Ergonomics, 1996, vol. 39, no. 2, 322–334

Trunk kinematics of one-handed lifting, and the effects of asymmetry and load weight

W. Gary Allread, William S. Marras and Mohamad Parnianpour

The Ohio State University, Biodynamics Laboratory, 1971 Neil Ave.,
210 Baker Systems, Columbus, OH 43210 USA

Keywords: Trunk kinematics; Lifting; Asymmetry; Manual materials handling.

This study investigated trunk kinematic differences between lifts performed using either one hand (unsupported) or two hands. These effects were studied while beginning the lifts from different asymmetric starting positions and while lifting different load weights. Each subject lifted a box from a lower to an upper platform under one- and two-handed lifting conditions. Subjects wore a lumbar spine electrogoniometer, from which relative motion components were calculated in the trunk's three cardinal planes. Results of this study showed that one-handed lifting resulted in significantly higher ranges of motion in the lateral and transverse planes and greater flexion in the sagittal plane. Back motion characteristics previously found to be associated with low back disorders were all significantly higher for one-handed lifts. The two-handed lift technique, on the other hand, produced overall faster trunk motions in the sagittal plane and equal or larger acceleration and deceleration magnitudes in all planes of motion. Increases in load asymmetry affected trunk kinematics, in that magnitude values for range of motion, velocity and acceleration became much greater with increasingly asymmetric load positions. Increasing the load weight appeared to have less of an effect on trunk kinematics, with increases in position mostly occurring during sagittal and lateral bending. These results suggest that unsupported one-handed lifting loads the spine more than two-handed lifts, due to the added coupling. Applying these results to a previously developed model, one-handed lifting was also found to increase one's risk of suffering a low back disorder.

1. Introduction

The costs associated with strains to the low back are substantial for American industries (National Safety Council, 1989). Several studies have identified repetitive manual materials handling (MMH) as a risk factor for low back disorders (LBD) (Bigos *et al.* 1986, U.S. Department of Labor 1989). In fact, these studies found MMH to be the dominant factor in occupationally related LBD.

Models incorporating the dynamic aspects of lifting have also received much attention (McGill and Norman 1985, Freivalds *et al.* 1984). Loading on the spine was found to increase from 19% to 52% when trunk movements were included in these models. Bigos *et al*'s (1986) occupational study found that dynamic lifting produced a three-fold increase in LBD risk as compared with awkward static postures.

Another factor, trunk twisting associated with asymmetric lifting, has been related to greater odds of LBD (Kelsey *et al.* 1984, Andersson 1981). Twisting has been linked with decreases in trunk torque production (Marras and Mirka 1989) and changes in the muscles that are the primary movers of the trunk (Marras *et al.* 1990) as well.

These studies suggest which activities and work place factors compromise the spine and its ability to counterbalance external loads. However, a work-related element not included in these studies, but frequently performed in MMH, may be relevant. That is, individuals who must handle odd-shaped objects, perform tasks in confined spaces, or work in poorly designed environments may handle the load using only one hand. Unfortunately, research into the biomechanical effects of one-handed lifting is sparse. In fact, most has relied on psychophysical methods (Garg and Saxena 1982, Garg 1983). These studies focused on assessing fatigue and maximum acceptable frequencies of one-handed lifting while subjects simulated work often done along industrial production lines. These researchers found that load weight and horizontal reach distance were the factors affecting lift frequency. Neither study compared their results with a corresponding two-handed lift.

The aforementioned studies have separately illustrated the biomechanical effects of dynamic, asymmetric and one-handed lifting. However, we are aware of no research that has incorporated the real-world task of dynamic, unsupported one-handed lifting under symmetric and asymmetric conditions. Furthermore, one- and two-handed lifting comparisons do not exist. The objective of this study was to

Figure 1. Lumbar Motion Monitor (LMM) on subject.

examine various lifting conditions and determine whether or not lifting a load with only one hand (with the body unsupported) changed trunk kinematics from those lifts done using the more common two-handed lifting technique. It is recognized that prevention is the first step toward reducing the spiraling rise in health care costs. Therefore, the need exists to provide ergonomists with kinematic and risk information for all types of lifting tasks found in industry.

2. Method

2.1. *Subjects*

Twenty-four males were used as subjects in this study. Calculations of pilot study data determined that this sample size generated a power of 0·80. All subjects were right-handed and reported to be free from low back injuries or other ailments. Mean (standard deviation) age, weight, and height for this group were 25·08 (4·03) years, 73·44 (10·17) kg and 176·91 (6·73) cm, respectively.

2.2. *Experimental Design*

This study used a three-way factorial design; each subject performed every lifting condition. The independent variables chosen were: lift technique (use of one or two hands); load asymmetry at the beginning of the lift (Sagittally symmetric and 45, 90, and 135 deg to the right of the mid-sagittal plane); and box weight (3·40, 6·80 and 10·20 kg). The model used to analyze these data included fixed main effects of these three variables, all three two-way interactions and the one three-way interaction. The dependent variables to be reported here were the kinematic lumbar spine variables (maximum position, average and maximum velocity, and maximum acceleration) in the sagittal, lateral (coronal) and transverse planes of the trunk.

2.3. *Apparatus*

A Lumbar Motion Monitor (LMM) was used to collect kinematic data in the three cardinal planes. The LMM, shown in figure 1, was an electrogoniometer that essentially represents an exoskeleton of the spine. It fitted closely onto subjects' backs using a waist and shoulder harness. A more complete, technical description of this device has been provided by Marras *et al.* (1992). Subjects stood on a Bertec^{TM} force plate, which was zeroed prior to each lift, in order to remove subject weight effects. Two time markers were used by the experimenter–one to indicate the onset and a second to signify the completion of the lift. In this way, extraneous movements of the unloaded spine could be deleted. Voltage outputs from the LMM, force plate

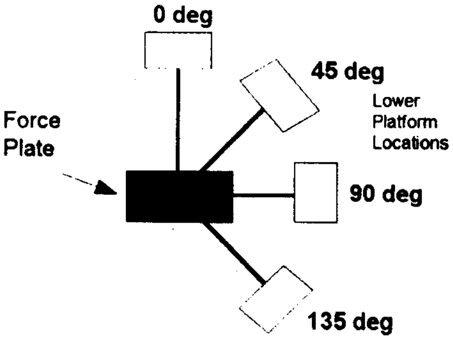

Figure 2. Locations of lower platform.

and time markers were input into a Labpac^{TM} A/D converter and the data were stored on a portable 386 computer. Data were sampled at a frequency of 60 Hz using customized data collection software.

The same box was handled in all trials, but it was weighted according to which experimental condition was being run. It measured 43·2 cm between the two outside handles, was 22·9 cm high and 27·9 cm deep. A single handle, used for one-handed lifting, was centred inside the box at the same vertical height as the two outer handles. All handles measured 2·9 cm in diameter. Subjects were required to use the (centre or two outside) handles for all lifts, rather than holding onto the box by its sides, for example. This was done in an effort to keep the variability in the conditions to a minimum and to ensure the lifting start and completion heights remained constant for all subjects.

Before the initiation of each lift, the box was set on the lower platform, which placed the handles 76·2 cm above the floor. There were four locations at which the lower platform was placed, sagittally symmetric (directly in front of the subject) and 45, 90, or 135 deg to the subject's right side. These locations are shown in figure 2. The upper platform was located directly above the sagittally symmetric lower platform position. Handle height at the completion of the lift, when the box was placed on the upper platform, was 137·2 cm. The horizontal distance from the center of the subject's standing position (i.e., the location of the spine) to all lower and upper platform positions was 63·5 cm. This distance corresponded to the average horizontal distance between material handlers' lumbar spines (at L5/S1) and the centre of the loads they handled, as found by Marras *et al.* (1993).

2.4 *Procedure*

2.4.1. *Training Session:* Each subject was trained first as to the correct method for lifting the box using either one or two hands. Subjects practised the lifting tasks for all conditions of asymmetry and load weight. They were instructed that lifts should be performed at a comfortable pace, one which subjects felt they should use if doing MMH for an entire eight-hour work shift. They were asked to continue at this pace in the testing session. No other restrictions were placed specifically on how the lifts were to be performed.

2.4.2. *Testing Session:* During testing, subjects were fitted with the appropriately sized LMM (based on spine length) and then asked to stand on the force plate. Because this plate was used, subjects were not permitted to move their feet while performing lifts. Subjects were told to lift the test box from the lower platform to the upper platform in accordance with the particular test condition. They were instructed which technique to use immediately before each lift and were told the weight level (given in relative terms of 'low,' 'medium,' or 'high' weight). Each experimental condition was tested three times. To reduce the possibility of fatigue, subjects were allowed to rest for at least one minute between lifts (while the subsequent test condition was set up) and they were provided with a stool for sitting on between trials. Two scheduled rest breaks were included during the testing session. A subject performing a one-handed lift from the 90 deg position is shown in figure 3.

3. Results

Multi-factor analysis of variance procedure were conducted on the data; all main effects and interactions were found to be significant ($p \leq 0·05$). Univariate analyses

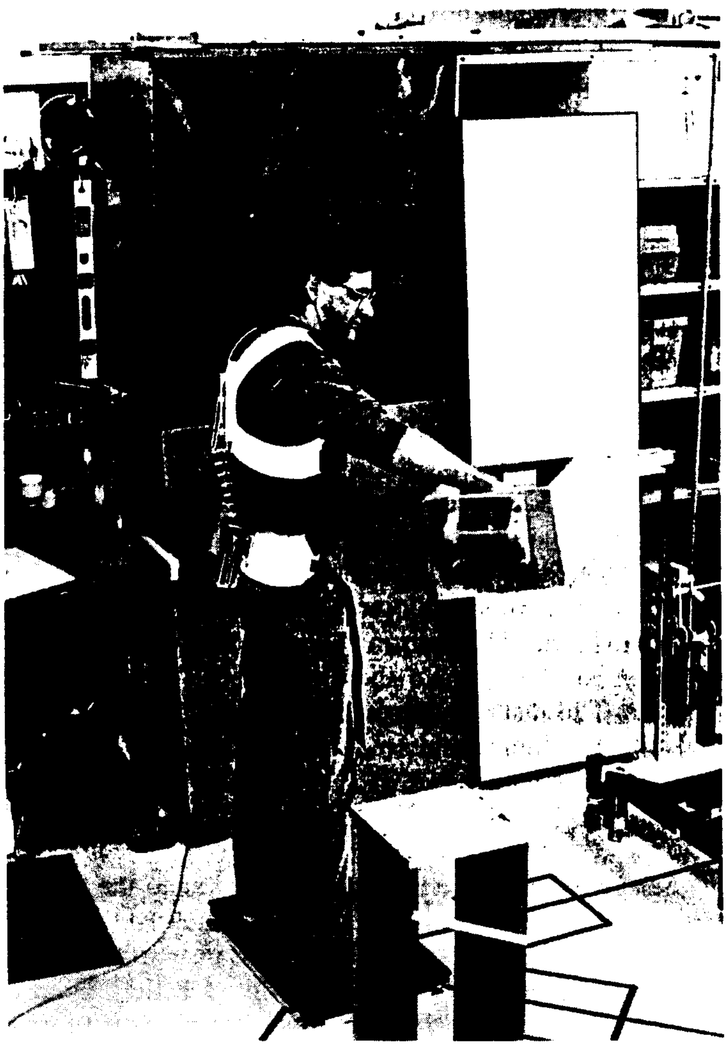

Figure 3. Subject lifting test box with one hand.

then were performed on the dependent variables. Force plate results will not be reported in this paper. Numerous main effects were significantly different from one another. Differences were seen between the two lift techniques for all sagittal plane variables, all lateral plane variables (except acceleration) and all twisting plane variables (except maximum velocity and acceleration). Task asymmetry also showed statistical significance for all measures, except maximum flexion in the sagittal plane. The varying of load weight was found to have fewer significant effects on the dependent variables. Several interactions also were found to be significant. Nearly half of these were lift technique-by-asymmetry (L × A) interactions.

3.1 *Lift technique*

Table 1 shows descriptive statistics for the lift technique main effects. As this table shows, all sagittal plane motion variables were significantly higher for two-handed lifts, except for maximum flexion. The fact that one-handed lifts produced more sagittal flexion, while two-handed lifts produced more sagittal range of motion, indicates subjects remained in a more flexed posture during the one-handed lifts.

Table 1. Descriptive statistics between lift techniques.

		Lift technique			
		1-handed		2-handed	
	Units	Mean	Std. dev.	Mean	Std. dev.
Sagittal plane					
Maximum flexion	deg	**32·13	5·15	28·54	8·06
Range of motion	deg	32·29	7·23	**43·36	12·65
Average velocity	deg/sec	14·06	3·46	**18·57	5·83
Maximum velocity	deg/sec	47·17	11·80	**60·22	20·93
Maximum acceleration	deg/sec^2	146·10	53·18	**194·21	104·60
Lateral plane					
Maximum right bend	deg	**12·69	5·97	−0·34	8·75
Range of motion	deg	**25·56	9·00	12·26	4·36
Average velocity	deg/sec	**11·47	4·11	7·16	2·96
Maximum velocity	deg/sec	**33·36	11·49	22·39	11·01
Maximum acceleration	deg/sec^2	120·22	73·41	128·47	96·99
Transverse plane					
Maximum right twist	deg	7·29	7·60	**14·80	7·95
Range of motion	deg	**10·96	6·86	8·76	6·66
Average velocity	deg/sec	**4·77	2·72	4·19	3·09
Maximum velocity	deg/sec	20·04	10·60	20·68	14·96
Maximum acceleraton	deg/sec^2	105·69	55·27	**111·68	78·63

**denotes significant higher, at $p < 0.05$

In the lateral plane, one-handed lifts resulted in a greater trunk position to the right (toward the load) and a larger range of motion. The one-handed lifts also produced significantly higher average and maximum lateral velocities, which were both approximately 50% higher than when two-hands were used.

In the transverse plane, two-handed lifts produced more twisting to the right. This was most likely due to the experimental set-up, which required subjects to not move their feet during the lifts. The overall twisting range of motion, though, was greater during one-handed lifting, as was average velocity (though the actual amount was about 0·6 deg/sec). In all three planes, two-handed lifts produced accelerations that were the same or higher than for one-handed lifting.

3.2 *Asymmetry*

A summary of trunk characteristics in response to asymmetric lifting is shown in table 2. Greater asymmetries produced significant changes in many of the kinematic parameters. Positioning the lower platform at more asymmetric positions produced greater sagittal and lateral ranges of motion as well as higher average and maximum velocities in these two planes. Increased asymmetry also brought about higher lateral and sagittal accelerations, but only at the most asymmetric angles. It is important to note the response to asymmetry of the transverse plane kinematic variables. For each variable studied, significant increases were found across every level of increasing asymmetry.

3.3 *Load weight*

Kinematic differences due to load weight, shown in table 3, exhibited less dramatic

Table 2. Descriptive statistics across asymmetry conditions.

	Asymmetry (deg)							
	0		45		90		135	
	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.
Sagittal plane								
Maximum flexion	31·22	5·49	30·98	5·32	30·01	5·39	29·14	10·32
Range of motion	^{A}33·26	5·84	^{A}33·10	6·73	^{B}37·18	10·12	^{C}47·85	15·03
Average velocity	^{A}13·50	3·11	^{B}15·10	3·49	^{C}16·93	4·71	^{D}19·75	6·90
Maximum velocity	^{A}41·49	11·57	^{B}50·66	10·84	^{B}56·53	14·70	^{C}66·24	23·28
Max. acceleration	^{A}146·98	63·83	^{A}153·08	45·79	^{A}172·73	77·43	^{B}208·12	124·99
Lateral plane								
Max. right bend	^{A}10·74	7·66	^{B}5·38	9·11	^{C}3·89	10·47	^{B,C}4·79	10·76
Range of motion	^{A}15·23	5·71	^{B}16·90	7·66	^{C}19·97	10·77	^{D}23·78	11·43
Average velocity	^{A}7·18	3·18	^{B}8·76	3·45	^{C}10·19	4·47	^{D}11·22	4·36
Maximum velocity	^{A}22·03	8·27	^{B}26·73	11·42	^{B,C}30·07	12·88	^{C}32·89	14·15
Max acceleration	^{A}88·06	37·45	^{A}107·42	34·62	^{B}142·73	106·13	^{B}159·82	113·02
Transverse plane								
Max. right twist	^{A}1·48	4·42	^{B}8·67	5·03	^{C}13·40	5·59	^{D}20·77	5·06
Range of motion	^{A}2·85	2·38	^{B}6·77	2·60	^{C}11·31	3·34	^{D}18·70	5·09
Average velocity	^{A}1·49	1·46	^{B}3·70	1·85	^{C}5·23	1·95	^{D}7·58	2·30
Maximum velocity	^{A}7·32	7·03	^{B}15·95	7·53	^{C}24·58	8·83	^{D}33·86	9·99
Max. acceleration	^{A}42·19	42·78	^{B}94·91	47·61	^{C}131·90	48·60	^{D}166·91	59·44

Note:
- Units for flexion, right bend, right twist and range of motion variables are deg.
- Units for average velocity and maximum velocity are deg/sec.
- Units for acceleration one deg/sec^2.

Dependent variables with the same superscripted letter (A, B, C, D) across asymmetry conditions were not statistically different from each other.

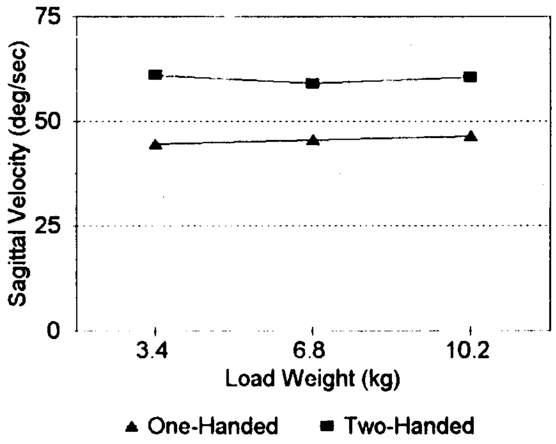

Figure 4. Example of an ordinal interaction: Sagittal plane–maximum velocity lift technique × load weight interaction.

results than the other independent variables. Increasing weights produced greater maximum sagittal flexion and range of motion, as well as increased right bending and lateral range of motion. Only slight increases in velocity of movement were seen for the average sagittal velocity and maximum lateral velocity. Twisting acceleration

Table 3. Descriptive statisticss across load weight conditons.

	Load weight (kg)					
	3·40		6·80		10·20	
	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.
Sagittal plane						
Maximum flexion	^{A}30·04	6·50	^{A,B}30·12	6·86	^{B}30·86	7·59
Range of motion	^{A}36·04	11·98	^{B}37·91	11·43	^{C}39·43	11·44
Average velocity	^{A}15·90	5·44	^{A,B}16·28	5·24	^{B}16·72	5·19
Maximum velocity	52·94	18·24	52·98	17·60	55·07	18·66
Max. acceleration	172·12	85·85	171·26	85·27	166·71	87·81
Lateral plane						
Max. right bend	^{A}5·10	9·17	^{B}6·37	10·12	^{C}7·16	10·37
Range of motion	^{A}18·24	9·27	^{B}19·22	9·90	^{B}19·38	9·96
Average velocity	9·22	4·00	9·38	4·24	9·38	4·31
Maximum velocity	^{A}26·72	11·20	^{A,B}28·01	12·36	^{B}28·97	13·80
Max. acceleration	114·94	53·56	131·41	104·66	126·61	91·02
Transverse plane						
Max right twist	11·11	8·71	10·91	8·67	11·06	8·55
Range of motion	9·79	6·81	9·84	6·88	9·96	6·87
Average velocity	4·59	3·02	4·43	2·91	4·43	2·85
Maximum velocity	20·82	13·59	20·22	12·79	20·03	12·49
Max acceleration	^{A}113·01	72·56	^{A,B}106·93	66·87	^{B}106·07	64·18

Note:
- Units for flexion, right bend, right twist and range of motion variables are deg.
- Units of average velocity and maximum velocity are deg/sec.
- Units for acceleration are deg/sec^2.

Dependent variables with the same superscripted letter (A, B, C) across conditions were not statistically different from each other.

actually decreased slightly. All changes in motion due to load weight variation were slight, though significant ($p \leq 0{\cdot}05$).

3.4. *Interactions*

Univariate analyses found that several two- and three-factor interactions were significant ($p < 0{\cdot}05$). However, over half of these interactions could be described as ordinal. That is, a majority of the differences between levels of the main effects were fairly consistent, but with slight magnitude differences across levels, enough to produce the statistical significance. An example of a typical ordinal interaction is shown in figure 4, for the lift technique × load weight interaction of the variable maximum sagittal velocity.

A third of all interactions could be classified as 'diverging.' These were found mainly with interactions involving asymmetry. For these, values were very similar at the sagittal symmetric position, but the responses grew dramatically different as asymmetry increased. An example of a diverging interaction is shown in figure 5. This figure represents the lift technique × asymmetry interaction for lateral range of motion.

Only three of the significant interactions were disordinal and all involved the L × A interaction. They occurred for the maximum lateral acceleration and maximum transverse velocity and acceleration variables. For these interactions, one-handed lifts produced greater values at the sagittally symmetric position, but as

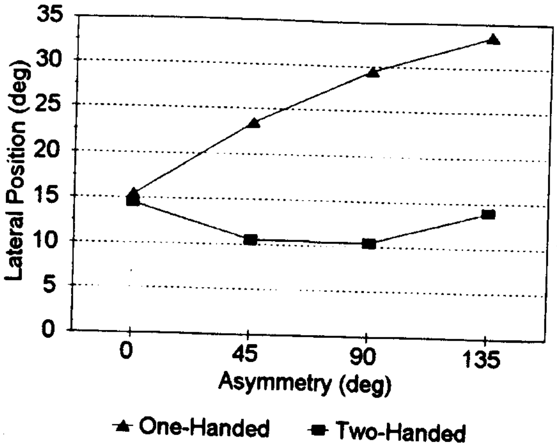

Figure 5. Example of a diverging interaction: Lateral plane–range of motion–lift technique × asymmetry interaction.

asymmetry increased, two-handed lift responses were higher in magnitude. This is believed to be a result of the experimental set-up and the requirement for subjects not to move their feet.

4. Discussion

4.1. *General findings*

Overall, trunk kinematic position and velocity variables collected in this study compared favorably with those found by Marras *et al.* (1993), indicating similar values to those produced by individuals doing MMH in industry. However, acceleration values were lower in this study, perhaps because subjects were asked to work at a comfortable pace. Often in industry, jobs are such that workers may move more rapidly than they consider 'comfortable' in order to keep up with production schedules. This may produce higher trunk accelerations.

4.2. *Effects of one-handed lifting*

Epidemiologically, movement in the lateral and transverse planes has been linked to higher risk of LBD. As reported by Snook (1982), 12% of back claims were associated with bending and 18% were identified with twisting. Kelsy *et al.* (1984) found that the risk of developing a prolapsed lumbar disc increased when twisting was required to lift an object, even when the lifts were not highly repetitive. Farfan *et al.* (1970) suggested that twisting may produce LBDs, as there was a linear relationship found between torque and angular deformation of lumbar vertebral segments. Unsupported one-handed lifts, therefore, could be considered to put workers more at risk of LBD because of this study's findings that the one-handed technique generated larger position ranges of motion and higher lateral and twisting velocities.

From a biomechanical perspective, these lateral and transverse motions have been associated with increased spinal loadings. Schultz *et al.*'s (1979) in-vitro examination of 42 lumbar motion segments found large lateral shear and increases in intradiskal pressure during lateral bending. A finite-element model developed by Shirazi-Adl (1989) calculated disc fibre tensile stains of approximately 10% when loads simulating symmetric lifting were analyzed. However, adding lateral bending and twisting components to the model increased the maximum fibre strain to over 20%. Also,

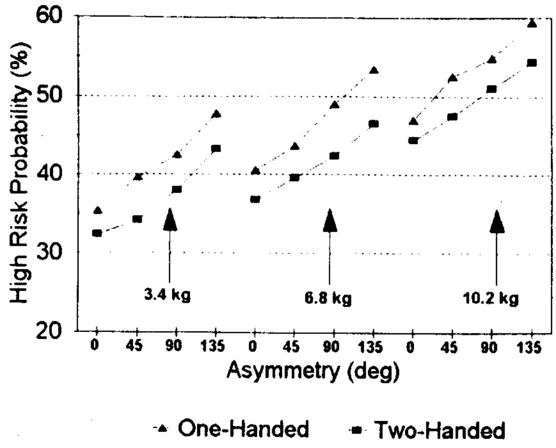

Figure 6. High risk group membership probabilities for each experimental conditon.

Shirazi-Adl (1991) determined that compressive loads on the facets and shear contact loads increased significantly when lifting involved lateral bending and twisting. These findings further suggest that additional loadings may be imposed on the spine during one-handed lifting.

Furthermore, results from Marras *et al.* (1993) suggested that, along with two work place factors (the maximum moment created during a lift and the repetitiveness of the job), three lumbar spine motion parameters were associated with the probability of being in a high risk of LBD group. These factors were maximum sagittal flexion, maximum lateral velocity and average twisting velocity. A probability model was developed that combined the risk values of each of these five factors. In this model, 0% indicated the lowest risk (no chance that a job would be considered 'high risk') and 100% signified highest risk (definite membership of a job in a high LBD risk group). Probability values were computed separately for each asymmetry and load weight condition and the results are graphed in figure 6. These probability values were computed using the constant horizontal moment arm of 63·5 cm. For all conditions, this figure shows that one-handed lifts produced larger risk probability values. Using *t*-statistics, these differences were found to be significant ($p \leq 0{\cdot}05$) between all lift technique conditions. Greater differences between the lifting techniques occurred with increasing asymmetries. In terms of these high-risk probabilities, trade-offs between lifting techniques can be considered based on this figure. In most cases, figure 6 illustrates that one-handed lifts generated probabilities equal to or greater than corresponding two-handed lifts that were 45 deg more asymmetric.

Table 1 shows that the three kinematic parameters used in the Marras LBD risk model, maximum sagittal flexion, maximum lateral velocity and average transverse velocity, were all statistically greater for one-handed lifting. Though significantly different, the mean values for the one-hand technique may appear to be comparable to those computed for two-handed lifting. However, the aforementioned model is capable of assessing predicted risk increases for each individual factor in the model. Sagittal flexion for one-handed lifting was 3·6 deg greater than the two-handed case. Using the Marras model, this translated to an increase in LBD risk of 10 to 20%. Similarly, the average transverse velocity for the one-handed technique was 0·6 deg/sec greater than for two-handed lifting. The Marras model assessed this difference as a 5 to 10% increase in risk for this factor. Finally, one-handed lifting produced a nearly

11 deg/sec increase in maximum lateral velocity as opposed to the two-handed case. This would be comparable to an increase in risk of 20% or more. Though the sagittal flexion and transverse velocity differences between lift techniques may appear not to be vastly different in magnitude, the individual and combined risk values for one-handed lifting, a shown by the Marras model, did produce significant increases over the two-handed technique. Figure 6 shows that performing one-handed lifts increased probability values by as much 7%. This demonstrates that a work place change as seemingly innocuous as using only one hand for lifting, can produce a notable increase in potential LBD risk.

The use of just one hand to lift a load may often be at the discretion of the material handler. It may be that both hands can be used for the task but the worker prefers not to do so. Ergonomic modifications to a work place are believed best implemented through engineering controls. However, using the results from this study in an administrative sense, instructing workers to use both hands, could ergonomically change a work place in which employees use one hand to lift, at no cost. These results imply that, by educating individuals that unsupported one-handed lifting may actually increase their risk of injury, following this instructional information alone could reduce risk by up to 7%.

These increased probability values for one-handed lifting suggest that a greater risk of injury exists when this lift technique is performed. These results also can be related to past psychophysical studies of asymmetric lifting. Garg and Badger's (1986) comparison of (two-handed) symmetric with asymmetric lifting (30, 60 and 90 deg to the right of the mid-sagittal plane) showed that the maximum acceptable weights subjects were willing to lift and the static strengths subjects could generate were lower for asymmetric lifting. Mital and Fard (1986) also found subjects lowered their maximal acceptable weights with (two-handed) lifting performed asymmetrically; in addition, subjects stated that these asymmetric lifts were physically more difficult for them. High-risk probability values found in the present study for one-handed lifts at more symmetric positions were equal to or greater than those for more asymmetric two-handed lifts. In comparison with these previous studies, one-handed lifting may lower subjects' capabilities; that is, reduce the weight found maximally acceptable to lift by subjects lower isometric strengths and create perceptions that the lift is physically more strenuous.

4.2. *Effects of two-handed lifting*

Two-handed lifts produced faster motions than one-handed lifting in the sagittal plane. The two-handed lift was done with the body in a more symmetric posture, making use of the erector spinae muscles (the primary movers of the trunk in this plane). This may have accounted for the faster movement. During one-handed lifting, use of other muscle groups that also move the trunk may have been required. These patterns of muscle recruitment that may not be as well-learned by subjects could have been responsible for the slower motions produced.

Acceleration and deceleration values were significantly higher for two-handed lifts in the sagittal and transverse planes. However, this may not translate to higher LBD risk. Marras *et al* (1993), for example, found that accelerations values between high- and low-risk jobs were not always statistically different and that velocity variables in the three planes were more consistently indicative of differences between risk groups.

5. Conclusions

The one-handed lift technique significantly altered motion of the lumbar spine. Due to increased range of motion in the lateral and transverse planes and the additional sagittal flexion produced, individuals who lifted loads with one-hand (without a structural support) were found to be at greater risk of suffering a LBD. This was determined using a previously developed model of LBD risk prediction (Marras *et al.* 1993).

'High risk' back motions were significantly greater for one-handed lifts. These were maximum sagittal flexion, maximum lateral velocity and average twisting velocity. One-handed lifts of moderate weight handled from extreme asymmetric positions, or of high weights handled in any asymmetric location generated probabilities of 'high risk' group membership over 50%.

Asymmetric load locations drastically increased the extent and speed at which the lifts were done; higher weights may pose additional problems for workers, in terms of greater spine motions required.

These results could be used to investigate MMH tasks in industry in which one-handed lifting is used. The implications of these types of lifts could be factored into the overall LBD risk of the job to better determine if the job still falls within 'safe' lifting limits. Further study is needed to understand how trunk kinematics differ in one-handed lifting when the unused hand can assist in supporting the body.

References

ANDERSSON, G. B. 1981. Epidemiologic aspects of low back pain in industry *Spine*, **6**, 53–60.

BIGOS, S. J., SPENGLER, D. M., MARTIN, N. A., ZEH, J., FISHER, L., NACHEMSON, A. and WANG, M. H. 1986, Back injuries in industry: A retrospective study, *Spine*, **11**, 246–251.

FARFAN, H. F., COSSETTE, J. W., ROBERTSON, G. H., WELLS, R. V. and KRAUS, H. 1970, The effects of torsion on the lumbar intervertebral joints: The role of torsion in the production of disc degeneration, *Journal of Bone Joint Surgery*, **52A**, 468.

FREIVALDS, A., CHAFFIN, D. B., GARG, A. and LEE, K. S. 1984, A dynamic biomechanical evaluation of lifting maximum acceptable loads, *Journal of Biomechanics*, **17**, 251 262.

GARG, A. 1983, Physiological responses to one-handed lift in the horizontal plane by female workers, *American Industrial Hygiene Association Journal*, **44**(3), 190–200.

GARG, A. and BADGER, D. 1986, Maximum acceptable weights and maximum voluntary isometric strengths for asymmetric lifting, *Ergonomics*, **29**, 879–892.

GARG, A. and SAXENA, U. 1982, Maximum frequency acceptable to female workers for one-handed lifts in the horizontal plane, *Ergonomics*, **25**, 839–853.

KELSEY, J. L., GITHENS, P. B., WHITE, A. A., HOLFORD, T. R., WALTER, S. D., O'CONNOR, T., OSTFELD, A. M., WEIL, U., SOUTHWICK, W. O. and CALOGERO, J. A. 1984, An epidemiologic study of lifting and twisting on the job and risk for acute prolapsed lumbar intervertebral disc, *Journal of Orthopaedic Research*, **2**, 61 66.

MARRAS, W. S., FATHALLAH, F. A., MILLER, R. J., DAVIS, S. W. and MIRKA, G. A. 1992, Accuracy of a three-dimensional lumbar motion monitor for recording dynamic trunk motion characteristics, *International Journal of Industrial Ergonomics*, **9**, 75 87.

MARRAS, W. S., FERGUSON, S. A. and SIMON, S. R. 1990, Three dimensional dynamic motor performance of the normal trunk, *International Journal of Industrial Ergonomics*, **6**, 211–224.

MARRAS, W. S., LAVENDER, S. A., LEURGANS, S. E., RAJULU, S. L., ALLREAD, W. G., FATHALLAH, F. A. and FERGUSON, S. A. 1993, The role of dynamic three-dimensional trunk motion in occupationally-related low back disorders, *Spine*, **18**, 617–628.

MARRAS, W. S. and MIRKA, G. A. 1989, Trunk strength as a function of trunk asymmetry and trunk velocity during concentric and eccentric exertions, *Advances in Industrial Ergonomics and Safety I*, (Taylor & Francis, London) 159–166.

MCGILL, S. M. and NORMAN, R. W. 1985, Dynamically and statically determined low back moments during lifting, *Journal of Biomechanics*, **18**, 877 885.

Mital, A. and Fard, H. F. 1986, Psychophysical and physiological responses to lifting symmetrical and asymmetrical loads symmetrically and asymmetrically, *Ergonomics*, **29**, 1263–1272.

National Safety Council, 1989, *Accident Facts.*

Schultz, A. B., Warwick, D. N., Berkson, M. H. and Nachemson, A. L. 1979, Mechanical properties of human lumbar spine motion segments, part I: Responses of flexion, extension, lateral bending, and torsion, *Biomechanical Engineering*, **101**, 46–52.

Shirazi-Adl, A. 1989, Stain in fibers of a lumbar disc–analysis of the role of lifting in producing disc prolapse. *Spine*, **14**, 96–103.

Shirazi-Adl, A. 1991, Finite-element evaluation of contact loads on facets of an L2-L3 lumbar segment in complex loads, *Spine*, **16**, 533–541.

Snook, S. H. 1982, Low back pain in industry, in *Symposium on Idiopathic low back pain*, A. A. White and S. L. Gordon (eds). St Louis, Mosby.

US Department of Labor, 1989 *Back injuries-nation's number one work place safety problem*, Fact Sheet No. OSHA 89-09, Washington D.C., Government Printing Office.