

## The effects of caregiver experience on low back loads during floor and overhead lift maneuvering activities

Tilak Dutta<sup>a,b,\*</sup>, Pamela J. Holliday<sup>a,c</sup>, Susan M. Gorski<sup>a</sup>, Mohammad S. Baharvandy<sup>a</sup>, Geoff R. Fernie<sup>a,b,c</sup>

<sup>a</sup>Toronto Rehabilitation Institute, 550 University Avenue, Suite 12029, Toronto, ON, Canada M5G 2A2

<sup>b</sup>Department of Mechanical and Industrial Engineering, University of Toronto, 5 King's College Road, Toronto, ON, Canada M5S 3G8

<sup>c</sup>Department of Surgery, University of Toronto, 100 College Street, Room 311, Toronto, ON, Canada M5G 1L5

### ARTICLE INFO

#### Article history:

Received 28 July 2010

Received in revised form

29 June 2011

Accepted 3 August 2011

Available online 6 September 2011

#### Keywords:

Patient transfer

Patient handling

Patient lifting

Safe patient handling

### ABSTRACT

This study investigated the effects of caregiver experience on peak external forces and moments generated at the L5/S1 joint of the low back when maneuvering loaded floor-based and overhead-mounted patient lifting devices. Twenty caregivers were divided into more-experienced and less-experienced groups based on the product of two factors: their years of lifting experience and the frequency of lifting the caregivers had done in the past. Ground reaction forces and moments as well as motion capture data were recorded while caregivers performed five different maneuvering tasks with both lifts in each of three conditions (caregiver subjects worked alone, as the primary caregiver in a pair, and as the secondary caregiver in a pair). Six outcome measures (net external forces and moments at the L5/S1 joint) were recorded. Multivariate analyses of variance of all net external forces and moments were done separately for the floor and overhead lifts. A significant effect of experience level was found for the floor lift ( $p = 0.006$ ) but not for the overhead lift ( $p = 0.163$ ). A follow-up univariate analysis of floor lift activities found significant differences between more-experienced and less-experienced caregivers for Turn, Push and Legs Up activities.

**Relevance to industry:** Previous work has shown that overhead lifts reduce the loads on caregivers compared to floor lifts. The findings of this study further underscore the need to purchase overhead lifts to protect less-experienced caregivers (including informal family caregivers) who are at increased risk of back injury when maneuvering floor lifts.

© 2011 Elsevier B.V. All rights reserved.

### 1. Introduction

Caregivers (including nurses, nursing aides, healthcare workers, etc.) have the highest incidence rates for nonfatal occupational injury and illness involving days away from work according to the Bureau of Labor Statistics (BLS, 2008). These injuries are largely due to patient handling tasks (Edlich et al., 2004; Engkvist, 2004; Leighton and Reilly, 1995; Nelson et al., 2007; Waters, 2007b). The use of mechanical patient lift devices (lifts) can reduce the risk of caregiver injury during patient transfers (Collins et al., 2004; Evanoff et al., 2003, 2004; Trinkoff et al., 2003; Zhuang et al.,

2000, 1999). However, there are important differences between the two main types of lift devices – floor lifts (devices that roll on a set of wheels on the floor) and overhead lifts (lifts that are suspended from a track attached to the ceiling). Some qualitative research has shown that overhead lifts are preferred to floor lifts based on psychophysical measurement (Alamgir et al., 2009; Engst et al., 2005; Holliday et al., 1994; Zhuang et al., 2000). Unfortunately, psychophysical measurements may over-estimate the capabilities of the body's tissues particularly when dealing with infrequent heavy lifting activities as is the case with patient handling (Waters, 2007a). Also, thresholds of discomfort can be lower for novice workers than for experienced workers (Parakkat et al., 2007). For these reasons, biomechanical studies may be better for comparing overhead and floor lifts.

The two most relevant biomechanical studies that investigated this issue both chose to use novices (individuals with little to no experience with patient lifting) as test subjects (Marras et al., 2009; Rice et al., 2009). Rice et al. (2009) measured horizontal hand forces generated by a single participant to maneuver lifts while varying

\* Corresponding author. Toronto Rehabilitation Institute, 550 University Avenue, Suite 13000, Toronto, ON, Canada M5G 2A2. Tel.: +1 416 597 3422x7956; fax: +1 416 597 3027.

E-mail addresses: [dutta.tilak@torontorehab.on.ca](mailto:dutta.tilak@torontorehab.on.ca) (T. Dutta), [holliday.pam@torontorehab.on.ca](mailto:holliday.pam@torontorehab.on.ca) (P.J. Holliday), [gorski.susan@torontorehab.on.ca](mailto:gorski.susan@torontorehab.on.ca) (S.M. Gorski), [m.baharvandy@alumni.utoronto.ca](mailto:m.baharvandy@alumni.utoronto.ca) (M.S. Baharvandy), [fernie.geoff@torontorehab.on.ca](mailto:fernie.geoff@torontorehab.on.ca) (G.R. Fernie).

the weight of the patient. A total of 18 surrogate patients ranging in weight from 51 kg to 146 kg were pushed, pulled and turned in both floor and overhead lifts. The authors found that the floor lift required significantly higher forces to maneuver. Marras et al. (2009) performed a similar comparison but using more sophisticated measurements. The authors examined the activities of maneuvering floor and overhead lifts using an EMG-assisted biomechanical model to estimate the compression and shear forces along the lumbar spine of 10 participants. Marras et al. found the loading due to floor lifts to be higher than the loading for overhead lift, which agrees with Rice et al.

However, these findings from novice subjects may not provide an accurate representation of loading patterns in experienced caregivers. For instance, there are two biomechanical studies that show more-experienced caregivers have different muscle activation patterns than novices (Hodder et al., 2010; Keir and MacDonell, 2004). Both studies found significant differences between experienced and inexperienced subjects. Keir and MacDonnell found mixed results in their pilot study of patient lifting activities with three experienced subjects producing lower mean erector spinae activity but higher shoulder activity than four novice subjects. Hodder et al. had similar findings in their study of 12 novice and 10 experienced nurses who were asked to perform a series of manual patient handling tasks. However there are no studies that compare the low back loading between caregivers with different levels of experience.

The question of whether low back loading changes with experience level is of particular importance because experienced caregivers tend to be older and risk of back injury increases with age (Jager and Luttmann, 1996). This increased risk of injury may be partially offset by the effect of increased experience and this may explain why we see lower rates of injury in older workers despite their higher susceptibility (Rong, 2008; Yassi et al., 1995). There are however some studies that had the opposite finding that older caregivers had higher prevalence of back injuries than younger workers (Karahan et al., 2009; Moscato et al., 2010). This latter case is more worrisome particularly in the case of inexperienced older workers in the workforce. Similarly, informal caregivers who look after family or friends at home are at particular risk as they often are both inexperienced and older. Fourteen percent of these informal workers report being in physical discomfort or pain (Canadian Home Care Association, 2003). The case of informal caregivers is the most troubling because these workers do not have access to the tools, training or support that their paid counterparts have at hand.

The studies that do recruit trained subjects either do not report how many years of experience their caregivers had (Santaguida et al., 2005; Zhuang et al., 1999) or report that the subjects are not considered true caregivers (Keir and MacDonell, 2004). Santaguida et al. (2005) and Zhuang et al. (1999) did not report the experience level of the caregivers, though they did report the mean ages of their subjects which were 27.3 and 45.8 years respectively. Caregiver mean age may give us a hint of their levels of experience. Santaguida et al. compared the loads at the L5/S1 joint resulting from three types of floor lifts and two different overhead lifts and found the loads from floor lifts to be higher than from overhead lifts. Zhuang et al. (1999) estimated the hand and L5/S1 forces required to push, pull and turn floor, overhead as well as stand-up lifts. They found that the floor lifts required the most force to move followed by the stand-up lifts and overhead lifts in that order. The three experienced participants of Keir and MacDonell's were "experienced with all transfer methods...but were not employed as healthcare professionals..." (p. 298). In their study Keir and MacDonell (2004) compared muscle activity patterns and found higher activity for floor lifts than with overhead lifts.

The motivation for this analysis came from observations during a related study on one and two caregiver lift use (Dutta et al., submitted). During data collection for this study, we noted that caregivers who had more experience moved very differently than those who had less experience. Our objective was to examine the data collected for the related lift use study to determine if there were differences in low back loading between more-experienced and less-experienced caregivers while maneuvering floor and overhead lift devices.

## 2. Methods

In our study, we estimated the net external forces and moments that result from moving a patient from a bed to a wheelchair and back to a bed using floor and overhead lifts in a simulated clinical environment. Previous biomechanical studies of lift maneuvering activities have used methods of varying complexity to estimate low back loading since there is no gold standard (Davis and Jorgensen, 2005; Kingma et al., 2001). We based our methods on those used by Santaguida et al. (2005) because these offered a reasonable compromise between simplicity of instrumentation to allow for data collection in the clinical environment and accuracy of force measurement. Santaguida et al. collected ground reaction forces from a pair of forceplates and kinematic data from a motion capture system and calculated compression and shear at the L5/S1 joint using a single equivalent muscle model. We improved on these methods by collecting ground reaction forces using recently developed ForceShoes rather than forceplates to allow the caregiver to move more naturally. We also chose to compare loading at the low back by calculating external forces and moments rather than internal compression and shear values. We limited our comparison to external loads because of the inaccuracies with single equivalent muscle models that do not account for co-contraction of trunk muscles (Granata and Marras, 1999). However, without an accurate estimate of co-contraction it is possible this investigation obscured experience related differences between our two groups.

### 2.1. Caregiver participants

A total of 21 female caregivers were recruited through advertisements at Toronto Rehabilitation Institute. Caregivers had an average (SD) age of 38.9 (10.8) years with all subjects between ages of 19 and 60. Our caregivers had an average (SD) of 8.7 (9.5) years of experience in patient lift/transfer activities using mechanical lift devices with all having at least one year of such experience. The average (SD) number of lifts they performed per shift was 8.5 (9.2). These 21 caregivers were ranked according to how much experience they had with patient lifting. A caregiver's experience level was calculated by multiplying the number of years of experience she had with the average number of patient lifts performed per shift. Based on this ranking, the 10 caregivers with the highest experience level were placed in the *more-experienced* category while the 10 caregivers with the lowest experience level were placed in the *less-experienced* category. The data from the 21st caregiver was removed from our data set because we determined she would be unrepresentative in either group with 6.5 years of experience. Table 1 summarizes experience and average number of lifts performed per shift for our two groups of caregivers. Matlab 7.9.0 (Mathworks, Natick, MA) was used to perform *t*-tests to show that the masses and heights of the caregiver subjects were not significantly different between our two groups ( $p = 0.58$  and  $p = 0.54$  for mass and height, respectively).

Exclusion criteria included pregnancy; musculoskeletal or neuromuscular injury of upper limbs, lower limbs, or back within

**Table 1**  
A comparison of the more-experienced and less-experienced caregiver groups.

	More-experienced (n = 10)	Less-experienced (n = 10)
Mean number of years working as a caregiver (SD)	15.35 (10.2)	2.25 (1.06)
Mean number of patient lifts performed per shift (SD)	14.10 (10.8)	3.60 (2.12)
Mass in kg (SD)	64.1 (12.2)	61.1 (9.5)
Height in m (SD)	1.62 (0.07)	1.64 (0.06)

the previous 3 months; medical conditions such as mobility impairment and cardio-respiratory problems. The study was approved by Toronto Rehabilitation Institute's Research Ethics Board and all participants provided informed consent.

## 2.2. Setting and equipment

All testing was done in a patient room at Toronto Rehabilitation Institute's E.W. Bickle Centre for Complex Continuing Care with lift equipment on loan from ArjoHuntleigh Canada Inc. (Mississauga, Ontario) and included an ArjoHuntleigh Quick Fit (TIR - L) sling (large size), floor lift (BHM Ergolift), an overhead lift (Maxi Sky 440) and a gantry system for use with the overhead lift (EasyTrack FS). A Carroll hospital bed (Carroll Hospital Group, London Ontario) was also used in this study.

## 2.3. Surrogate patient

A  $90 \pm 0.5$  kg male surrogate patient was asked to simulate an entirely dependent patient. A lighter surrogate patient was used after adjusting his weight with a weighted vest and leg weights during some testing sessions if the 90 kg surrogate patient was not available. The appropriate amount of weight was strapped to the surrogate patient's lower leg at the location of the centre of mass of the segment (Winter, 2004). Any remaining weight discrepancy was made up by adding weight to the vest.

## 2.4. Biomechanical measurement

Measurements were taken to determine the loading of the spine at the low back during the lift maneuvering activities. Two pieces of information were needed to calculate the loading at the L5/S1 joint: 1) ground reaction forces and moments measured at the feet; and, 2) three-dimensional locations of the segments of the lower body. Ground reaction forces and moments were collected using our recently developed ForceShoes based on an existing design (Veltink et al., 2005). The ForceShoes were found to be in good agreement with AMTI BP2505000-2K-3847 forceplates (Watertown, MA). Errors between ForceShoe and forceplate readings were:  $1.88 \pm 0.91\%$ ,  $2.06 \pm 0.91\%$  and  $2.34 \pm 1.69\%$  in the medial–lateral, anterior–posterior and vertical directions. Signals from the ForceShoes were sampled at 100 Hz. The signals were amplified (settings: 2000 gain, 5 V excitation) via a PowerDNA Cube equipped with three DNA-AI-208 8-channel strain gage input layers (which provided signal conditioning and analog to digital conversion) (United Electronic Industries, Walpole, MA) worn in a waist pack. A Toshiba Satellite laptop computer running LabVIEW (National Instruments Corporation, Austin, Texas) was used to capture the force signals. An eight-camera Vicon motion capture system (Centennial, CO) was used to collect motion capture data at 100 Hz. Digital video of all trials was also collected on the same Vicon system using a Basler video camera.

## 2.5. Procedure

Upon arrival at the testing session, the study was explained to the caregiver and she was asked to give informed consent. The caregivers then filled out a caregiver history questionnaire that asked questions regarding their background including their age, number of years of experience they had in patient lifting and number of lifts they typically performed in a shift.

The caregiver then put on the ForceShoes and a set of reflective marker clusters bilaterally on the posterior superior iliac spines (PSIS), around the knee joint (two markers equidistant from the lateral femoral epicondyle, one above and one below, and a third marker on the midline of the knee joint posterior to the knee, at the same height as the lateral femoral epicondyle when the subject was standing), as well as on the T10 vertebral spinous process as shown in Fig. 1. Six reflective markers were attached to each shoe with three at the ball of the foot and three near the heel. Finally, a number of anthropometric measurements were taken so that a custom biomechanical model of each caregiver could be created.

The order of lift use was pseudo randomized and the surrogate patient was suspended 2 cm above the surface of the bed in one of the two lifts after the bed height was adjusted by the caregiver. The participant was then asked to perform the activities listed in Table 2 five times each. The activities listed in Table 2 were meant to simulate the activity of transferring a patient from a bed to a wheelchair and vice-versa.



**Fig. 1.** Subject performing the Legs Down activity in the 'secondary' condition using a floor lift.

**Table 2**  
Activities that caregiver subjects were asked to perform.

Activity	Abbreviated activity name
1. Lower surrogate patient's feet and legs off bed	Legs Down
2. Pull floor lift 30 cm backward	Pull
3. Turn lift 90° to right	Turn
4. Push floor lift 30 cm forward	Push
5. Lift surrogate patient's feet and legs back onto bed	Legs Up

Each activity in Table 2 was performed by caregivers working alone as well as in pairs using both floor and overhead lifts while force and motion capture data were recorded. Caregivers performed the activity twice while working with a second caregiver: once as the primary caregiver (primary) and again as the secondary caregiver (secondary) in addition to working alone (solo). The three conditions were tested in a pseudo randomized order. The two caregivers' responsibilities during the two caregiver conditions are shown in Table 3. A member of our research team with experience in-patient lifting was the other caregiver in the two caregiver cases and did not wear ForceShoes or reflective markers.

## 2.6. Data analyses

### 2.6.1. Biomechanical measurement

3D motion capture data were processed for the first three trials of each activity/condition combination. The motion capture data were combined with ground reaction and anthropometric data in a custom biomechanical model adapted from previous studies (Carmichael, 2006; Dutta, 2006; Santaguida et al., 2005). The joint centers of the ankles, knees, hips and L5/S1 disc centroid were predicted using rigid body theory. The joint centers of the ankles and knees were estimated to be the midpoints of the medial and lateral malleoli and femoral epicondyles respectively (Blankevoort et al., 1990; Cappozzo et al., 1995). The hip joint centers were predicted by adapting the method used by Seidel et al. (1995). Finally, the L5/S1 joint was taken to be 34% of the anterior/posterior distance between the midpoint between the right and left anterior superior iliac spines and the midpoint between the right and left PSIS (McNeill et al., 1980).

Table 4 lists outcome variables that were calculated for each activity/condition combination. The vertical force outcome was normalized by subtracting the subject's body mass to reduce variability. Net external moments at the L5/S1 joint were calculated about all three axes by summing the moments resulting from ground reaction forces as well as the moments resulting from gravity acting on the pelvis, thighs and the lower legs (the foot and

**Table 3**  
Primary and secondary caregiver roles for two caregiver conditions with floor and overhead lifts.

Activity	Primary caregiver		Secondary caregiver	
	Floor lift	Overhead lift	Floor lift	Overhead lift
Legs Down	Brace lift device	Guide patient's torso	Lower patient's legs off bed	Lower patient's legs off bed
Pull	Pull lift device	Pull patient	Guide patient and guide lift	Pull patient
Turn	Turn lift device	Turn patient	Guide patient and guide lift	Turn patient
Push	Push lift device	Push patient	Guide patient and guide lift	Push patient
Legs Up	Brace lift device	Guide patient's torso	Lift patient's legs onto bed	Lift patient's legs onto bed

**Table 4**  
Methods of determining biomechanical outcome variables.

Outcome variable	Description
Medial-lateral force	Peak ground reaction force
Anterior-posterior force	(Peak ground reaction force) – (subject's body weight)
Normalized vertical force	
Forward bending moment	Peak external moment calculated at the L5/S1 joint
Side bending moment	
Twisting moment	

shank were considered a single rigid body) using mass and centre of mass values from the literature (Young et al., 1983).

### 2.6.2. Statistical analysis

Two multivariate analyses of variance (MANOVA) were done in SAS 9.1 (Cary, NC) using the net external forces and moments at the L5/S1 joint as the response variables and including fixed factors for condition, experience and all 2- and 3-way interactions as well as a random effect for subjects. One MANOVA was done using the data from floor lift use and the second for data from overhead lift use. In each case, a test for equality of experience across all variables was done based on Wilk's lambda using  $p < 0.05$  as the cut-off for statistical significance.

A follow-up repeated measures analysis of variance (ANOVA) was conducted for the floor lift data using condition and experience as factors in the model which also included the possible interaction between these factors. Subjects were included in the model as a random effect. A separate model was fit for each activity, for each of the six outcome variables listed in Table 4. If a significant interaction of condition and experience was found, the repeated measures ANOVA was fit for each condition to probe the relationship further. *P*-values obtained from the statistical analyses were treated only as guides to expose the underlying univariate effects responsible for the observed multivariate effect therefore no adjustment was made for multiplicity of testing. Activities and/or conditions for which significant differences were found are indicted in Tables 5 and 6.

## 3. Results and discussion

Table 5 shows the comparisons of external forces at the L5/S1 joint for each activity/condition/outcome combination between more-experienced and less-experienced caregivers for both floor and overhead lifts. Table 6 shows an analogous comparison for the net external moments at the L5/S1 joint.

The results of the MANOVA of the floor lift data showed a significant effect of experience level ( $p = 0.006$ ). However, there was no significant effect of experience level with overhead lift use ( $p = 0.163$ ). Still, we note a similar trend was present with the overhead lift use as more-experienced caregivers generated lower loads in 74 of the 90 activity/condition/outcome combinations tested when compared with the less-experienced caregivers.

Further probing of the floor lift data to find the underlying univariate effects showed significant differences between more-experienced and less-experienced caregivers for the Turn, Push and Legs Up activities. The peak forces and moments resulting from these activities are shown in Fig. 2.

### 3.1. Differences in movement patterns with the floor lift

We reviewed video footage for trials where significant differences were found between the two groups of caregivers and

**Table 5**

Mean and standard deviation of external forces at the L5/S1 joint resulting from the lift maneuvering tasks.

Activity	Lift	Cond	Medial–lateral force (N)						Anterior–posterior force (N)						Normalized vertical force (N)					
			More exp		Less exp		Sig	More exp		Less exp		Sig	More exp		Less exp		Sig			
			Mean	SD	Mean	SD		Mean	SD	Mean	SD		Mean	SD	Mean	SD				
Legs Down	F	Pri	27	23.9	32.6	25.4		28.1	22.4	27.4	11.9		41.3	22.2	77.9	76.6				
		Sec	44.4	15.2	55.1	13.6		63	35.4	67.8	24.8		104.7	16.6	129.4	51.6				
		Solo	42.6	12.5	56.7	21		66.8	28.4	75.1	25.5		106.4	20.5	138.8	54				
	O	Pri	18.7	11.2	27.5	17.5		19.8	12.4	19.8	9.1		30.2	14.5	76.2	62.6				
		Sec	48.9	21.9	47.6	12.6		60.6	34	59.3	21.9		104	37.3	111.6	31.4				
		Solo	36.6	13.2	45.6	20.8		56.6	19.1	62.2	22.4		91	20.2	103.4	30.3				
Pull	F	Pri	61.8	32.7	61.2	31.5		109.2	27.9	119.9	27.6		74	33.2	121	91.9				
		Sec	54.7	24.1	52.9	34.2		31.1	15	30.4	14		45.7	17.3	66.7	40.4				
		Solo	63.7	25.8	58.6	20.3		128.2	29	118.1	38.8		78.9	28.7	113.5	71.7				
	O	Pri	40.4	17.6	44.3	18		20.4	7	25.9	8.8		38.8	14.5	67.6	36.8				
		Sec	34.7	15.6	47	17.3		23.9	15.1	32.4	25.9		43.3	27.1	87.2	61.6				
		Solo	48	15.3	62	18.4		30.2	14	47.3	31.1		44.1	22.2	99.1	65.7				
Turn	F	Pri	110.8	24.5	106.5	37		88.6	34.4	108.2	40.7	*	113	45.5	164.2	83	*			
		Sec	81.4	43.2	63.9	36.4		59.1	17.7	48.9	28.2		90.9	33.2	99.4	57.6				
		Solo	110.6	36.2	141.2	35.5	*	94.5	32.2	113.6	28.3	*	116	61.3	211.6	90.7	*			
	O	Pri	31	16.2	41	25.8		21.3	14.6	41	32		42.1	22.6	99.6	61.3				
		Sec	32.5	18.4	49.9	35.8		25.2	14	50	29.6		42.7	35.9	107.6	60.5				
		Solo	43.3	29.3	51.7	31.2		33.5	15.8	54.9	27		51.3	28.1	102.5	57				
Push	F	Pri	47.3	16.3	54.4	22.1		88.8	22	90.2	27.8		76	29.9	107	58.5				
		Sec	53.9	19.5	57.4	31.5		27.7	9.8	33.6	11.9		47.9	28.9	101.2	77.8				
		Solo	47.2	15.5	57.2	20.7		104.9	23.5	96.5	33.2		85	45.3	155.1	107.2	*			
	O	Pri	43.6	19.4	54.8	29.9		24.6	15.4	26.1	13.8		46	21.4	78.6	49.6				
		Sec	46.4	23.3	56.8	25.3		22.7	7.7	31.3	22.5		39.9	17	88.8	50.2				
		Solo	51.4	22.9	61.4	30		31.6	10.8	50.5	24.8		45.1	15.5	102.8	42.8				
Legs Up	F	Pri	24.6	22.4	25.2	14.3		25.6	27.7	22.3	14.6		41.2	45	75.1	55.3				
		Sec	41.4	13.5	61.8	20.9	*	63.4	28.8	80.6	28.8		124.5	39.2	177.2	51.5	*			
		Solo	44.7	12.1	65.6	20.7	*	69	27.2	81.8	33.6		127.9	43.8	219.4	118.9	*			
	O	Pri	23.9	15.7	27.6	14.8		22.8	12.2	37.5	26.3		36.2	17.8	78.2	49.3				
		Sec	41.2	14.6	50.1	18.5		53.9	26.8	51	15.7		120.3	33.2	127.9	34.3				
		Solo	42.5	14.5	55.1	22.1		48.7	17.1	55.2	24.1		124.3	30.4	143.6	47.4				

Legend: F – floor lift; O – overhead lift; Cond – condition; Pri – primary caregiver; Sec – secondary caregiver; Solo – solo caregiver; More Exp – more-experienced; Less Exp – less-experienced; Sig – significant for  $p > 0.05$ .

noticed a number of variations in technique that could explain the increased loading on less-experienced caregivers in comparison to the more-experienced group when using the floor lift.

For the Turn activity, significant differences were found with the forward bending moments (primary and solo conditions), medial–lateral forces (solo condition), anterior–posterior forces (primary and solo conditions) and normalized vertical forces (primary and solo conditions). In the primary and solo conditions, we noted the more-experienced caregivers would often push the base of the floor lift with their feet during the pushing activity while their less-experienced counterparts tended to only use their hands to turn the lift. Using the feet to turn the lift was beneficial for two reasons. First, it reduced the forces that had to be transmitted through the spine. Second, it caused the caregiver to be closer to the lift and reduced how far they had to bend to reach it.

For the Push activity, significant differences were found with forward bending moments (secondary condition) and normalized vertical forces (solo condition). We suspect the higher bending moments during the secondary condition was the result of less-experienced caregivers not moving with the lift as it was pushed forward. Video footage showed the less-experienced caregivers tended to keep their feet planted in fixed position while attempting to guide the patient. As a result, they had to reach forward and bend more than their more-experienced counterparts who tended to position themselves closer to the lift. In the solo condition, the reduced vertical forces for more-experienced caregivers may again be the result of the use of the feet for pushing the lift while their less-experienced counterparts tended to only use their hands similar to the Turn activity. The

use of feet would have reduced the net external force generated at the spine.

Finally, for the Legs Up activity, significant differences were found with forward bending moments and medial–lateral forces for secondary and solo conditions for both outcomes. These findings are consistent with our observations from video footage where less-experienced caregivers supported the patient's legs near the heels while more-experienced caregivers provided support from higher up the leg – often midway between the ankle and knee – allowing these caregivers to bend less. In one case, a more-experienced caregiver used the patient's pant cuff to support the lower leg as the leg was raised. Additionally, caregivers in the more-experienced group tended to minimize the amount of time they supported any of the surrogate patient's body directly. For instance, during the Legs Up activity with the floor lift, more-experienced caregivers did not start to lift the patient's legs until they had positioned themselves and the patient as close to the bed as possible. Less-experienced caregivers would lift and support the legs through their entire movement.

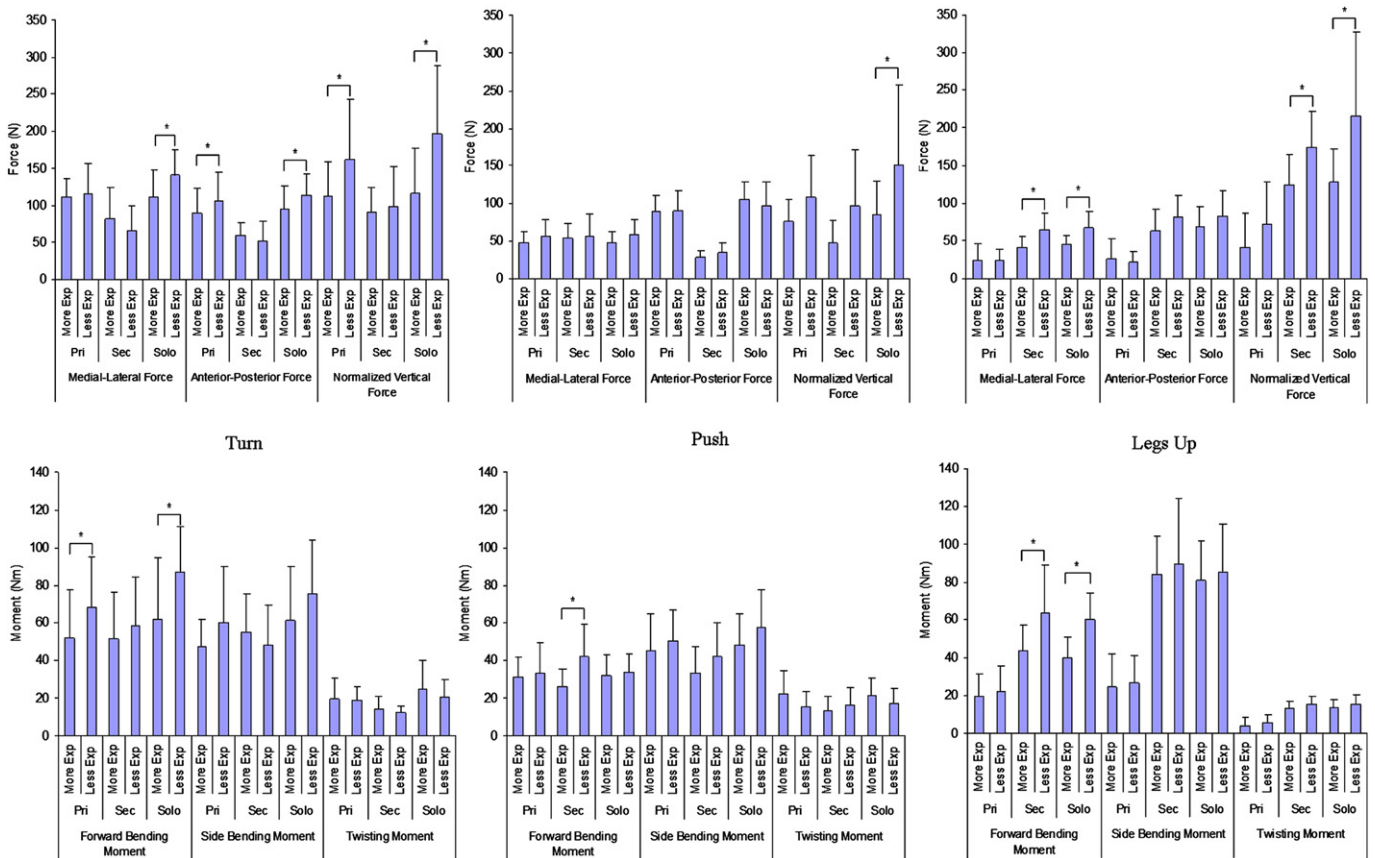
### 3.2. Differences in movement patterns with the overhead lift

Some differences between the two groups of caregivers were noted with overhead lift use even though no significant effect of experience level was found. For example, during the Turn activity with the overhead lift, more-experienced caregivers typically spun the patient with a single arm motion, remaining stationary, out of the way of the rotation. In contrast, less-experienced caregivers often chose to keep facing the patient, holding the patient with both hands. This required less-experienced caregivers to adopt

**Table 6**  
Mean and standard deviation of external moments at the L5/S1 joint resulting from the lift maneuvering tasks.

Activity	Lift	Cond	Forward bending moment (Nm)						Side bending moment (Nm)						Twisting moment (Nm)					
			More exp		Less exp		Sig	More exp		Less exp		Sig	More exp		Less exp		Sig			
			Mean	SD	Mean	SD		Mean	SD	Mean	SD		Mean	SD	Mean	SD				
Legs Down	F	Pri	20.9	9.1	24.4	10.3		23.5	19.2	28.2	17.7		5.6	5.3	5.8	3.1				
		Sec	44.9	14	45.6	13.1		75.2	25.3	98.9	68.9		11.4	3.9	11.9	4				
		Solo	42.9	18.3	48.4	20		79.2	18.1	86.2	33.9		10.1	2.7	12.3	6.3				
Pull	F	Pri	25.1	24.4	28.6	10.3		31.6	29.8	28.7	14.5		5.2	2.4	5	2.3				
		Sec	37.7	12.5	43	20		92	35.3	84	31.8		12.4	5.6	14.2	6.5				
		Solo	38.2	14.4	40.1	12.8		84.3	21	82	27.5		12.9	5.6	11.7	3.7				
Turn	F	Pri	37.8	11.5	46	26		57.6	27.3	72.1	30.8		16	9.3	17.7	8.7				
		Sec	30.1	15.3	38.3	16.3		40.8	19.3	35.5	13.2		12.1	7.2	11.2	7.6				
		Solo	34.2	10.6	39.3	14.7		57.1	28.5	83.2	68.8		15.7	8	17.8	7.9				
Push	F	Pri	25.2	8.6	30.9	11.1		32	17.2	32.8	13.9		8.2	3.3	8.8	2.4				
		Sec	26.8	10.3	29.2	10.3		35.8	17.1	44.1	20.8		8	3.9	9.1	3.3				
		Solo	30.9	12.1	30.9	9.5		40.3	25.7	52	19.3		14.9	5.4	13.3	3.6				
Legs Up	F	Pri	51.8	26	69.4	27.4	*	47.1	14.8	60.9	31.7		19.7	11.4	18.7	8				
		Sec	51.7	24.5	61	26.7		55.2	20.7	48	20.7		14.2	6.9	12.3	4				
		Solo	61.8	33.1	89.3	24.3	*	61.5	28.7	72.2	27		24.9	15.3	21.2	10.1				
Legs Down	O	Pri	27.1	13.2	38.5	19		29.2	22.3	34.3	18.3		4.3	1.6	8	5.3				
		Sec	30.5	9.6	47.3	22.8		29.1	14.4	39.1	20.9		5.4	2.1	9.7	4.5				
		Solo	34.5	23.1	43.2	24.6		37.6	31	37.2	17.5		13.3	7.5	11.6	6.1				
Push	O	Pri	31.2	10.5	33	16.2		45.4	19.3	51.2	17.3		21.9	12.8	15.8	8.4				
		Sec	26	9.4	44.3	17.1	*	33.7	13.4	41.2	19.3		13.6	7.6	18	8.7				
		Solo	31.9	11.4	34.5	9.5		48.5	16.1	56.9	20.1		21.5	9.2	17.5	8.1				
Legs Up	O	Pri	28.9	15.4	27.6	7.9		29.1	12.1	29.9	13.1		9.3	3.5	10.9	4.4				
		Sec	27.4	10.7	29.1	7.6		32.1	17.9	33.2	13.6		11.1	5.5	11.7	5.1				
		Solo	28.7	12.7	33.3	12.4		37.9	18.8	47.6	22		15.2	6.6	14.7	6.1				
Legs Down	O	Pri	19.5	12	19.5	12		24.8	17.2	28	13.7		4.3	4.3	5.6	4.4				
		Sec	43.8	13.4	66.3	26.2	*	83.7	21	87.5	36		13.2	3.8	15.4	4.3				
		Solo	40.2	10.8	61.4	14.4	*	80.6	21.1	83.2	26.4		14.1	3.9	15.5	5.5				
Legs Up	O	Pri	22.1	11.8	31.2	15.5		40.8	34.3	39.1	22		7.8	5.7	7.9	5.3				
		Sec	33.5	11	37.3	5.8		91.6	32.2	73.8	24.6		13.3	7	15.5	5.2				
		Solo	33	12.8	41.3	14.4		90	23.6	78.4	28.8		13.6	4	15.9	6.5				

Legend: F – floor lift; O – overhead lift; Cond – condition; Pri – primary caregiver; Sec – secondary caregiver; Solo – solo caregiver; More Exp –more-experienced; Less Exp –less-experienced; Sig – significant for  $p > 0.05$ .



**Fig. 2.** Peak forces and moments resulting from the Turn, Push and Legs Up activities with the floor lift.

awkward positions to avoid the hitting the patient's legs and feet, the lift, the other caregiver or other items in the environment, while sidestepping along a semi-circular path to obtain the same rotation.

### 3.3. Study limitations

The findings of this study suggest that caregivers learn how to perform lift maneuvering tasks in ways that are protective of their backs over time. It is possible that this protection of their backs occurs at a cost to exposing other parts of the body to higher loads such as the shoulder as has been found in previous work (Hodder et al., 2010; Keir and MacDonell, 2004). This possible tradeoff of injury risk should be studied further. Similarly, the influence of experience level on the co-contraction of the trunk muscles should be studied in combination with a more detailed biomechanical model.

### 3.4. Future work

More study is required to determine whether different types of training can be used to boost a caregiver's effective experience level. The efficacy of training programs remains inconclusive. While training has been shown to improve work technique (Johnsson et al., 2002; Reid and Mirka, 2007), it has also been shown to be largely ineffective in reducing back pain, back injury or other musculoskeletal symptoms (Bos et al., 2006; Clemes et al., 2010; Warming et al., 2008). This work on increasing an individual's effective experience level would be particularly important for protecting informal caregivers in the home environment – often family or friends of the patient who likely have minimal experience in their caregiving roles. It may be possible to shorten the process of gaining experience for newer caregivers by developing a set of illustrations to help teach new caregivers the 'tricks' that can reduce loading during key actions.

## 4. Conclusions

More-experienced caregivers generated lower loads on their low-backs compared to less-experienced caregivers when maneuvering floor lifts but not with overhead lifts. These differences appear to be due to variations in technique that allow more-experienced caregivers to limit the amount they bend as well as reduce the forces they apply using their hands by preferentially using their feet when possible to maneuver floor lifts. These findings indicate that workplaces should consider instituting greater protection for less-experienced caregivers if they are required to work with floor lifts and preferentially install overhead lifts whenever possible.

## Acknowledgments

This project was funded by a research grant provided by the Workplace Safety and Insurance Board (Ontario). We also acknowledge the support of Toronto Rehabilitation Institute who receives funding under the Provincial Rehabilitation Research Program from the Ministry of Health and Long-Term Care in Ontario (MOHLTC Grant #06036). Equipment was funded in part by Canada Foundation for Innovation (Grant #8708), Ontario Innovation Trust, Ministry of Research and Innovation and Toronto Rehab Foundation. The first author (TD) received funding from the National Science and Engineering Research Council as well as the MITACS Accelerate internship program. The views expressed do not necessarily reflect those of these organizations.

## References

- Alamgir, H., Li, O.W., Yu, S., Gorman, E., Fast, C., Kidd, C., 2009. Evaluation of ceiling lifts: transfer time, patient comfort and staff perceptions. *Injury* 40 (9), 987–992.
- Blankevoort, L., Huiskes, R., Lange, A.d., 1990. Helical axes of passive knee joint motions. *Journal of Biomechanics* 23 (12), 1219–1229.
- BLS, 2008. Table 21. Incidence Rates for Nonfatal Occupational Injuries and Illnesses Involving Days away from Work per 10,000 Full-time Workers by Selected Worker Occupation and Selected Parts of Body Available from: <http://www.bls.gov/news.release/osh2.t21.htm> (accessed 27.01.10.).
- Bos, E.H., Krol, B., van der Star, A., Groothoff, J.W., 2006. The effects of occupational interventions on reduction of musculoskeletal symptoms in the nursing profession. *Ergonomics* 49 (7), 706–723.
- Canadian Home Care Association, 2003. Canada Home Care Human Resources Study Available from: [www.cdnhomocare.ca/content.php?doc=33](http://www.cdnhomocare.ca/content.php?doc=33) (accessed 29.06.10.).
- Cappozzo, A., Catani, F., Croce, U.D., Leardini, A., 1995. Position and orientation in space of bones during movement: anatomical frame definition and determination. *Clinical Biomechanics* 10 (4), 171–178.
- Carmichael, B., 2006. Development and Testing of a Portable Force Sensing System for biomechanical Assessment of Actual Workplace Settings. Institute of Biomaterials and Biomedical Engineering, University of Toronto, Toronto, pp. 1–195.
- Cleaves, S.A., Haslam, C.O., Haslam, R.A., 2010. What constitutes effective manual handling training? A systematic review. *Occupational Medicine* 60 (2), 101–107.
- Collins, J.W., Wolf, L., Bell, J., Evanoff, B., 2004. An evaluation of a "best practices" musculoskeletal injury prevention program in nursing homes. *Injury Prevention* 10 (4), 206–211.
- Davis, K.G., Jorgensen, M.J., 2005. Biomechanical modeling for understanding of low back injuries: a systematic review. *Occupational Ergonomics* 5 (1), 57–76.
- Dutta, T., 2006. Development of a Portable Motion Capture System. Department of Mechanical and Industrial Engineering, University of Toronto, Toronto.
- Dutta, T., Holliday, P., Gorski, S., Baharvandy, M., Fernie, G., submitted. A biomechanical assessment of floor and overhead lifts using one and two caregivers for patient transfers. *Applied Ergonomics*.
- Edlich, R.E., Winters, K.L., Hudson, M.A., Britt, L.D., Long, W.B., 2004. Prevention of disabling back injuries in nurses by the use of mechanical patient lift systems. *Journal of Long-term Effects of Medical Implants* 14 (6), 521–533.
- Engkvist, I.L., 2004. The accident process preceding back injuries among Australian nurses. *Safety Science* 42 (3), 221–235.
- Engst, C., Chhokar, R., Miller, A., Tate, R.B., Yassi, A., 2005. Effectiveness of overhead lifting devices in reducing the risk of injury to care staff in extended care facilities. *Ergonomics* 48 (2), 187–199.
- Evanoff, B., Aton, E., Canos, J., Wolf, L., Collins, J., 2003. Reduction in injury rates in nursing personnel through introduction of mechanical lifts in the workplace. *American Journal of Industrial Medicine* 44 (5), 451–457.
- Evanoff, B., Li, J., Wolf, L., 2004. Use of mechanical patient lifts decreased musculoskeletal symptoms and injuries among health care workers. *Injury Prevention* 10 (4), 212–216.
- Granata, K.P., Marras, W.S., 1999. Relation between spinal load factors and the high-risk probability of occupational low-back disorder. *Ergonomics* 42 (9), 1187–1199.
- Hodder, J.N., MacKinnon, S.N., Ralhan, A., Keir, P.J., 2010. Effects of training and experience on patient transfer biomechanics. *International Journal of Industrial Ergonomics* 40 (3), 282–288.
- Holliday, P.J., Fernie, G.R., Plowman, S., 1994. The impact of new lifting technology in long term care: a pilot study. *AAOHN Journal* 42 (12), 582–589.
- Jager, M., Luttmann, A., 1996. Extended compilation of cadaver-related measurements on lumbar ultimate compressive strength. In: Mital, A., Krueger, H., Kumar, S., Menozzi, M., Fernandez, J. (Eds.), *Advances in Occupational Ergonomics and Safety I*, pp. 297–302. Cincinnati, Ohio.
- Johnsson, C., Carlsson, R., Lagerstrom, M., 2002. Evaluation of training in patient handling and moving skills among hospital and home care personnel. *Ergonomics* 45 (12), 850–865.
- Karahan, A., Kav, S., Abbasoglu, A., Dogan, N., 2009. Low back pain: prevalence and associated risk factors among hospital staff. *Journal of Advanced Nursing* 65 (3), 516–524.
- Keir, P., MacDonell, C., 2004. Muscle activity during patient transfers: a preliminary study on the influence of lift assists and experience. *Ergonomics* 47 (3), 296–306.
- Kingma, I., Baten, C.T.M., Dolan, P., Toussaint, H.M., Van Dieen, J.H., De Looze, M.P., Adams, M.A., 2001. Lumbar loading during lifting: a comparative study of three measurement techniques. *Journal of Electromyography and Kinesiology* 11 (5), 337–345.
- Leighton, D.J., Reilly, T., 1995. Epidemiological aspects of back pain: the incidence and prevalence of back pain in nurses compared to the general population. *Occupational Medicine* 45, 263–267.
- Marras, W.S., Knapik, G.G., Ferguson, S., 2009. Lumbar spine forces during manoeuvring of ceiling-based and floor-based patient transfer devices. *Ergonomics* 52 (3), 384–397.
- McNeill, T., Warwick, D., Andersson, G., Schultz, A., 1980. Trunk strengths in attempted flexion, extension, and lateral bending in healthy subjects and patients with low-back disorders. *Spine* 5 (6), 529–537.
- Moscato, U., Trinca, D., Rega, M.L., Mannocci, A., Chiaradia, G., Grieco, G., Ricciardi, W., La Torre, G., 2010. Musculoskeletal injuries among operating room nurses: results from a multicenter survey in Rome, Italy. *Journal of Public Health*, 1–7.

- Nelson, A.L., Collins, J., Knibbe, H., Cookson, K., de Castro, A.B., Whipple, K.L., 2007. Safer patient handling. *Nursing Management* 38 (3), 26–32.
- Parakkat, J., Yang, G., Chany, A.M., Burr, D., Marras, W.S., 2007. The influence of lift frequency, lift duration and work experience on discomfort reporting. *Ergonomics* 50 (3), 396–409.
- Reid, S.A., Mirka, G.A., 2007. Learning curve analysis of a patient lift-assist device. *Appl Ergon* 38 (6), 765–771.
- Rice, M.S., Woolley, S.M., Waters, T.R., 2009. Comparison of required operating forces between floor-based and overhead-mounted patient lifting devices. *Ergonomics* 52 (1), 112–120.
- Rong, C.X., 2008. Occupational back pain among hospital nurses. *Singapore General Hospital Proceedings* 17 (2), 79–87.
- Santaguida, P.L., Pierrynowski, M., Goldsmith, C., Fernie, G., 2005. Comparison of cumulative low back loads of caregivers when transferring patients using overhead and floor mechanical lifting devices. *Clinical Biomechanics* 20, 906–916.
- Seidel, G.K., Marchinda, D.M., Dijkers, M., Soutas-Little, R.W., 1995. Hip joint center location from palpable bony landmarks – a cadaver study. *Journal of Biomechanics* 28 (8), 995–998.
- Trinkoff, A.M., Brady, B., Nielsen, K., 2003. Workplace prevention and musculoskeletal injuries in nurses. *Journal of Nursing Administration* 33 (3), 153–158.
- Veltink, P.H., Liedtke, C., Droog, E., Van Der Kooij, H., 2005. Ambulatory measurement of ground reaction forces. *IEEE Transactions on Neural Systems and Rehabilitation Engineering* 13 (3), 423–427.
- Warming, S., Ebbehøj, N.E., Wiese, N., Larsen, L.H., Duckert, J., Tonnesen, H., 2008. Little effect of transfer technique instruction and physical fitness training in reducing low back pain among nurses: a cluster randomised intervention study. *Ergonomics* 51 (10), 1530–1548.
- Waters, T.R., 2007a. Evidence-based practices for safe patient handling, in: 7th Annual Safe Patient Handling and Movement Conference, Lake Buena Vista, Florida.
- Waters, T.R., 2007b. When is it safe to manually lift a patient? *American Journal of Nursing* 107 (8), 53–58.
- Winter, D.A., 2004. *Biomechanics and Motor Control of Human Movement*. Wiley, Hoboken, NJ.
- Yassi, A., Khokhar, J., Tate, R., Cooper, J., Snow, C., Vallentyne, S., 1995. The epidemiology of back injuries in nurses at a large Canadian Tertiary care hospital: implications for prevention. *Occupational Medicine* 45 (4), 215–220.
- Young, J.W., Chandler, R.F., Snow, C.C., Robinette, K.M., Zehner, G.F., Lofberg, Ms., 1983. *Anthropometric and Mass Distribution Characteristics of Adult Females*. FAA Civil Aeromedical Institute, Oklahoma City.
- Zhuang, Z., Collins, J.W., Hongwei, H., Stobbe, T.J., Hobbs, G.R., 2000. Psychophysical assessment of assistive devices for transferring patients/residents. *Appl Ergon* 31 (1), 35–44.
- Zhuang, Z., Stobbe, T.J., Hsiao, H., Collins, J.W., Hobbs, G.R., 1999. Biomechanical evaluation of assistive devices for transferring residents. *Applied Ergonomics* 30 (4), 285–294.