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Reduction of spinal loading through the use of handles

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A study was performed to investigate how different types of handle coupling affect the loading on the spine. Ten male grocery item selectors performed a laboratory simulation of a warehouse palletizing task. Participants transferred the cases from a pallet in a storage bin to the destination pallet. The trunk motions and muscle activities were monitored by a Lumbar Motion Monitor (LMM) and electromyographic electrodes, respectively, and used as input to an EMG-assisted biomechanical model. The results of the study revealed that the presence of handles reduced the complex loads on the spine. This was particuarly true when lifting to the lowest positions of the pallet, where the highest forces occurred. It was determined that the maximum spinal compression forces were reduced by an average of 6.8% when handles were added to the cases. The presence of handles affected the moments imposed on the trunk in the lower regions on the pallet, indicating a difference in lifting style and/or more sagittal flexion. The results of this study suggest that the multiplier for handle coupling in the 1991 NIOSH Revised Lifting Equation was appropriate for higher lifts (at 133.8 cm), but needs to be more protective for 'poor' coupling conditions with lower vertical heights, which are the most common in industry. Based on these results, it is recommended that handles be designed into the cases that are commonly lifted from low levels in warehousing and other manual materials handling situations.

1. Introduction

Manual Materials Handling (MMH) tasks have been associated with lower back injuries (Snook *et al.* 1978, Bigos *et al.* 1986). One major job that requires a tremendous amount of MMH is that of the item selector in a distribution warehouse. The job of the grocery item selector requires lifting and lowering of various containers ranging from cases to bags. These grocery item selectors transfer 1500 to 2000 cases each day, from pallets located in storage bins throughout the warehouse to a pallet that is generally positioned on the pallet jack located in front of the storage bin. The majority of the cases found in industry have no handles. Drury *et al.* (1982) found that only 2.6% of the cases in industry had handles in the form of cut-outs on the ends of the cases.

The benefit of placing handles on the sides of the cases has yet to be fully evaluated in terms of the risk of injury to the lower back. A wide range of research investigating the effects of handles during lifting has been performed using psychophysical methods that attempt to define safe load limits for lifting or the maximum acceptable weight of lift (MAWL) (Garg and Saxena 1980, Smith and

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Jiang 1984, Snook and Ciriello 1991). These reseachers found the MAWLs to be larger for cases with handles than without handles. Conversely, Morrissey and Liou (1988) found that cases with cut-out handles had lower MAWLs than cases without handles during carrying tasks. The differences in the above studies might have resulted from different tasks being performed. Other researchers have found that participants rate the perceived exertion and body discomfort greater for lifting boxes without handles than for lifting boxes with handles (Drury *et al*. 1989). Thus, psychophysical studies have produced conflicting results on the effects of handles during an MMH task.

Based on the above psychophysical research, NIOSH (1991) developed a revised lifting equation that incorporated the type of handle coupling as a multiplier (Waters *et al*. 1993, 1994). This multiplier had three levels (good, fair and poor), which are based on the effectiveness of the coupling. As with the other multipliers, the handle coupling component changed the recommended weight to be lifted. Although much of the psychophysical research supports the addition of the coupling factor, there has been limited biomechanical evidence to advocate such a multiplier.

Much of the biomechanical research evaluating the different handle couplings has focused on estimating the forces on the hands and the angles of the upper extremities (Coury and Drury 1982, Drury and Deeb 1986). Others have explored the effects of handles through the modelling of spinal loads, under both static and dynamic conditions (Freivalds *et al*. 1984, Kromodihardjo and Mital 1987, Drury *et al*. 1989). These authors found that handles reduced the compression and shear forces placed on L5/S1 during lifting. Yet, these researchers have neglected to consider the coactivity of trunk muscles commonly associated with complex and dynamic motions that would be expected to result in larger spinal loads (Pope *et al*. 1986, McGill 1991, Marras and Mirka 1992, 1993, Granata and Marras 1993, Mirka and Marras 1993, Marras and Granata 1995, 1997a).

The EMG-assisted spinal loading model developed at the Biodynamics Laboratory over the past decade accounts for coactivity of the trunk muscles to acquire more reliable results. This model allowed a more accurate evaluation of the effect of handles on trunk loading. This EMG-assisted model estimates the trunk moments and spinal loads that result during a particular task such as the palletizing of cases. The model has been validated for sagittal bending (Marras and Sommerich 1991a, b, Granata and Marras 1993, 1995a, Mirka and Marras 1993), lateral bending (Marras and Granata 1997a), and axial twisting (Marras and Granata 1995) when using typical trunk motions found in industry.

It has been commonly assumed that the magnitude of the spinal loads is directly associated with low-back disorder (LBD) risk (Nachemson 1975). Many researchers have found spinal load levels that approach spine tolerance limits (3400 N — compression (NIOSH 1981) and 1000 N — shear (McGill 1996)) to be related to higher incidence rates of LBD (Chaffin and Park 1973, Herrin *et al*. 1986). However, recent researchers have found that complex loading of the spine is common during lifting, not just simple compression loading (Shirazi-Adl 1991, Fathallah 1995).

The main objective of this study was to accurately evaluate three-dimensional spine loading as a function of presence of handles on cases commonly found in an industrial palletizing task. Since the authors believe that the position of the load on the pallet is a significant risk factor, a secondary objective was to evaluate handle coupling as a function of the various positions on the pallet.

2. Method

2.1. *Participants*

Ten male participants who worked as item selectors at a local warehouse volunteered to depalletize/palletize the grocery items of interest. None of the participants had a prior history of LBD. The participants' ages ranged from 19 to 49 years, with a work experience range of 0.25 to 23.0 years in a warehouse setting. The participants' mean (SD) weight and height were 80.1 (8.4) kg and 180.3 (2.3) cm, respectively.

2.2. *Experimental design*

The experimental design consisted of a two-way, within-subject design. The independent variables were: case-handle coupling and position on the pallet. In order to account for variability between the participants, participants were used as a random effect, while case weight and size were used as blocking factors. Handle conditions consisted of cardboard cases with cut-out handles and without handles. The cut-out handles were 8.9 cm (3.5 in) wide and 2.5 cm (1 in) high, positioned at the centre of the sides of the cases, 5.1 cm (2 in) below the top of the case. The position and size of the handles were similar to those commonly found on cases in warehouse environments.

Each of the pallets were divided into six regions corresponding to front-top, back-top, front-middle, back-middle, front-bottom, and back-bottom areas. Figure 1 shows a schematic view of these six regions on a standard pallet. The handles of the cases in each of the regions remained at a set level corresponding approximately to: regions A and B at a height of 133.8 cm (52.7 in) from the floor, regions C and D at a height of 95.3 cm (37.5 in) from the floor, and E and F at a height of 47.6 cm (18.75 in) from the floor.

The dependent variables were the spinal loads estimated by the EMG-assisted biomechanical model developed by the Ohio State Biodynamics Laboratory over the past decade (Marras and Reilly 1988, Reilly and Marras 1989, Marras and

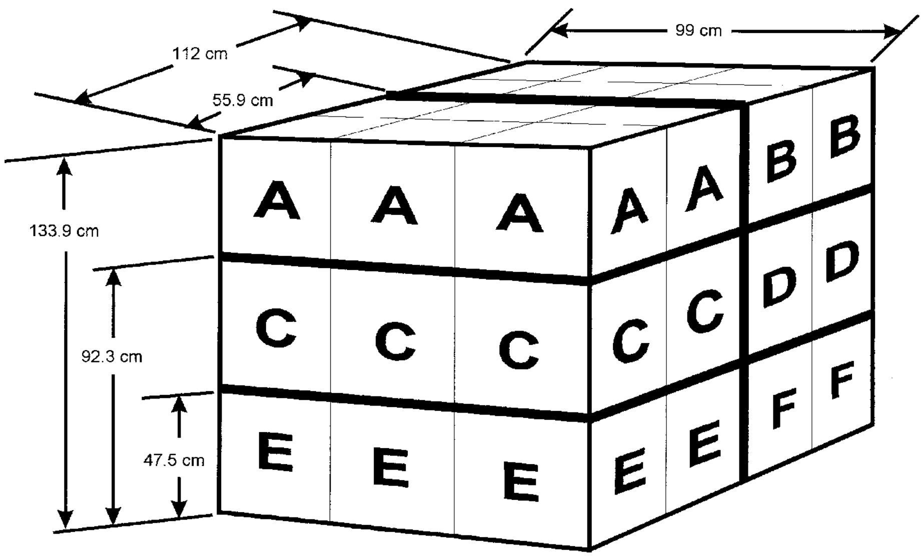

Figure 1. A schematic view of the six regions of the pallet.

Sommerich 1991a, b, Granata and Marras 1993, 1995a, b, Mirka and Marras 1993, Marras and Granata 1995, 1997a). The spinal loads estimated in this study were the maximum values of compression, anterior-posterior shear and lateral shear forces on the lower back at the lumbosacral joint.

2.3. *Task*

In order to simulate a 'realistic' warehousing depalletizing/palletizing task, participants transferred cases from one pallet in a slot to a destination pallet on a pallet jack. The depalletizing task started when the subject grasped the case and ended when he crossed an imaginary line that coincided with the point at which the subject was upright and facing the 'palletizing' pallet. Conversely, the palletizing task started where the depalletizing task stopped and continued until the subject released the case on the pallet. Data were analysed for only the interval of time that the subject was performing the 'palletizing' task. Marras *et al.* (1997) have analysed and reported on the spinal loads that occurred during the 'depalletizing' portion of the job. An overhead view of the arrangement is shown in figure 2. The travel distance between the two pallets was approximately 3 m. The lifting cycle was one case lifted every 10 s (360 per hour) which was signalled by a computer-generated tone.

The cases for each of the combinations of independent variables were stacked on a standard pallet generally found in a warehouse. The pallet was constructed of wood with a width of 101.5 cm and a depth of 112 cm. Both the size and weight of the cases were used as blocking variables. Two sizes of cases were used in this study — a 'small' case with dimensions of 20.3 cm by 40.6 cm by 30.5 cm (H × W × D) and a 'large' case with dimensions of 27.5 cm by 49.5 cm by 30.5 cm (H × W × D) which corresponded to volumes of 0.026 m^3 and 0.044 m^3, respectively.

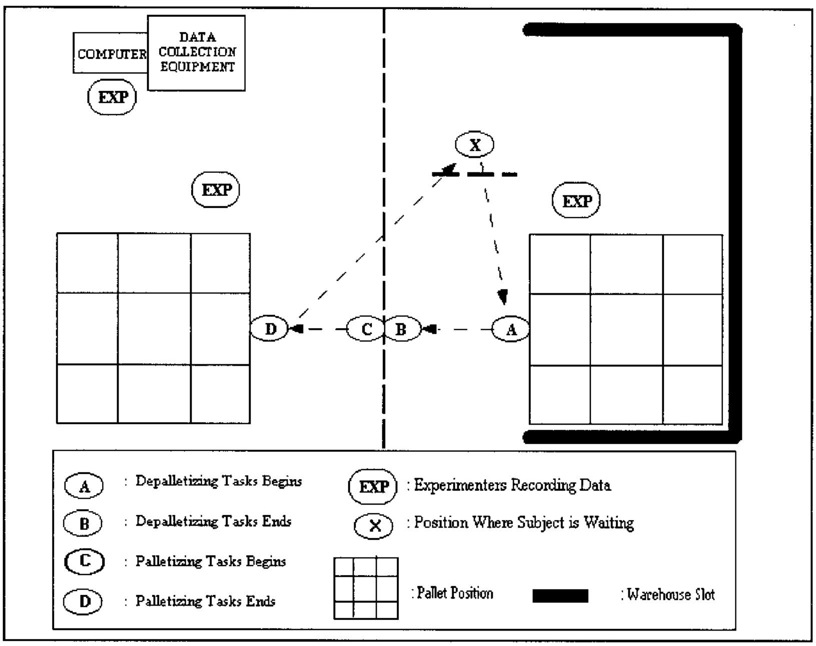

Figure 2. A schematic overhead view of the experimental layout.

The weights of the cases in this study were 18.2, 22.7 and 27.3 kg. These weights were at the upper percentiles of typical case weights in a common warehouse setting.

2.4. *Apparatus*

The Lumbar Motion Monitor (LMM) was used to collect the trunk motion variables. The LMM is essentially an exoskeleton of the spine in the form of a triaxial electrogoniometer that measures instantaneous three-dimensional position, velocity, and acceleration of the trunk (Marras *et al.* 1992).

Electromyographic (EMG) activity was monitored through the use of bi-polar electrodes spaced approximately 3 cm apart at the ten major trunk muscle sites. The ten muscles of interest were: right and left erector spinae; right and left latissimus dorsi; right and left internal obliques; right and left external obliques; and right and left rectus abdominus (Mirka and Marras 1993).

A force plate (Bertec 4060A, Worthington, OH) and a set of electrogoniometers measured the external loads and moments placed on L_5/S_1 during calibration lifts performed by the participants. The electrogoniometers measured the relative position of L_5/S_1 with respect to the centre of the force plate, along with the participant's pelvic angle. The forces and moments were translated and rotated from the centre of the force plate to L_5/S_1 (Fathallah *et al.* 1997).

All signals from the above equipment were collected simultaneously through a customized Windows™-based software developed in the Biodynamics Laboratory. The signals were collected at 100 Hz and recorded on a 486 portable computer via an analogue-to-digital board. The data were saved by the computer for subsequent analysis.

2.5. *Procedure*

Following a brief orientation about the study, participants completed a consent form and anthropometric measurements were collected. The EMG electrodes were applied to the ten trunk muscle locations and maximum exertions were performed in six directions: sagittal extension with the trunk at a 20° forward flexion angle; sagittal flexion at 0° flexion; right lateral flexion at 0° flexion; left lateral flexion at 0° flexion; right twist at 0° flexion; and left twist at 0° flexion. The impedance at each electrode site was kept below 1 MΩ.

Before handling each pallet of cases, the subject completed a set of calibration lifts. During the calibration exertions, the subject lifted a 22.7 kg box from a sagittally symmetric position at a low, smooth pace (controlled by the subject). The lift started at the subject's knee height and ended in an upright position. Initial voltage values for the electrogoniometers, LMM and force plate were collected. Figure 3 shows a subject lifting the box during a calibration exertion. Data collected from these lifts were used to calibrate the EMG-assisted model's performance and determine the individual subject parameters, i.e. estimated muscle force per unit area. The EMG-assisted model employed the calibration results to estimate the spinal loads during the palletizing portion of the task.

2.6. *Data analysis*

The kinematic, kinetic, and electromyographic data were used as inputs in the EMG-assisted spinal load model. The kinematic variables were measured and recorded by the LMM and electrogoniometers. Customized software converted the voltages into the respective angles, velocities, and accelerations of the trunk. The raw EMG

Figure 3. A participant performing a calibration exertion.

signals were pre-amplified, high-pass filtered at 30 Hz, low pass filtered at 1000 Hz, rectified, and integrated via a 20 ms sliding window hardware filter.

For all of the dependent variables, descriptive statistics were computed. These statistics were means and standard deviations. Univariate descriptive statistics were performed on all dependent variables to identify any outliers, which were then excluded. Univariate Analysis of Variance (ANOVA) statistical analyses were then performed on all the dependent variables. Based on the ANOVA analyses, Tukey multiple pairwise comparison *post-hoc* analyses were performed to determine significant differences among the different levels of any significant independent variables.

3. Results

Several significant findings were identified and are summarized in table 1. Handle coupling (H) and pallet region (R) were found to significantly influence both anterior-posterior shear as well as compression forces. The interaction between handle coupling and pallet region (H $\times$R) was found to be significant for lateral shear and compression forces.

Figure 4 shows the spinal loads in all three planes that resulted for cases with and without handles. The cases with handles resulted in lower anterior-posterior (A-P) shear and compression forces than cases without handles. On average, the use of handles reduced A-P shear and compression by 50 N and 270 N, respectively.

Subsequent analyses were performed to investigate the difference between the handle couplings for the trunk moments and muscle activities. First, handle coupling was found not to influence the trunk moments (sagittal, lateral, and twist). Thus, it appears that the presence of handles did not significantly alter the overall lifting technique of the item selectors. Second, muscle activities of the antagonistic muscles

Table 1. Results of the univariate analysis of variance for the maximum spinal loads.

		ANOVA					
		Lateral shear forces		Anterior-posterior shear forces		Compression forces	
Effects	df	*F*-value	*p*-value	*F*-value	*p*-value	*F*-value	*p*-value
Handle (H)	1	3.82	0.08	**8.76**	**0.02**	**7.21**	**0.03**
Pallet region (R)	5	2.27	0.06	**8.99**	**0.0001**	**32.04**	**0.0001**
H × R	5	**2.77**	**0.03**	2.06	0.09	**10.79**	**0.0001**

Bold indicates significant effect at $p \leqslant 0.05$.

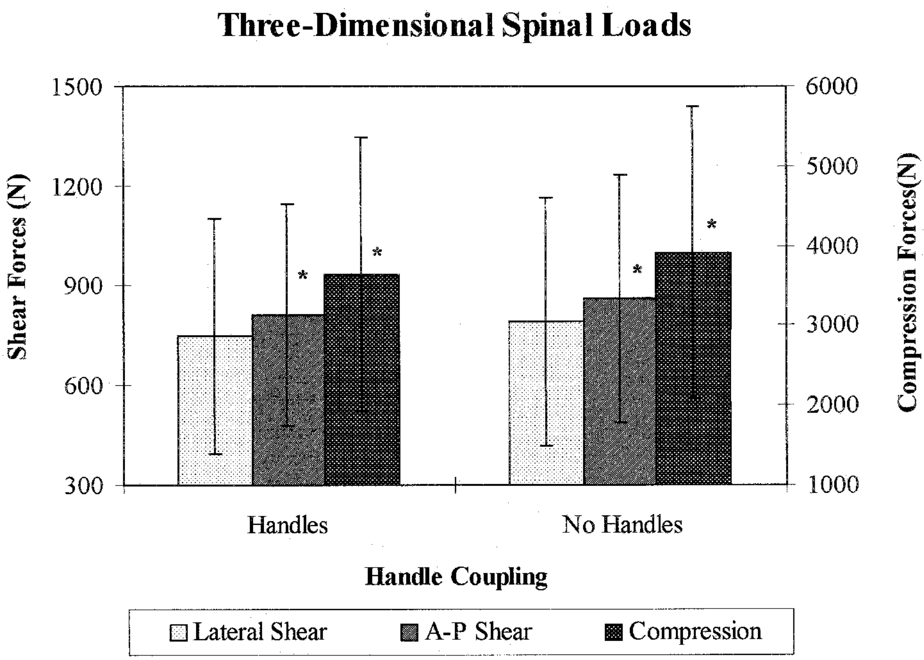

Figure 4. Maximum spinal loading as a function of handle condition (* indicates a significant difference between the handle couplings).

were greater when lifting the cases without handles. The results of the ANOVA indicate that there was a significant difference between the two handle conditions for the left erector spinae, right and left rectus abdominus, right external oblique, and right and left internal oblique muscles (table 2). Figure 5 shows the levels of muscle activity for the ten major trunk muscles. The rectus abdominus muscles were found to have higher levels of muscle activity for the no-handle cases than for the cases with handles. Hence, this increase in antagonistic activity, even though the left erector spinae muscle had higher activity, would help to explain the increase in the spinal loads found for the cases without handles.

The effects of pallet position on the spinal loads during the palletizing task were consistent with results found during the depalletizing portion of the task (Marras *et al.* 1997). In general, the lower regions of the pallet were found to be associated with higher spinal loads and trunk moments. The influence of handles on the spinal

Table 2. Results of the univariate analysis of variance of the maximum muscle activities for the ten trunk muscles.

Effects	df		ANOVA RLAT	LLAT	RES	LES	RABS	LABS	REO	LEO	RIO	LIO
Handle (H)	1	F-value	0.01	0.49	0.07	**18.81**	**6.57**	**15.94**	**5.78**	0.67	**6.91**	**8.83**
		p-value	0.92	0.50	0.79	**0.002**	**0.003**	**0.003**	**0.04**	0.43	**0.02**	**0.03**
Pallet region (R)	5	F-value	**7.54**	**4.30**	**33.41**	**80.73**	**10.86**	**3.10**	**18.65**	**4.53**	**22.90**	**30.01**
		p-value	**0.0001**	**0.003**	**0.0001**	**0.0001**	**0.0001**	**0.02**	**0.0001**	**0.002**	**0.0001**	**0.0001**
Handle by region	5	F-value	0.65	**6.31**	1.70	0.41	0.47	1.04	**6.81**	**3.97**	0.86	1.55
		p-value	0.66	**0.0002**	0.15	0.84	0.80	0.41	**0.0001**	**0.005**	0.19	0.51

Bold indicates significant effect at $p \leqslant 0.05$.

RLAT: right latissimus dorsus; LLAT: left latissimus dorsus; RES: right erector spinae; LES: left erector spinae; RABS: right rectus abdominus; LABS: left rectus abdominus; REO: right external oblique; LEO: left external oblique; RIO: right internal olibique; LIO: left internal olibique.

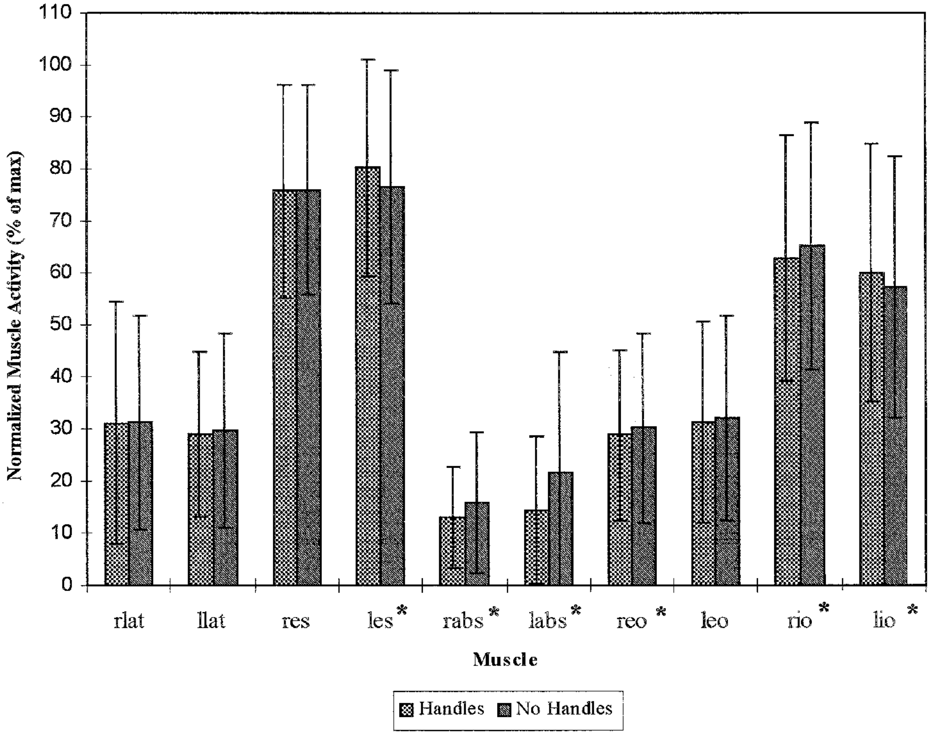

Figure 5. Maximum muscle activity for the ten major trunk muscles (* indicates a significant difference beween the handle couplings).

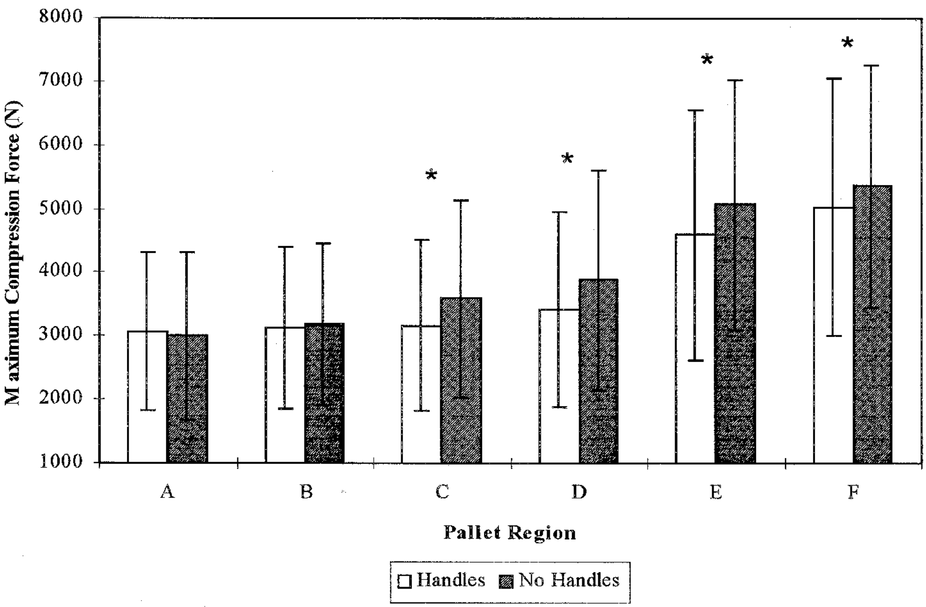

Figure 6. Maximum compression force as a function of handle coupling and pallet region (* indicates a significant difference between the hand couplings).

loading depended upon the destination position on the pallet, as indicated by the significant interactions between handle coupling and pallet region ($H \times R$). All the significant $H \times R$ interactions that resulted were divergent in that there was no difference between the handle conditions in the top regions (A and B), however, there was a large difference between the types of coupling for the lower regions of the pallet.

In the middle and bottom layers (regions C, D, E and F), the cases with handles produced significantly lower lateral shear and compression forces than cases without handles. Figure 6 represents the typical trend found for the interaction between handles and pallet region for the spinal loads. Similar results were found for the moments imposed on the trunk (sagittal, lateral and twisting). The difference between the handle conditions in trunk moments for the lower pallet regions would indicate that the presence of handles altered the way in which participants performed the lift, which corresponded to changes in muscle activity. Cases with handles were found to have significantly lower sagittal bending in these lower regions, which would further suggest a different lifting style. The location of the handles allowed the participants to remain more upright when positioning the cases on the pallet. For cases without handles, the hands were positioned, most of the time, diagonally at the upper and lower corners of the case. This hand positioning would require the participants to bend forward more with cases without handles than when handles were present.

4. Discussion

The presence of handles on the cases decreased anterior-posterior shear and compression forces for the entire pallet. The reduction of compression forces for the cases with handles was mainly found in the bottom layers of the pallet. Although the benefit of handles was limited in the lateral shear plane, handles reduced the lateral shear forces in the lower regions. Having handles on the cases decreased the complex loading of multi-dimensional forces, especially in the lower regions.

The reduction of spinal loads through the use of handles was contrary to Freivalds *et al.* (1984) who found that the peak compression forces were lower for cases without handles than with handles. Their model used rigid links to estimate the forces on the L_5/S_1 and used a single equivalent extensor muscle. This model neglected the forces from antagonistic muscles such as the external obliques and rectus abdominus muscles. In the present study, the higher coactivity for the no-handle condition was found to contribute to the higher loads on the spine. Additionally, in the study by Freivalds *et al.* (1984), the lifts were performed from the same position (sagittally symmetric from the floor) that would eliminate the complex loading observed in the present study. Conversely, Kromodihardjo and Mital (1987) found that no handles increased the compression and shear loads on the spine. The tasks performed in their study were from the floor with both symmetrical and asymmetrical starting positions. These authors investigated several case characteristics but did not evaluate the interactions between the characteristics. In addition, the Kromodihardjo and Mital model used optimization techniques that contained several muscles. Hence, the differences of the other two studies are probably a result of different model assumptions.

The reduction in spinal loading due to handles might be explained by a combination of several factors such as the kinematic variables, muscle coactivity, and increased vertical height resulting from different hand positions. The muscle activity of the antagonistic muscles (rectus abdominus) were found to be significantly higher for the cases without handles. Also, the maximum sagittal flexion for the cases without handles was found to be significantly larger than for the cases with handles (about 2° on average). A larger maximum sagittal flexion corresponds to higher external moment; however, the magnitude of the difference between coupling conditions was not reflected in the predicted trunk moment for the entire pallet. The difference between handle conditions for trunk moments was mainly in the lower regions of the pallet. The maximum sagittal velocity was also higher for the no-handle cases (on average 3°). Other researchers have found that higher velocities result in higher coactivity, and ultimately, higher spinal loads (Marras and Mirka 1992).

The type of handle coupling influenced the maximum trunk moments in all three dimensions in the lower regions of the pallet. Thus, the cases could have been lifted differently under the two types of handle coupling. These results agree with Mirka *et al.* (1994) who found that the peak sagittal external torque was greater for the cases with handles than without handles for a case weight of 22.5 kg. These tasks were performed under sagittally symmetric conditions limiting the trunk moments to the sagittal plane. In the present study, the participants performed exertions under completely free-dynamic conditions, thus allowing a more realistic motion. These motions would impose moments on the trunk in all three planes.

The reduction of the spinal loading when handles are present on the cases would further support the addition of a handle coupling factor in the NIOSH (1991) Lifting Equation (Waters *et al.* 1993). The present types of coupling represented a 'good' and a 'poor' hand-case coupling. These results revealed that the maximum spinal compression was reduced by 6.8% when handles were added to the cases. When compared to increases in case weight, the benefit of handles (in terms of reduction in compression) was equivalent to reducing the case weight by 2.2 kg. The difference in handle conditions in the lower regions of the pallet was more substantial, equivalent to a 3.5 kg weight reduction. For the NIOSH lifting equation, the decrease in the recommended weight limit (RWL) resulting from the 'poor' handle coupling multiplier was 2.3 kg. Hence, it appears that the lifting equation adequately represents the physical demands associated with lifting at a vertical height of 133.8 cm (52.7 in). However, the NIOSH multiplier of 0.90 would be too 'liberal' for the cases with destination heights lower than 133.8 cm. According to the results of this study, the appropriate multiplier for this region would actually be 0.85.

When the difference between the handle conditions was compared to increases in case weight, the reduction of anterior-posterior shear forces when handles were present was equivalent to a reduction of 1.8 kg of case weight. A larger case weight equivalent (4.5 kg of case weight) for the lateral shear forces was found in the lower regions of the pallet. Again, this would indicate that the handle coupling multiplier could actually be more protective for the 'poor' coupling condition below 76.2 cm (30 in).

Several potential limitations of the study must be considered. First, each subject performed the entire study during a full-day session (all 12 pallets). This repetition could have caused fatigue as the day progressed. However, the experimental design was randomized to control for fatigue. Other reseachers have documented changes in trunk motions and spine loading due to fatigue (Marras and Granata 1997b). Second, some of the results could have been affected by controlling the movement of the cases. For the actual tasks themselves, the participants had to place the cases in an exact pattern on each row. However, this pattern was constant for all pallets and participants. The control of the palletizing pattern was necessary to ensure that all participants performed the palletizing task in the same way. Third, the movement was further restricted by the cables connecting the EMG electrodes and LMM to the data collection system. These cables required all the participants to turn to the right when transferring cases from the 'depalletizing' pallet to the 'palletizing' pallet. Again, this movement was constant for all participants and conditions. However, this movement would be expected to minimally influence the lifting motions.

The present study investigated only two types of handle couplings (cut-out handles and no handles). Other types of handles would result in different loads placed on the spine, i.e. a better designed handle could result in an even larger benefit. The effects of other types of handles and positions of the handles on the cases should be investigated in the future.

The present study was a laboratory simulation of the palletizing task commonly found in grocery warehouses. When applying these results to the actual warehouse settings, it must be remembered that the warehouse environment requires a variety of other tasks as well as MMH activities that may contribute to the total spinal loading.

5. Conclusion

The presence of handles has been shown to minimize many of the common risk factors associated with LBD. The results of this analysis indicated that cases with handles significantly reduced spinal loading. The importance of handles became particularly relevant for the lower regions of the pallet where the individuals seemed to change the nature of the lift under the no-handle conditions. Based on the results of the study, it can be concluded that handles should be incorporated into the cases that are commonly used in MMH tasks.

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