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Ergonomic Assessment of Floor-based and Overhead Lifts

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Abstract

Manual full-body vertical lifts of patients have high risk for developing musculoskeletal disorders. Two primary types of battery-powered lift assist devices are available for these tasks: floor-based and overhead-mounted devices. Studies suggest that the operation of floor-based devices may require excessive pushing and pulling forces and that overhead-mounted devices are safer and require lower operating forces. This study evaluated required operating hand forces and resulting biomechanical spinal loading for overhead-mounted lifts versus floor-based lifts across various floor surfaces and patient weight conditions. We did not examine differences in how operators performed the tasks, but rather focused on differences in required operating forces and estimated biomechanical loads across various exposure conditions for a typical operator. Findings show that the floor-based lifts exceeded recommended exposure limits for pushing and pulling for many of the floor/weight conditions and that the overhead-mounted lifts did not. As expected, forces and spinal loads were greater for nonlinoleum floor surfaces compared with linoleum floors. Based on these findings, it is suggested that overhead-mounted devices be used whenever possible, particularly in instances where carpeted floors would be encountered.

Keywords

floor-based lifts; overhead lifts; operating hand forces

Introduction

The health services sector is one of the largest employers in the United States, and it continues to grow. Annual incidence reporting data shows that healthcare workers have high rates of overexertion injuries that involve the back, shoulders, and neck. These injuries are frequently grouped as musculoskeletal disorders (MSDs) and are strongly related to job tasks requiring forceful exertions, repetitive exertions, and awkward postures.[1] Women are often at the highest risk for job-related back pain because of their large numbers employed in the nursing and personal care facilities.[2]

Musculoskeletal system diseases (including connective diseases and tendonitis) rank third in total costs at $1954 billion for all types of occupational injuries and illnesses based on workers' compensation records, estimates of lost wages, and jury awards.[3] Patient lifts and transfers are among the most frequently cited causes of back injury among healthcare professionals. The financial costs associated with the injuries, coupled with loss of productivity and high employee turnover rates, create formidable cost problems within the healthcare industry today. Within the health services sector, injury and illness costs were

$900 million for registered nurses, $40 million for licensed practical nurses, and $2.2 billion for aides and orderlies.[4] Injuries to the back, shoulder, knee, wrist, and neck were the most costly. Unfortunately, these figures are based on 1993 data published in government data sets; present day costs are presumably much higher.

The use of mechanical lifting devices for patient handling in Canada, Europe, and the United States to alleviate and prevent lift- and transfer-related MSDs is becoming more common. Several issues, however, have led to resistance in adopting the technology, including (1) purchase and installation costs; (2) time involved in using the devices; (3) acceptability of the devices for use by facilities and personnel; and (4) uncertainty of whether or not the devices actually reduce the mechanical forces involved in lifting and patient transfers to acceptable levels. Additionally, an important issue concerns what types of mechanical lifting devices are most appropriate for patient transfers and in what environments the type of lift is most appropriate.

In the past decade, studies have evaluated the advantages and disadvantages of mechanical lifting assist devices (MLADs). Yassi et al[5] conducted a 3-year intervention study using 9 hospital wards organized into 3 service area types to compare lifting practices, lifting techniques, and lifting devices. Patient handling tasks were compared between wards operating under “Usual Practice” (ie, the control ward) and wards implementing 2 types of service area interventions: (1) “Safe-Lifting” (where a sit-stand lift was used); and (2) “No Strenuous Lifts” (where a transfer lift was used and manual patient handling was eliminated). The intervention wards received extensive training in back care, patient assessment, and handling techniques, whereas the “Usual Practice” wards’ staff only received training by request. Interviews with hospital staff (346 nurses and unit assistants) were conducted at baseline, 6 months, and 1 year to determine the number and type of patient lifts completed, type of lift, intensity of physical discomfort, work fatigue, and other symptoms. The “No Strenuous Lifting” intervention effectively reduced the frequency of manual patient handling tasks. Both interventions also reduced workers’ perceived work fatigue, back and shoulder pain, and physical discomfort symptoms. Musculoskeletal injury rates, however, were not significantly changed in the intervention wards.

In a study to assess the effectiveness of overhead lift devices in extended care facilities, Engst et al[6] reported that ceiling lifts compared to manual lifting were a preferred and effective method for lifting and transferring residents but not effective in reducing the risk of injury or compensation costs for repositioning tasks. The use of ceiling lifts was also associated with perceived reductions in risk of injury and discomfort.

In similar study, Miller et al[7] reported on risk of injury in a newly designed, long-term care facility equipped with ceiling lifts for each bed compared to a long-term care facility without ceiling lifts. Each facility had floor lifts, but the newly designed unit also had portable ceiling lifts. The Engst et al and Miller et al studies used similar questionnaires and prestudy and poststudy designs. Miller et al and Engst et al both found significantly less perceived risk of injury with ceiling lifts compared with floor lifts. Additionally, 75% of staff preferred ceiling lifts over the other available transfer methods. Injury rates were not significantly different between the 2 facilities, but there was a 70% decrease in compensation costs in the intervention facility compared to an increase in the comparison facility.[6,7]

Alamgir et al[8] evaluated the effects of ceiling and floor lifts on transfer time, patient comfort, and staff perceptions on barriers to using patient transfer devices. Three long-term care facilities were selected based on their ceiling/lift floor coverage rates (facility one, 100% lift coverage; facility two, 33% lift coverage; and facility three, no lift coverage). Results from a survey of 143 volunteers across the 3 facilities indicated that the time required for bed-to-chair transfers was shorter for ceiling lifts than floor lifts. Ceiling lifts were also found to be more comfortable for the patients. For both transfer and repositioning tasks, staff preferred ceiling lifts, which they perceived as less physically demanding.

Several research studies have used biomechanical evaluations of various assistive lifting devices (eg, basket-sling and overhead) to measure the loads and forces involved in patient handling activities. Zhuang et al[9] conducted a biomechanical evaluation of 9 battery-powered lifts, a sliding board, and a walking belt to a manual method for transferring nursing home patients from a bed to a chair. Results showed that average back compressive forces during the activities of patient lifting, rolling, and rotating when using a floor-based basket-sling lifts or an overhead lift were less than those forces using manual lifting methods and under the National Institute for Occupational Safety and Health (NIOSH) recommended disc compression force (DCF) criterion limit (3400 N). Use of manual methods produced forces that frequently exceeded the NIOSH DCF criterion. Approximately two-thirds of the physical exposure forces were removed by using the basket-sling and overhead lifts.

In a biomechanical analysis of spinal loads during simulated patient-handling activities, Daynard et al[10] reported somewhat conflicting results suggesting that while the use of assistive devices (eg, mechanical lifts) reduced peak spinal loads below the NIOSH recommended criterion limits, the variation in techniques used and the increased time involved using mechanical devices resulted in increases in cumulative spinal loading.

Keir and MacDonell[11] evaluated muscle activity patterns in manual and lift-assisted patient transfers of experienced and inexperienced patient handlers. Surface EMG was used to record muscle activity when bed-to-wheelchair and wheel-chair-to-bed patient handling tasks were performed. Very little differences were noted in EMG measurements in the 2 transfer tasks, but muscle activity was lowest using the ceiling lift, increasing with use of the floor lift and highest for the manual lift. Similar to the Daynard et al[10] findings, cumulative lumbar compression was lowest for the manual lifts because of the shorter transfer times.

Santaguida et al[12] measured the cumulative spinal loading patterns in a bed-to-chair transfer task with 5 mechanical lifting devices (MLD). The devices included overhead and floor types. Use of the overhead lifts resulted in lower cumulative spinal loads than the floor devices during the transport phases in the bed-to-wheelchair transfer task. The nurse volunteers also rated the overhead devices as the most preferred.

Two recent articles have focused more on the biomechanical differences between ceiling-based patient transfer devices and floor-based devices. Marras et al[13] investigated the forces on the lumbar spine in 10 volunteers performing various patient handling tasks using both a ceiling-based system and a floor-based system. The experimental situation also evaluated floor conditions (hard surface vs. carpet), wheel configuration in the floor-based systems and patient weights (using 125, 160, and 360 lb mannequins). Results showed that the ceiling-based system produced significantly lower spine loads for the patient handling activities investigated compared with the floor-based system. Both ceiling-based and floor-based systems provided significant benefits over the 1 or 2 caregiver manual techniques, but the floor-based systems resulted in shear forces of sufficient magnitude that they could lead to possible disc damage and increased risk of back disorders. While patient weight had a nominal effect on spinal loads with the ceiling-based system, there were significant effects with the floor-based system, especially during the controlled turns in a restricted space (ie, simulated bathroom). Also, with floor-based systems, floor surface type and wheel type had a significant effect on low back spinal loading.

In a similar study, Rice et al[14] evaluated differences in hand forces between ceiling-based and floor-based models in patient transfer activities. Two floor-based systems and one overhead system were evaluated on pushing, pulling, and rotating a patient while in the devices. Floor type was constant with vinyl tile over concrete. Results showed that the hand forces required for the floor-based lifts were approximately 10 times more than the force required by an overhead-mounted lift. Based on a comparison between the measured hand forces and Liberty Mutual psychophysical tables of acceptable forces,[15] all of the tasks examined were within acceptable psychophysical recommendations for initial push or pull forces for 90% of the female population. The authors suggested that rough surfaces and carpeting, however, could present problems that might exceed acceptable psychophysical pushing and pulling limits for many healthcare personnel.

The purpose of the current study was to expand upon the findings of Rice et al[14] by examining the effects of additional weight categories across 3 different floor types (linoleum, indoor/outdoor carpet, and pile carpet). In lieu of volunteers, sandbags were used to simulate patients of varying weight. A single subject design was chosen for this study similar to the designs used in the Lloyd et al[16] and Rice et al[14] studies. Single subject study designs allow simple comparisons between equipment being tested without risk of introducing between subjects variability. While they provide an estimate of within-subject variability, they do not provide an estimate of between subjects variability, which may limit interpretations to the general population of patient handlers.

Materials and Methods

Participants

A single female operator (height: 160.02 cm; weight: 115.7 kg) performed all the simulated patient handling tasks for this study (See Figures 1-5). Four patient weights were simulated using combinations of sandbags weighing 25 (11.34 kg) and 50 (22.67 kg) lb. The 4 patient weights simulated included the following categories: 125 lb (56.70 kg); 175 lb (79.38 kg); 225 lb (102.06 kg); and 350 lb (158.76 kg). These weight categories correspond to approximate values for 5th percentile female weight, 50th percentile for a 50/50 male/female mix, 95th percentile male weight, and a weight representative of an obese population, respectively.[17]

Apparatus

Two powered overhead-mounted devices and 2 powered floor-based devices were used in the study. The overhead-mounted devices were the following models: (1) Liko® Freestanding Overhead lift using the Multirall 200 and Universal Slingbar 450; and (2) Surehands®-2000 Series Overhead Lift. The floor-based lifts were the following models: (1) Liko® Viking M with the Viking Armrest and Universal 450 Slingbar; and, (2) Surehands® 5002 Mobile Lift System with the Standard spreader bar. The Liko® Original Highback Sling XL was used for evaluation of all lifting devices.

Three floor conditions were tested in the study. These included the following conditions: (1) linoleum floor tile mounted on plywood; (2) indoor/outdoor carpet with standard backing, total thickness 0.36 in (9.14 mm), mounted on plywood; and (3) pile carpet over self-adhesive foam carpet pad, 7/16 in (1.1 cm) thick, mounted on plywood.

Horizontal push/pull forces at the hands were measured with 2 uniaxial tension/compression load cells mounted between each of the 2 handles on each transfer device. The load cells were Transducer Techniques (Temecula, CA) model MLP-150 (150 lb capacity). The load cells were oriented in line with the axis of the forearm (eg, in the sagittal plane), except for the rotate trials on the floor models where the handles were mounted 90-degrees from the sagittal plane. The forces recorded were either a push with both hands, a pull with both hands, a rotation consisting of a push with one hand and pull with the other (rotate condition with overhead devices), or a rotation using lateral forces in the same direction (eg, rotate task with floor devices). Push forces were recorded as positive values and pull forces were recorded as negative values. For the rotate conditions, the absolute value of the two hand forces were added together to obtain an overall force value. Analog voltage outputs of the load cells were sampled digitally with a 12-bit PCMCIA analog/digital card (ComputerBoard, Inc.; Norton, MA). Data acquisition software was developed in LabVIEW (National Instruments, Austin, TX) and included a presession calibration of the load cells. The load cells were calibrated in pounds by hanging known calibration weights from the handle and measurement trial data were recorded as pounds force (lbf). Data were sampled at 100 Hz and low pass filtered (5 Hz cut off) prior to calculation of hand push/pull/rotate force sum mary measures.

Procedure

The test procedure had 8 treatment combinations (four devices and four floor types), four weights, and three handling tasks (push, pull, rotate). The overhead devices were only tested on the hard surface (linoleum) floor type. Due to space restrictions, the similar models (floor-based or overhead-based) of the 2 lifting device brands were tested on the same floor type as a pair on successive trials. Each device was tested in 12 experimental conditions; 3 patient handling tasks (push, pull, rotate), and 4 weight levels, with 3 replications, yielding a total of 36 data collection trials for each device. Except for the floor model rotation trials, the trial order was randomized (handling task and weight). The floor model rotation trials were tested separately because the load cells had to be repositioned (rotated 90-degrees from the sagittal plane into the frontal plane) to be in line with the operator's laterally applied force. In these rotation trials, trial order followed an ascending/descending by weight scheme for the 3 replications.

Prior to each experimental condition, the proper numbers of sandbags were placed in the patient sling and the device was positioned for zero offsets. The positioning of the load cells was 41.5 in (105.4 cm) above the floor surface for all devices. The wheels (floor models), in each trial, were aligned in the direction of motion (ie, direction of applied force); thus, for the push and pull trials, the wheels were in line with the operator's sagittal plane, and for the floor-based device rotate trials, the wheels were in line with the operator's frontal plane. The operator placed her hands on the handles of the device to begin the trial. Each trial required the operator to start from a stationary position and move the device 2 feet for the push and pull tasks and one-quarter turn for the ceiling-mounted model rotation trials and one-eighth turn for the floor models. Trials lasted 5 seconds. Based on our experience, it is likely that peak forces occur at the point when the device first begins to move, so longer movements or larger rotations might result in higher peak forces, but this was not evaluated in the present study. Each rotation trial was performed in a clockwise direction. At the end of first trial, the device was repositioned and the data collection procedure repeated 2 more times, for 3 replications at each experimental condition. Testing took place over a 2-month period. Figures 1-5 show examples of a trial for various devices and tasks.

Simulation Procedures

All trials were videotaped for simulation of posture and entry of postural parameters into the University of Michigan 3D Static Strength Prediction Program (3DSSPP). Forty-eight recordings, representative of one trial of each device, weight, and task direction were reviewed to locate the time frame when the lift operator began moving the lift device, which would isolate the body posture when hand forces and exertion were assumed to be at maximal levels. The human simulation approach for obtaining body postures described by Waters et al[18] and Lu et al[19] was used with the measured hand force data to estimate the spinal forces using the 3DSSPP model (version 6.0.4). The corresponding analyses produced several outcome measures, which are reported in the Results section.

Results

Hand Load Forces

To simplify the data analysis, it was decided to combine the device and floor surface factors and analyze the data separately for the push, pull, and rotate trials using a 4 X 4 model (device/floor type x patient weight). The individual equipment manufacturers could be averaged by device/floor type because the mean hand force difference over all trials was less than 1.5 lbf for the overhead devices and less than 1 lbf for the floor devices.

The measurement of load force (lbf) for each trial was determined by taking the sum of the peak forces for the left and right hands. A linear model was used to test for the effects of device/floor type and patient weight and the device/floor type x patient weight interaction on summed mean peak hand forces. Fisher's Least Significant Difference (LSD) was used to test for the multiple comparisons. The analysis program SAS® (Version 9.2, SAS Institute, Inc., Cary, North Carolina) was used for all calculations.

Table 1 presents the mean peak hand forces (kg) and standard deviations by device, floor type, task, and patient weight. Figures 6-8 graphically present the data from Table 1. As can be seen in Figures 6-8, the hand load forces required to perform a push, pull, or rotate task were significantly greater for floor-based devices compared to the overhead devices. Also, the required hand forces increased significantly as the floor conditions varied from linoleum to indoor/outdoor carpet and finally to pile carpet, and the hand load forces increased as the patient weight increased from 125 to 350 lb. Examination of the interaction between floor condition and patient weight shown in Figures 6-8 reveal that as the patient weight increased, the required hand force for the pushing, pulling, and rotating tasks increased at a greater rate as the floor condition changed from ideal (overhead) to less ideal (carpet). However, the rate of change in required hand force, as a function of increasing patient weight, was similar between the overhead and floor-based lifts on linoleum.

Table 2 presents the Analysis of Variance (ANOVA) results for the analysis of the push, pull, and rotate tasks. As can be seen in Table 2, the main effects of all the independent variables were statistically significant for the outcome hand load force (lbf). The 2-factor interaction between device/floor type and patient weight was significant for the pull and push tasks, but not for the rotate task ($F_{(9,32)} = 1.8$, $p = 0.1074$). This indicates that the main effects, not the interaction effect, are responsible for the changes in load forces for the rotate task. Therefore, only the multiple comparisons for the push/pull tasks were examined. Most of the comparisons (240 out of 264) were significant.

Biomechanical Modeling

To estimate spinal loading, a single trial per combination (device type, flooring, task direction, patient weight) was simulated and modeled biomechanically using the University of Michigan 3DSSPP. Thus, calculation of standard deviations on the biomechanical results was not possible. From the many outcome measurements available from the biomechanical model generated by 3DSSPP, 6 variables related to spinal loading were selected for analysis: (1) L5/S1 moments about the x-axis; (2) L5/S1 moments about the z-axis; (3) L5/S1 total moments; (4) L4/L5 disc compression; (5) L4/L5 anterior-posterior (AP) shear; and (6) L4/L5 lateral shear. Results from the biomechanical assessment are shown in Table 3 and graphically in Figures 9-14. Examining the results for the moment measurements reflects the general trends reported for the load forces: that is, as patient weight increases, the measures of L5/S1 x-moment, z-moment and total moments also increase (Table 3). It should be noted that these increases could result from the increased hand forces or to changes in body postures. When patient weights are combined and the results are compared by floor surface, the moment measures are the highest for the carpet floor surface, followed by the indoor/out, linoleum, and overhead (Figures 12-14). Figures 12-14 also shows that for total moments and moments about the x-axis, the pull task generates the greatest forces, but for the rotate task, the greatest moment is about the z-axis for the floor-based devices.

The results in Table 3 reveal that none of the peak compression forces for any of the tasks evaluated exceeded the 3400 N NIOSH recommended exposure limit for spine compression loading.[20-22] The highest overall peak compression force of 2334.3 N occurred during the pull task on carpet for the heaviest patient weight. The heaviest patient weight also created a high compression force (1437 N) for the rotate task on carpet. Overall, the push task generally created the lowest L4/L5 disc compression forces of the 3 task types, regardless of the patient weight level. Results in Table 3 also show that the peak AP shear force for any of the conditions did not exceed the suggested shear force exposure limit of between 500 and 1000 N.[23(p96)] Overall, across all conditions, the highest estimated AP shear forces occurred for the pull task (range 169.0 N to 401.2 N), followed by the rotate task on carpet (138.0 N to 165.0 N), with the lowest AP forces occurring with the pushing task (−88.6 N to 91.0 N). As would be expected, the highest peak lateral shear force occurred with the rotate task for the heaviest patient weight (220.3 N) and the lowest occurred with the pushing task (0.1 N). The highest lateral shear forces for the rotate task occurred on carpet, and the lowest lateral shear force occurred with the overhead device.

An interesting and unexpected finding is that the AP shear force for the rotate task was similar for all task conditions, regardless of the task type, floor type, or magnitude of patient weight. This may be due to limitations of the 3DSSPP biomechanical model used in the study.

Discussion

The hand forces required to perform a push, pull, or rotate task led to the following findings: (1) Hand forces were significantly greater for floor-based devices compared to overhead ceiling-mounted devices. (2) Hand forces increased significantly as the weight of the patient increased. (3) Hand forces increased significantly as the floor condition changed from linoleum to carpeted surfaces. These results are in general agreement with previous research on lifting devices. Also, the hand force results showed that there was an interaction between flooring condition and patient weight for the indoor/outdoor and pile carpet conditions.

To evaluate the consistency of our results with respect to previously published data on the effects of patient handling devices on pushing, pulling, and rotating tasks, the present results were compared with those from Rice et al[14] for pushing, pulling, and rotating patient lifting devices on linoleum. These comparisons are presented in Table 4. The patient weights used in the present study (ie, 125 lb/57 kg, 175 lb/80 kg, 225 lb/102 kg, and 350 lb/159 kg) were similar to the average weights used in the Rice study (56 kg, 75 kg, 98 kg; and 143 kg). As can be seen in Table 4, the required hand force values reported in the present study are similar to those reported by Rice et al. The correlation coefficients between the 2 studies were high (between 0.95 and 0.98) across the various task conditions.[14]

A comparison of the differences in the magnitude of the hand forces for the rotation task for the floor-based lift conditions between the present study and the Rice et al study shows that the required hand forces for the Rice et al study were higher than in the present study. This interstudy difference is likely due to dissimilarities in how the rotation task was performed in the 2 studies. In the Rice et al study, the operator simply rotated the device about the center of the hands with 2 opposing forces in the sagittal plane. In the present study, however, the operator actually performed a lateral movement of the device with the 2 hand forces parallel to her frontal plane. This difference led to the forces for lateral movement being higher in the current study regarding pure rotation movement for the ceiling devices and lower for the floor-based results as compared to findings in the Rice et al study.[14]

It is likely that the required forces for the rotate task in the present study were less than in the Rice et al study because the lateral movement in the present study required movement of only 3 of the 4 wheels, whereas the technique used in the Rice et al study required movement of all 4 wheels. These findings would be expected, since the rolling resistance of 4 wheels would be greater than the rolling resistance of 3 wheels. Additionally, when the rotation task is performed laterally compared to a pure arm-based rotation, the legs can be used to generate higher loads of force due to the added inertia of the body. A trade-off factor to consider, however, is that the lateral shear force will likely be significantly higher for a lateral movement compared to a pure rotation task using the arms. It is worth noting here that the study by Marras et al[13] allowed the lift operators to apply their hand forces in any direction they preferred during the rotate task, which is different from either the present study or the Rice et al study. Again, this third approach to rotation resulted in different conclusions for the forces required for rotation than either the present study or the Rice et al study.[14]

As an additional evaluation of the potential risk of back injury due to pushing, pulling, and rotating the patient handling devices, the force values obtained in this study (converted from lbf to kilogram force [kgf]) were compared to Snook and Ciriello's[15] maximum acceptable forces for males and females for similar task conditions (The Snook and Ciriello maximum acceptable forces for pushing and pulling for task frequency of one push/pull every 2 minutes or one per 30 minutes are listed in the first 3 rows of Table 5.). The results of the comparison are shown in Table 5. Both the 75% and 90% levels for acceptable forces are reported to indicate the acceptability levels for both males and females. The floor to hand distance in the present study was 105.4 cm, so the nearest values in the Snook tables were 95 cm for males and 89 cm for females. As can be seen in Table 5, areas of potential risk are marked as unacceptable using the letter *U*. From this comparison, the results showed that the required hand forces for many of the pushing and pulling tasks in the present study exceed what 75% and 90% of females report as acceptable from a psychophysical standpoint. In fact, most of the pushing and pulling tasks on indoor/outdoor or pile carpeting exceed the 75% level of female acceptability for patient weights of 225 lb and above, and some exceeded the 75% level for patient weights as low as 175 lb. For males, only some tasks were unacceptable on the carpet surface at higher patient weight levels. Overall, the results of the current study show that floor-based lifting devices require high magnitudes of hand forces to operate on any type of carpeted surface and likely are unacceptable for many personnel. This finding is important because it is likely that many home health care environments would include at least partial carpeting. Also, there have been anecdotal reports of long-term care institutions considering switching to carpeted surfaces recently noted by the authors (reports from attendees at the 2010 Safe Patient Handling Conference, Orlando, Florida). This change in floor type might help mitigate slips and falls, but floor-based lifting devices would not be the best option for caregivers in carpeted environments, and ceiling-mounted devices would be highly recommended.

From a biomechanical perspective, spinal loading has been used to assess risk of work-related low back disorders in numerous studies of manual handling. It is believed that when internally developed spinal loads exceed the tissue tolerance levels of the spinal disc, the disc may be irreversibly damaged and result in severe low back pain or disability. These limiting values for spinal disc loading have been reported to be approximately 3400 N (770 lb) of disc compression force (DCF)[21] and somewhere between 500 N (110 lb) and 1000 N (225 lb) of disc shear force (DSF) loading. Moreover, it has also been suggested that the spinal tissue tolerance levels may decrease as a result of repetitive loading, such as when tasks are performed frequently. Although the spinal loads estimated from the pushing, pulling, and rotating tasks examined in this study were sometimes very high (550 lb, or 2450 N, of compression and 100 lb, or 445 N, of spinal shear), none of the tasks resulted in compression or shear force loading values exceeding recommended spinal tissue tolerance limits. An unexpected finding was that the estimated spine forces and moments were somewhat higher for the ceiling-mounted device compared to the other floor-based devices, despite the fact that the applied hand forces were significantly lower for the ceiling-mounted device. This finding is not intuitive and is difficult to explain. It should be noted that the differences are not very large and since we did not have multiple biomechanical simulations, it is not possible to calculate standard deviations and test for statistical significance of the differences. Also, there is some concern that the biomechanical model used in this study (3DSSPP model) underestimated the complex shear forces created during pushing, pulling, and rotating tasks. The 3DSSPP model, for example, does not account for the loading contribution of the spinal ligaments and muscular cocontraction that typically occurs during a manual material handling task, such as pushing, pulling, or rotating. A further weakness of the 3DSSPP model is that it cannot compute spinal loading at spinal segments above the L4/L5 region, where higher spinal shear loading force has actually been reported for complex pushing, pulling, and rotating tasks performed with patient lifting devices.[13]

As noted in the study results, the AP shear force for the rotate task was similar for all conditions regardless of the task type, floor type, or magnitude of patient weight. This is likely due to the fact that total AP shear is the sum of the left and right force components. Since the lateral force application for a rotate task in this study created a positive force in one side of the body and a negative value for the opposing side, the magnitude of the total shear force (left and right components) offset one another and resulted in small overall total values that are similar across all conditions, regardless of the magnitude of the externally applied hand loads. This runs counter to findings by Marras et al,[13] where spinal loading was very high during the difficult rotate component of a transfer task along a predefined track. Marras et al attributed this to the amount of control required to turn a patient in a floor-based lifting device in a constrained workspace and showed that the spinal loading was significantly higher for rotation than for the pushing and pulling phases of the transfer task. Marras et al also indicated that the higher spinal loads during rotation “required the operator to recruit more of the antagonistic muscles and increase coactivation, which increased A/P shear.” In fact, for a floor-based lift with small wheels on carpeting in a bathroom, the L1/L2 Superior Endplate A/P shear exceeded 1200 N on average, with peak values exceeding 1800 N during the rotate phase of the confined space task (ie, simulation of moving the patient into a bathroom).[13]

In order to assess potential biomechanical risk associated with pushing and pulling in our study, we compared our total spinal moment results to previously published data that proposed various risk categories for development of low back pain based on measurements of external moments.[24] In that study, Marras et al stated that maximum external moment values of 23.6 N m, 73.5 N m, and 76.7 N m were associated with low, medium, and high risk of probability for low back disorder, respectively. As can be seen in Table 3 and Figure 13, the values obtained in this study for maximum measured L5/S1 total moment were high compared, relatively, to the values proposed by Marras et al,[24] for many conditions. Comparing these values suggests that the pulling tasks on pile carpeting would be comparable to the high risk tasks reported by Marras et al, and that the peak for the pulling tasks on the indoor/outdoor carpeting, linoleum, and overhead devices would fall in the medium risk category. Similarly, the rotating tasks on pile carpeting would be near the medium risk category value reported by Marras et al and the indoor/outdoor carpeting condition would be somewhere between low and medium risk, respectively. It should be noted that the Marras et al maximum moment is not the same as the total spinal moment reported in this study, but these comparisons do suggest that spinal loading for certain pulling tasks of floor-based lifting devices would be very large and likely present a biomechanical risk for development of low back disorders, especially for the floor-based devices.[24]

One limitation to the current study is that it used a single-axis load cell, rather than a tri-axial load cell, to measure the hand forces. This choice was not a problem for the pushing and pulling tasks, but it did limit the ability to perform the rotating task in a more realistic manner and required prescription of how the rotating task was performed rather than allowing the operator to perform the task in any manner of her choosing. We believe our choice to have the operator perform the rotating task using 2 lateral forces (right and left hand) applied parallel to the frontal plane of the operator was more realistic than the method used in the Rice et al[14] study, but use of a tri-axial load cell likely would have made the task even more realistic. The purpose of this paper was to examine the required operating forces for ceiling-mounted and floor-based patient handling equipment on various floor surfaces. We did not attempt to examine differences in how operators performed the tasks and recognize that various individuals might perform the tasks differently and could introduce style factors and different motion profiles. For this reason, we used a single operator to perform all of the tests in order to minimize inter-subject variability.

Conclusions

In summary, spinal compression forces were not shown to be a potential risk factor for low back pain for any of the devices tested in this study, but A/P and lateral shear forces, as well as total spinal moments, did approach, and in some cases exceed, recommended safe exposure levels. In addition, the hand forces required to operate the equipment exceeded psychophysically acceptable levels for many of the tasks. The floor-based devices required significantly greater hand forces than the ceiling-mounted lifts, and operation of the floor-based lifts on carpet of any kind significantly increases the risk of musculoskeletal disorders. Based on these findings, when the floor surface is linoleum, floor-based lifts likely will be acceptable. When the floor surfaces are not linoleum or when the patient weights are very heavy, floor-based lifts could be hazardous; ceiling-mounted lifts should be used to the extent feasible. In situations where floor-based lifts must be used, regardless of the floor type or patient weight, users should consider using other assistive equipment, such as a powered transport device or equipment tugger that could help move the fully loaded device. Some lift devices have built in motorized drive trains to transport a fully loaded device along the floor surface.

It is clear that a number of the patient handling tasks evaluated in this study have the potential for causing or exacerbating low back disorders. The impact of these findings suggests that the risk of musculoskeletal injury will be greater for caregivers moving heavier patients on carpeting with floor-based lifting devices compared with using an overhead lift. Also, caregiver's risk of back disorders will increase as the weight of the patient increases. This is of critical interest to the healthcare community due to the increasing obesity epidemic in the United States.[25] Additionally, patient handling in home care settings may be particularly problematic, as it is more likely in the home care environment that a floor-based lifting devices will need to be used on carpeted floors and/or in restricted workspaces.

Biography

Thomas Waters, PhD, CPE is a certified professional ergonomist and holds advanced degrees in Engineering Science and Biomechanics from the University of Cincinnati. As a researcher at the National Institute for Occupational Safety and Health (NIOSH) for the past 25 years, Dr. Waters has published more than 75 papers, chapters, and books on manual material handling and prevention of low back disorders. He holds adjunct faculty positions in the Department of Environmental Health at the University of Cincinnati and in the Systems and Industrial Engineering Department at The Ohio State University. Dr. Waters is recognized internationally for his work on the revised NIOSH lifting equation. His primary research interests include occupational biomechanics, work physiology, low back injury prevention, safe patient handling and movement, and ergonomic risk assessment.

Robert Dick, PhD is a Retired Captain from the U.S. Public Health Service and is currently a visiting Scientist at the Centers for Disease Control and Prevention-National Institute for Occupational Safety and Health- Taft Laboratory in Cincinnati, Ohio. He has previously conducted research on the neurotoxic effects of solvents, metals and pesticides on humans and currently serves as a human factors consultant in ergonomics at NIOSH. Most recent research has focused on Work-Related Musculoskeletal Disorders using data from the General Social Survey and Airport baggage screening activities.

Brian Lowe, PhD, CPE is a Research Industrial Engineer with the Division of Applied Research and Technology at NIOSH in Cincinnati, Ohio. He has conducted research at NIOSH since 1998, mostly focusing on the assessment of exposure to risk factors for musculoskeletal disorders of the upper limbs. He serves on the editorial board of the journal Applied Ergonomics and has served as a reviewer for numerous professional and scientific journals. He received a Ph.D. in Industrial Engineering from Penn State and is a Certified Professional Ergonomist.

Dwight Werren, BS is an IT Specialist for the Division of Applied Research and Technology at the National Institute for Occupational Safety and Health (NIOSH) in Cincinnati. Dwight holds a Bachelor's degree in Zoology from Miami University, Oxford, Ohio and completed two years of computer science and programming at the University of Cincinnati. He has conducted pulmonary, dermal, reproductive, and toxicological animal research and currently develops software applications for postural and biomechanical analyses of worker lifting and repetitive motion tasks associ ated with musculoskeletal disorders.

Kelley Parsons, PhD earned her Ph.D. in Psychology from the University of Cincinnati (Cincinnati, OH) in 2007. During the time that this work was done, she was a Research Psychogist with the National Institute for Occupational Safety and Health (NIOSH). Most recently, she held a position as a Human Factors Engineer with the Eastman Kodak Company (Rochester, NY) following completion of a Postdoc at Cornell University where she examined the complex relationships between factors such as the physical design of hospital units and stress, workload and job satisfaction among hospital nursing professionals. Currently, she is working as an Independent Human Factors Consultant based out of Syracuse NY.

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Figure 1.
Push task with floor-based device

Figure 2.
Pull task with floor-based device

Figure 3.
Pull task with overhead device

Figure 4.
Rotate task with overhead device

Figure 5.
Rotate task with floor-based device

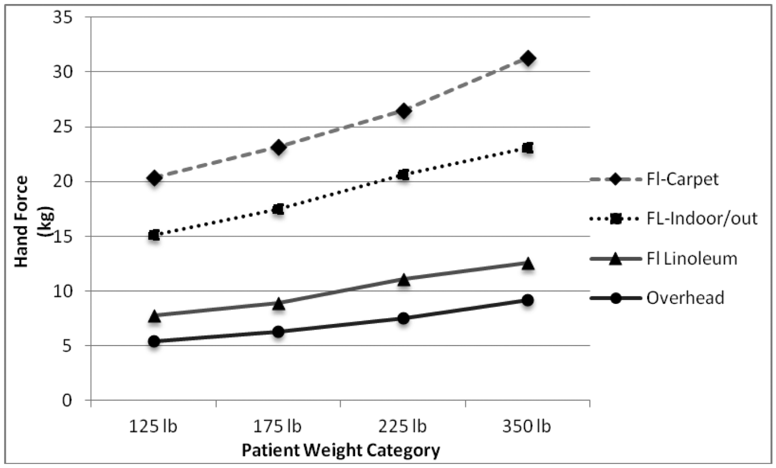

Figure 6.
Required hand forces (kg) for pull task by device/floor type and patient weight

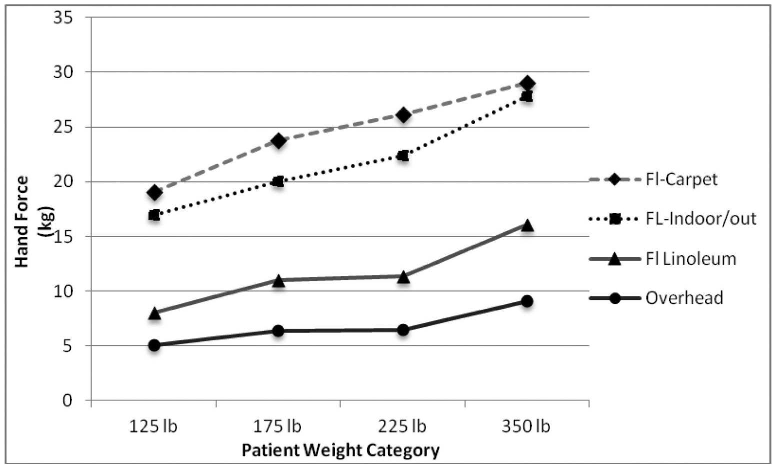

Figure 7.

Required hand forces (kg) for push task by device/floor type and patient weight

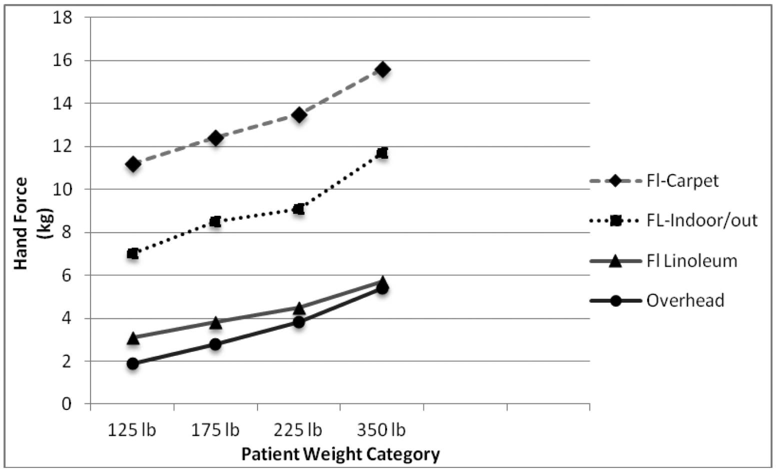

Figure 8.

Required hand forces (kg) for rotate task by device/floor type and patient weight

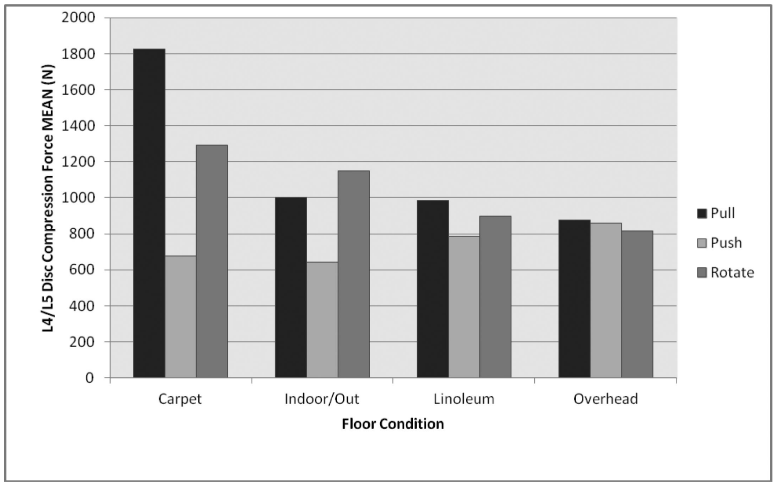

Figure 9.
L4/L5 Compression force by task and floor condition

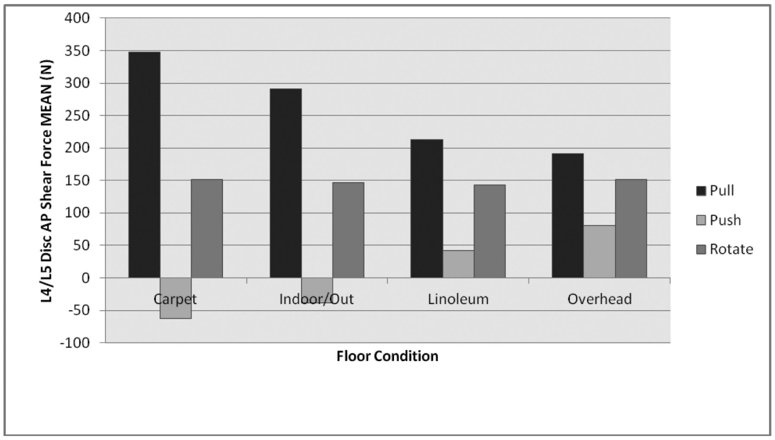

Figure 10.
L4/L5 Anterior posterior (AP) shear force by task and floor condition

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Figure 11.
L4/L5 Lateral shear force by task and floor condition

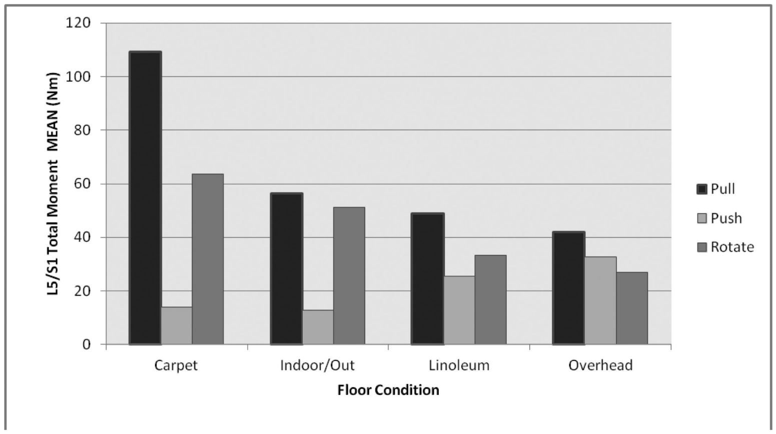

Figure 12.
L5/S1 Total moment by task and floor condition

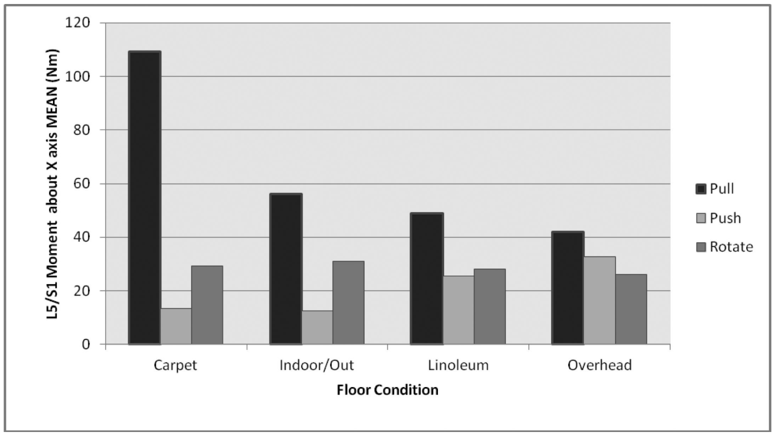

Figure 13.
L5/S1 Moment about x-axis by task and floor condition

Figure 14.

L5/S1 Moment about z-axis by task and floor condition

Table 1

Mean Peak Force (kg), Standard Deviations by Device, Floor Type, Direction Task, and Patient Weight

Patient Lifting Device	Floor Surface	Task	Weight			
			125 lb	175 lb	225 lb	350 lb
			Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Overhead	Linoleum	Pull	5.4 (0.4)	6.3 (0.2)	7.5 (0.4)	9.2 (1.1)
		Push	5.1 (0.6)	6.4 (0.9)	6.5 (0.7)	9.1 (0.8)
		Rotate	1.9 (0.2)	2.8 (0.3)	3.8 (0.6)	5.4 (1.1)
Floor	Linoleum	Pull	7.8 (0.8)	8.9 (1.5)	11.1 (0.4)	12.6 (1.1)
		Push	8.0 (0.6)	11.0 (1.2)	11.4 (1.0)	16.1 (1.3)
		Rotate	3.1 (0.2)	3.8 (0.4)	4.5 (0.6)	5.7 (0.7)
Floor	Ind.-Out	Pull	15.1 (1.1)	17.5 (0.7)	20.6 (0.8)	23.1 (0.3)
		Push	17.0 (1.2)	20.0 (0.6)	22.4 (2.7)	27.8 (1.4)
		Rotate	7.0 (0.6)	8.5 (0.6)	9.1 (0.4)	11.7 (0.9)
Floor	Carpet	Pull	20.4 (1.0)	23.2 (1.1)	26.5 (0.6)	31.3 (2.5)
		Push	19.1 (1.4)	23.8 (0.6)	26.1 (2.1)	29.0 (1.3)
		Rotate	11.2 (0.2)	12.4 (0.3)	13.5 (0.4)	15.6 (0.9)

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Table 2

Analysis of Variance of Mean Peak Forces (lbf) Showing Main Effects and 2-Factor Interactions for the Push, Pull, and Rotate Tasks

	df	*F* Value	p > *F*
Pull Task			
Device - Floor Type	3,32	785.8	0.0001
Patient Weight	3,32	100.1	0.0001
Device - Floor Type × Patient Weight	9,32	5.51	0.0001
Push Task			
Device - Floor Type	3,32	533.28	0.0001
Patient Weight	3,32	83.0	0.0001
Device - Floor Type × Patient Weight	9,32	3.40	0.0001
Rotate Task			
Device - Floor Type	3,32	834.1	0.0001
Patient Weight	3,32	106.5	0.0001
Device - Floor Type × Patient Weight	9,32	1.8	0.1074

Table 3

3DSSPP Model Simulations

Variable	Task	Carpet				Indoor/Out				Linoleum				Overhead-Linoleum			
		125 lb cat.	**175 lb cat.**	**225 lb cat.**	**350 lb cat.**	**125 lb cat.**	**175 lb cat.**	**225 lb cat.**	**350 lb cat.**	**125 lb cat.**	**175 lb cat.**	**225 lb cat.**	**350 lb cat.**	**125 lb cat.**	**175 lb cat.**	**225 lb cat.**	**350 lb cat.**
L5/S1 x-moment (N m)	Pull	−54.6	−119.6	−124.0	−138.5	−51.1	−51.3	−56.6	−66.0	−39.4	−42.9	−53.6	−59.3	−24.0	−45.7	−48.6	−50.0
	Push	−6.0	2.4	−17.6	−27.5	−7.9	9.2	−14.1	−19.2	−20.3	−27.1	−25.3	−28.8	−36.2	−26.0	−32.3	−36.0
	Rotate	−21.8	−32.1	−31.7	−32.1	−29.1	−30.2	−27.6	−36.6	−27.5	−26.7	−30.0	−27.5	−24.6	−24.7	−27.6	−27.1
L5/S1 z-moment (N m)	Pull	−0.3	−0.9	−2.7	−4.6	0.6	1.8	−2.5	−1.1	1.2	1.5	−1.1	1.2	0.1	0.5	−0.0	−1.0
	Push	3.8	1.5	−3.0	−2.1	1.5	−1.0	0.1	3.3	0.3	−0.7	−1.6	1.1	−1.2	−0.1	−0.5	1.5
	Rotate	−42.4	−60.1	−62.2	−60.4	−30.1	−37.7	−37.5	−54.7	−12.4	−16.3	−18.2	−24.2	2.8	4.0	5.4	8.2
L5/S1 total-moment (N m)	Pull	54.6	119.6	124.1	138.6	51.1	51.4	56.7	66	39.5	43.0	53.6	59.3	24.0	45.7	48.6	50.0
	Push	7.5	2.9	18.0	27.7	8.1	9.3	14.1	19.1	20.3	27.1	25.4	28.9	36.3	26.0	32.3	35.9
	Rotate	48.1	68.1	70.0	68.5	42.5	49.4	46.8	65.9	30.4	31.3	35.1	36.8	25.0	25.0	28.1	29.5
L4/L5 disc compress (N)	Pull	929.4	1952.2	2083.9	2334.3	941.0	958.0	995.4	1111.2	851.8	905.7	1054.6	1131.6	578.0	951.0	975.7	996.4
	Push	515.5	406.6	791.7	996.0	506.7	538.0	666.2	856.9	643.4	803.5	784.6	910.8	904.0	734.1	851.6	951.8
	Rotate	1010.5	1331.5	1390.0	1437.1	1051.8	1075.5	1069.0	1400.4	841.0	846.1	929.7	976.7	757.0	773.0	845.0	881.0
L4/L5 AP shear (N)	Pull	303.6	332.6	352.2	401.2	261.6	264.0	317.7	318.8	185.8	196.4	224.2	244.4	169.0	189.3	197.46	211.1
	Push	−20.4	−74.7	−63.8	−88.6	4.7	−2.3	−45.6	−71.3	71.0	46.3	51.7	−0.1	91.0	80.7	79.0	72.9
	Rotate	144.2	150.0	152.3	160.0	144.1	144.0	144.8	155.0	142.3	140.1	143.1	144.4	138.0	147.0	156.0	165.0
L4/L5 lateral shear (N)	Pull	3.8	11.3	12.1	14.0	1.7	4.9	5.3	6.0	3.9	4.2	5.3	5.4	−0.5	4.1	1.11	4.9
	Push	−5.4	−1.6	13.4	19.8	0.4	0.1	−0.2	2.3	0.4	6.7	2.8	3.9	20.4	2.4	12.5	−0.4
	Rotate	154.4	183.5	199.3	220.3	102.0	122.0	128.4	173.2	44.2	56.8	64.0	83.3	−13.2	4.5	4.5	−17.8

Note: Moments are reported in newton meters (N m) and compression and shear are reported in newtons (N).

Table 4

Comparison of Mean (lbf) Hand Force Values and Correlation Coefficients betwen Present Study and Rice et al[14] by Patient Weight Categories

Patient Lifting Device	Task	Patient Weight Category								
		Present Low	**Rice Low**	**Present Average**	**Rice Average**	**Present High**	**Rice High**	**Present Obese**	**Rice Obese**	**Correlation Coefficient**
		125 lb	**123 lb**	**175 lb**	**165 lb**	**225 lb**	**215 lb**	**350 lb**	**314 lb**	
Overhead	Pull	5.4	4.5	6.3	5.1	7.5	5.1	9.2	6.2	0.95
	Push	5.1	4.7	6.4	5.5	6.5	6.4	9.1	9.3	0.98
	Rotate	1.9	0.4	2.8	0.5	3.8	0.6	5.4	0.8	0.99
Floor	Pull	7.8	10.3	8.9	11.6	11.1	13.0	12.6	17.3	0.95
	Push	8.0	9.7	11.0	10.8	11.4	13.4	16.1	15.8	0.94
	Rotate	3.1	5.3	3.8	6.0	4.5	5.9	5.7	7.42	0.95

Table 5

Acceptable Push/Pull Forces for Males and Females

	Male-Push Forces[1]					Female-Push Forces					Male-Pull Forces				Female-Pull Forces			
Percent[2]		75	75	90	90	75	75	90	90		75	75	90	90	75	75	90	90
Frequency[3]		2	30	2	30	2	30	2	30		2	30	2	30	2	30	2	30
Kgf-Threshold		34	36	26	28	22	25	18	21		31	33	25	27	22	26	19	22
	Hand Force[4]									Hand Force[4]								
H-Linoleum																		
125 lb	5.1	A[5]	A	A	A	A	A	A	A	5.4	A	A	A	A	A	A	A	A
175 lb	6.4	A	A	A	A	A	A	A	A	6.3	A	A	A	A	A	A	A	A
225 lb	6.5	A	A	A	A	A	A	A	A	7.5	A	A	A	A	A	A	A	A
350 lb	9.1	A	A	A	A	A	A	A	A	9.2	A	A	A	A	A	A	A	A
Fl.-Linoleum																		
125 lb	8.0	A	A	A	A	A	A	A	A	7.8	A	A	A	A	A	A	A	A
175 lb	11.0	A	A	A	A	A	A	A	A	8.9	A	A	A	A	A	A	A	A
225 lb	11.4	A	A	A	A	A	A	A	A	11.1	A	A	A	A	A	A	A	A
350 lb	16.1	A	A	A	A	A	A	A	A	12.6	A	A	A	A	A	A	A	A
Fl.-Ind-Out																		
125 lb	17.0	A	A	A	A	A	A	A	A	15.1	A	A	A	A	A	A	A	A
175 lb	20.0	A	A	A	A	A	A	**U**[5]	A	17.5	A	A	A	A	A	A	A	A
225 lb	22.4	A	A	A	A	**U**	A	**U**	**U**	20.6	A	A	A	A	A	A	**U**	A
350 lb	27.8	A	A	A	A	**U**	**U**	**U**	**U**	23.1	A	A	A	A	**U**	A	**U**	**U**
Fl.-Carpet																		
125 lb	19.1	A	A	A	A	A	A	**U**	A	20.4	A	A	A	A	A	A	**U**	A
175 lb	23.8	A	A	A	A	**U**	A	**U**	**U**	23.2	A	A	A	A	**U**	A	**U**	**U**
225 lb	26.1	A	A	**U**	A	**U**	**U**	**U**	**U**	26.5	A	A	**U**	A	**U**	**U**	**U**	**U**
350 lb	29.0	A	A	**U**	**U**	**U**	**U**	**U**	**U**	31.3	**U**	**U**	**U**	**U**	**U**	**U**	**U**	**U**

Notes:

[1] Threshold Values are adapted from Snook and Ciriello,[15] Tables 6, 7, 8, 9, Ergonomics, 34(9), 1197-1213.

[2] 75th and 90th percent values were chosen using the vertical distance from floor to hands of 95 cm for males and 89 cm for females for a horizontal distance of 2.3 meters. These forces represent initial forces, not sustained forces.

[3] 1 push or pull every 2 minutes or 1 every 30 minutes.

[4] Mean hand force in kg for comparison to the Snook tables.

[5] A = acceptable forces from Table 1. **U** = unacceptable forces from Table 1 that exceed maximum acceptable forces for the percentage of the population. At 90%, the forces required for a push/pull show a risk is possible for 10% of the industrial population.