	0.0003*	0.0087*
Support*feet	0.1500	0.0100*	0.2400
Region of bin*feet	0.9200	0.0300*	0.0400*

*Significant difference at $\alpha = 0.05$.

back region of the bin may create up to a 160% increase in anterior–posterior shear, 100% increase in compression and 60% increase in lateral shear, whereas changes in the number of feet create a 32% change in lateral shear and a 9% change in compression. A one-handed lifting style created a 100% increase in lateral shear compared with a two-handed lifting style, but there was no significant change in compression or anterior–posterior shear. This study shows that ergonomic changes to the bin design allowing the worker to lift from the upper front region in all lifts would significantly reduce spinal load more effectively than a specific lifting style. Thus, appropriate ergonomic bin design employing lift tables, bin tilting, and spring loaded bins would reduce risk of low-back injury more effectively than training workers on a specific lifting style.

The results of the study can be compared with Jager *et al.* (1991), who evaluated one moment arm and three work heights and determined that lumbar loading is reduced when lifting originates from >50 cm. In this study, the upper two regions were 50.8 cm above the force plate or from the bottom of the bin. The results of the current study indicate that spinal loading was significantly greater in the bottom two regions compared with the upper two regions. This confirms the results of Jager *et al.* (1991). The results of the current study make it possible to evaluate the effects of trade-offs between moment arm and start height on spinal loading. The compressive load significantly changed in each region with the lowest load in the upper front region, followed by the upper back region, increasing in the lower front region, finally culminating with the highest load in the lower back region. The lateral and anterior–posterior shear forces were significantly greater for the lower regions compared with the upper regions, but shear forces were not significantly different from front to back of the bin (increased moment arm) within one height. In the upper region, the muscle activity occurring is due to the external moment. In the

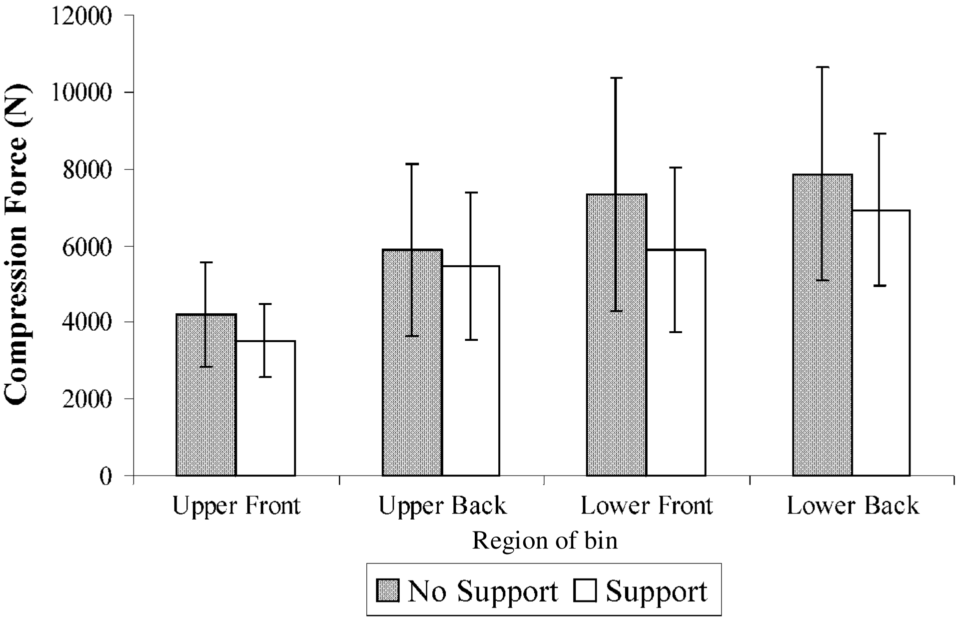

Figure 6. Mean and SD of spinal compression as a function of support and region of bin.

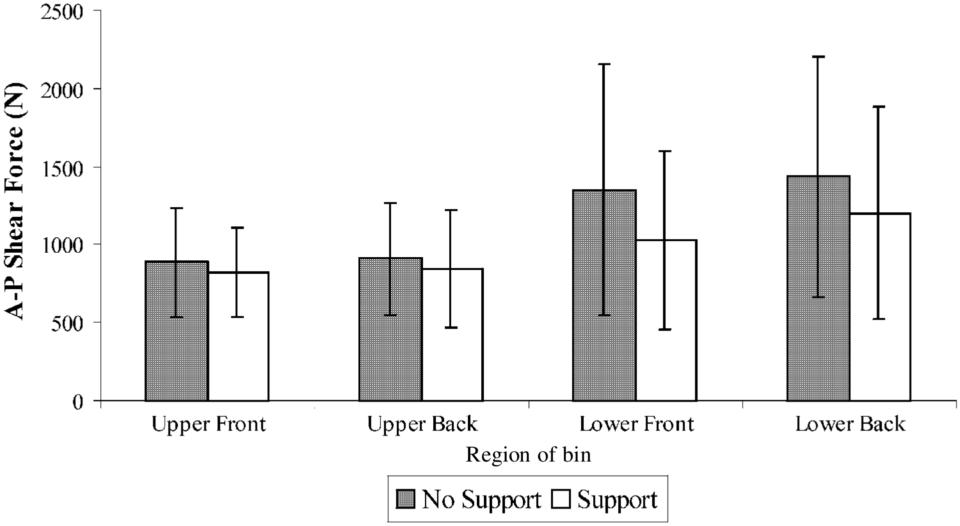

Figure 7. Mean and SD for anterior–posterior shear force as a function of support and region of bin.

lower regions, muscle activity occurs due to both trunk flexion and moment arm, resulting in higher spinal loads in the lower regions compared with the upper regions. From a bin design point of view, this again emphasized the need for ergonomic workplace consideration as discussed above when lifting from bins.

Research has been done to determine the kinematic differences associated with unsupported one-handed lifting. Allread (1993) examined trunk kinematics during one- and two-handed lifting and found significantly more lateral and twisting motion during one- than two-handed lifts but significantly less sagittal motion with one-handed lifts. In addition, the risk of suffering a low-back disorder was assessed to be higher when lifting with only one hand. However, Allread did not investigate spinal loading so that only the trunk kinematic results can be compared with this study. The kinematic measures of this study showed significantly less forward bend but significantly more lateral and twisting motion with one-handed lifts compared with two-handed lifts. Thus, the results of this study are in agreement with the findings of Allread (1993). The spinal loading results indicated that one-handed lifting significantly increases the lateral shear forces on the spine, which might be due to the increase in coupled motion. In a sagittally symmetrical lift, a two-handed lifting style would reduce spinal loading, thereby reducing the risk of injury. This finding is contrary to Marras and Davis (1998) who found that in sagittally symmetric lifts the spinal loads were lower for one- rather than for two-handed lifts. The contradiction in findings between the two studies may be due to changes in kinematics of the lift when lifting from a bin. In this case, participants would have to lift up and over the bin whereas in Marras and Davis (1998) participants had a lift with no obstruction. The differences between these studies indicate the complexity of ergonomic problems. One lifting guideline to serve all workplace situations may inadequately quantify the risk of low-back injury due to spinal loading. Thus, specific guidelines may be needed for lifting from a bin that minimize spinal loading and thereby reduce the risk of low-back injury.

This was the first study to examine a lifting style of standing on one versus two feet. The spinal loading results indicate that standing on one foot more than doubled the lateral shear force on the spine. In addition, the compressive force was significantly increased while standing on one foot. A lifting technique with both feet on the ground should be recommended to reduce spinal loading, thereby reducing the risk of low-back injury. Furthermore, having two feet on the ground would reduce the likelihood of a slip and fall, thereby reducing the risk of a potential traumatic injury. Thus, from both an ergonomic and a safety perspective, two feet should be on the ground when lifting an object from a bin.

In Phase II, support and non-supported lifting styles for one-handed lifts were evaluated. Analysis of the results showed that the influence of support was greater when lifting from the lower regions compared with the upper regions of the bin. In all regions, supported lifting style reduced spinal loads. The Phase I two-handed lifting results can be compared with the Phase II one-handed supported lifting results to determine which techniques may reduce spinal loading. In the lower two regions of the bin, anterior–posterior shear and compression are lower with one-handed supported lifting style, but lateral shear is greater. In the upper front region, the two-handed lifting style has lower lateral shear and anterior–posterior shear, but a higher compressive load than the one-handed supported lifting style. Thus, in the upper front region a two-handed lifting style would reduce spinal loading, whereas in the upper back and two lower regions a one-handed supported lifting style would reduce spinal loading. Based on these findings it may be suggested that bins be designed with handholds on the side of the bin.

This study has shown significant changes in spinal loads due to both workplace design factors and lifting style factors. However, these significant changes do not necessarily indicate an increased risk of injury. To evaluate the risk of injury the spinal loads from this study must be compared with tolerances in the literature. The NIOSH Work Practices Guide for Manual Lifting (NIOSH 1981) suggests that 3400 N of compression is where vertebral end plate microfractures begin and at 6400 N of compression about half of the workers will experience microfractures. McGill (1996) suggests a maximum shear tolerance of 1000 N. When lifting from the bin, in the upper front region 3% of lifts had lateral shear loads that were >1000 N tolerance, 8% of lifts had anterior–posterior shear loads >1000 N tolerance, and 5% of lifts had compressive loads >6400 N tolerance. In the lower back region of the bin, however, 10% of lifts were >1000 N tolerance for lateral shear, 62% of lifts were greater than the anterior–posterior criteria and 58% of lifts were >6400 N compressive load tolerance. Comparing the upper front region to the lower back region, there is nearly a 12-fold increase in the number of lifts exceeding the known tolerance for compressive load and nearly an 8-fold increase in the number of lifts exceeding the known tolerance for anterior–posterior shear. Thus, lifting from the lower back region of a bin would increase the risk of low-back injury compared with lifting from the upper front region.

One- versus two-handed lifting style only significantly influenced the lateral shear loads; therefore, only these loads will be compared with tolerances in the literature. The comparison to tolerance showed little difference between the one- and two-handed lifting style. The worst case was in the lower back region of the bin where 16% of one-handed lifts had lateral shear forces >1000 N tolerance. The two-handed lifting style created shear loads greater than the tolerance in 6% of lifts.

Thus, even though one-handed lifts created significantly greater lateral shear loads than two-handed lifts the number of one-handed lifts over the tolerance was not high even in the worst region.

The Phase II one-handed supported versus non-supported lifts can be similarly compared with tolerances in the literature. Once again, the highest spinal loads were found in the lower back region of the bin and therefore a comparison of spinal loads to tolerance was made in this region. Lateral shear force was >1000 N in 18% of lifts in the non-supported lifts and in 9% of cases in supported lifts. Anterior–posterior shear was >1000 N in 62 and 57% of lifts for non-supported and supported lift, respectively. Compression was >6400 N in 63 and 51% of lifts for non-supported and supported lifts, respectively. Thus, lifting with a supported lifting technique would reduce the number of lifts that create spinal loads greater than known tolerances, thereby reducing the risk of low-back injury.

Several potential limitations of this study should be noted. First, only one bin configuration was used for all lifting conditions. Changing the bin design may cause changes in spinal loading, however, it is believed that, in general, the results apply. Second, the subjects had to maintain the same foot position on the force plate. In a more realistic situation, subjects would be able to move their feet during a lift. Thus, in this manner, the study may not exactly replicate an industrial lifting task where the worker is free to move. Third, leaning against the bin with the legs may be another method of leaning not examined by this study and this may influence spinal loading. Thus, the results of this study apply to workers leaning or supporting their weight with their hand on the side of the bin. Fourth, the subject population was inexperienced with manual material handling tasks. It is hypothesized that a more experienced population would have had reduced spinal loads because specific motor programs would be developed through experience that minimized spinal loading. Thus, the spinal loads reported in this study may represent a worst case situation. Finally, this study took place in a laboratory setting free of psychosocial and extraneous situations that may influence the results.

6. Conclusions

- Workers lifting from the lower regions or upper back region of a bin should be encouraged to use one-handed supported lifting styles to minimize spinal loading.
- While lifting from a bin (in all regions), workers should maintain contact with the floor with both feet to reduce spinal loading.
- Supporting body weight on the side of the bin with one hand reduces spinal loading by at least 15%.
- To minimize spinal loading, lifts should originate from the upper front region within a bin. Thus, bins should be designed so that the load height is maintained throughout the lifts. In addition, bins should rotate to allow the lift origin horizontal distance to be as close to the worker as possible.

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