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Quantification of back motion during asymmetric lifting

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The objective of this study was to determine how trunk motion characteristics (in all three planes of the trunk) change as a free dynamic lifting task becomes more asymmetric. Trunk motion characteristics included range of motion, velocity (peak and average), and acceleration. Previous studies have shown that trunk motion characteristics affect trunk strength as well as the action of the trunk musculature. These trunk motion characteristics were quantified as a function of seven task asymmetries and three task weights. The experimental task required the subject to lift materials in positions commonly seen in the workplace. The range of motion, peak velocity, average velocity, and peak acceleration in each plane of the body were documented during the tasks. Generally, trunk motion characteristics in all three planes increased with an increase in task asymmetry. However, with an increase in task weight all the sagittal plane parameters and one transverse plane parameter decreased. Models were constructed to predict trunk motion characteristics given a task asymmetry and weight. When these motion components were compared to dynamic strength estimates from previous studies it was found that dynamic asymmetric lifts could reduce available strength up to 21% of maximum static strength. The results provide new insight into factors associated with the risk of developing low back disorders.

1. Introduction

Eighty per cent of the population will suffer from low back pain (LBP) during their lifetime, (Andersson 1981). Back injuries not only afflict the elderly, but also young adults. Among the population under age 45, low back injuries are estimated to be the number one disabling injury in the United States, (Bigos *et al.* 1986). In addition, once a person has sustained an initial back injury, there is often reoccurrence of the injury within two years.

In order to help control musculoskeletal back injuries in the workplace, the National Institute for Occupational Safety and Health (NIOSH) published the *Work Practices Guide for Manual Lifting* in 1981. The NIOSH guide was based on a static two-dimensional model, which assumed a slow smooth lift in the mid-sagittal plane. The dynamic and three-dimensional aspects of the workplace were not addressed in the NIOSH guide. However, we now know that these three-dimensional dynamic factors are important since epidemiologic studies by Andersson (1981), Frymoyer *et al.* (1980) and Bigos *et al.* (1986) have cited that occupational factors such as frequent bending and twisting, lifting and forceful movement, and repetitive work contribute to low back disorders (LBD).

In biomechanical terms, changes in these occupational factors affect the forces acting on the spine by changing the back motion characteristics (i.e., the range of motion during the lift, velocity, and acceleration). The forces acting on the spine are both external and internal. External forces produce moments about the spine caused by the object weight, body segment weight, and their distance from the spine.

Internal forces act to counterbalance the external forces. The internal forces are created by the muscles, abdominal pressures, and passive component of the body. The internal forces are much greater than the external forces due to their mechanical disadvantage. An increase in the range of motion may cause an increase in the external moment arm, therefore increasing the external forces. The internal muscle force would increase in order to counterbalance the increased external force. Therefore, the load on the spine would be increased.

Marras and Mirka (1992) have found that EMG levels increase as isokinetic velocity increases. This may indicate that the muscle is producing more force. There are also theoretical reasons to believe that trunk motion increases spine loading. Newton's Second Law states that force is equal to mass times acceleration. If the mass of the trunk remained the same then one would expect as back acceleration increases the magnitude of the forces acting on the spine would also increase. Hence, it may be hypothesized that increases in back motion characteristics (i.e., range of motion, velocity, and acceleration) increase the risk of LBD.

Asymmetric lifting conditions were initially studied by Garg and Badger (1986). In their study, lifting capacity was measured as a function of task asymmetry. Subjects were instructed to use a free lifting style but maintain their feet in the sagittal plane. The subjects lifted from an asymmetric position (30, 60, and 90°) to a symmetric position. Garg and Badger found that at 90° asymmetry the maximum acceptable weight of lift for subjects decreased 22%. This psychophysical study indicates much lower acceptable strength levels outside the sagittal plane.

Mital and Fard (1986) also conducted a psychophysical study comparing the maximum acceptable weight of a sagittally symmetric lift and one performed at 90° asymmetry. In the asymmetric lifting task, the load was lifted from a sagittally symmetric position to a destination of 90°. However, subjects were permitted to move their feet to accommodate the lift. Mital and Fard found that at 90° of asymmetry the maximum acceptable weight decreased 8·5%. The difference in the results of these two psychophysical studies may be due to foot position.

Marras and Mirka (1989) measured trunk torque around the lumbo-sacral joint using an asymmetric reference frame, which controlled the trunk asymmetry and velocity. Three trunk asymmetries were investigated: 0° (symmetric), 15°, and 30° from a sagittally symmetric position. Marras and Mirka found that trunk torque decreased 8·5% of maximum for every 15° of asymmetric trunk angle. Marras and Mirka also found that maximum concentric trunk strength decreased 0·33% for every degree per second increase in sagittal velocity. Kumar *et al.* (1988) studied the effects of increasing the linear velocity of the object lifted. Kumar *et al.* found that trunk strength decreased as linear velocity increased for sagittally symmetric lifts.

Task asymmetries of between 90° and 180° are commonly found in the industrial workplace. However, there is a void in the literature that explores asymmetric lifts beyond 90°. Thus, we do not understand how much back motion really exists with common lifting tasks.

1.1. *Research objective*

The objective of this study was to document how back motion characteristics in the three planes of the body, were influenced by changes in task asymmetry and task weight. In this study, the goal was to allow a person to perform a lifting task and quantify the back motions for that particular task design. The benefit of this information is that it will allow one to match subject back motion behaviour with quantitative laboratory studies of trunk strength and loading during motion.

2. Methods

2.1. *Approach*

In order tô address the research objective, an experiment was performed. The workplace factors of asymmetry and weight were manipulated to simulate situations often experienced in industry. In order that these results could be compared to laboratory investigations of muscle loading, the motion characteristics of the back were documented in the study.

2.2. *Subjects*

Twenty-one males with no history of low back pain volunteered to participate in the experiment. The subjects were all students at the Ohio State University. The age of the subjects ranged from 21 to 33 years. Gross anthropometric measurements were collected from all subjects. The mean (standard deviation) standing height was 181·3 cm. (6·8), and weight 78·7 kg (27·1), respectively.

2.3. *Equipment*

The lumbar motion monitor (LMM) developed and built in the Biodynamics Laboratory was worn by subjects when performing MMH tasks. This device is essentially an exoskeleton of the spine and is attached to two pieces of moulded plastic (Orthoplast) which anchor the LMM to the hips and shoulders (see figure 1). The LMM measures position changes of the lumbar spine relative to the lumbosacral joint (L5/S1) via potentiometers attached to the exoskeleton. The LMM was calibrated on a reference frame so that the potentiometer readings related to trunk position. A detailed description of the LMM may be found in Marras *et al.* (1991). Potentiometers are used to measure the instantaneous changes in position of the LMM in each plane of the body. The data collection rate was 60 Hz. The signal from the LMM is sent via hard wire to the analogue-to-digital converter board, resident on a Compaq 386 microcomputer. The digitized signal was stored in the Compaq 386 microcomputer memory.

The data were first analysed using custom software developed at the Biodynamics Laboratory. The software successively differentiated and smoothed the position data to determine the velocity and acceleration in each plane of the body. The custom software determined the range of motion, peak velocity, average velocity and peak acceleration for each plane of the body.

A wooden box 12 in. × 12 in. × 11 in. with a lid and handles was used for all manual material handling tasks. The box was lifted from a handle height of 18 in. from the floor, approximately knee height, to a handle height of 42 in. Footprints were placed on the floor to indicate where the subject was supposed to stand at the beginning of the lift. Figure 2 shows a floor plan of the testing facility. The destination of the box was a platform 24 in. × 18 in. with a 12 in. × 12 in. target in the center. The height of the platform was 36 in.

The weight to be lifted was determined using the *Work Practices Guide for Manual Lifting* (1981 NIOSH) referred to earlier. The horizontal factor (H) was 19 in. The vertical height was 18 in. (V). The vertical factor is $|V-30|$; thus, the vertical factor was 12. The distance the box travelled was 24 in. The frequency was one lift per min. The action limit (AL) was 19·6 lb. Since the guide has no asymmetry factor,

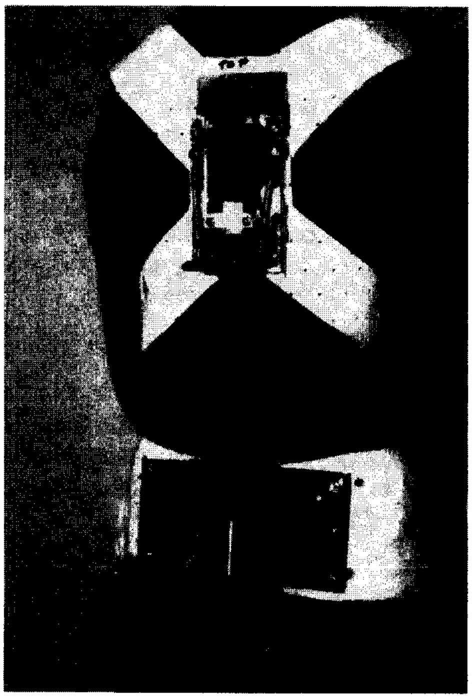

Figure 1. Lumbar motion monitor.

an added correction factor of 0·7 (based on previous studies by Garg 1986) was assumed and multiplied by the action limit. The new action limit was 13·7 lb, which was approximated to 14 lb. The weights used for the MMH tasks were 14 lb (AL), 28 lb (2AL), and 42 lb (3AL or MPL).

2.4. *Experiment design*

Two independent variables consisting of asymmetry and weight were identified in this study. Asymmetry had seven levels: 0 (sagittally symmetric), 30°, 60°, 90°, 120°, 150°, and 180°. The experimental positions were marked on the floor as shown in figure 2. In this document, the notation for task asymmetry (measured in degrees) is *T* followed by the number of degrees of task asymmetry (*T*0, *T*30, *T*60, *T*90, *T*120, *T*150, and *T*180). The number of degrees represent the change in asymmetric position of the box. The weight variable had three levels: 14, 28, and 42 pounds. These weights were determined by the NIOSH lifting guide and ranged from the AL to the MPL as previously discussed.

The combination of these two independent variables created a 7 × 3 factorial design. Each task was repeated three times for each subject. The 43 lifting tasks were completely randomized in their presentation order. This randomization of the tasks created a situation similar to that of a sorting operation in industry. In this manner, an experimental task resembling a realistic industrial task was used to quantify trunk motion characteristics.

Twelve dependent variables (motion parameters) involving trunk motion characteristics were measured. These twelve dependent variables with their respective abbreviations are listed in table 1. Range of motion was defined as the

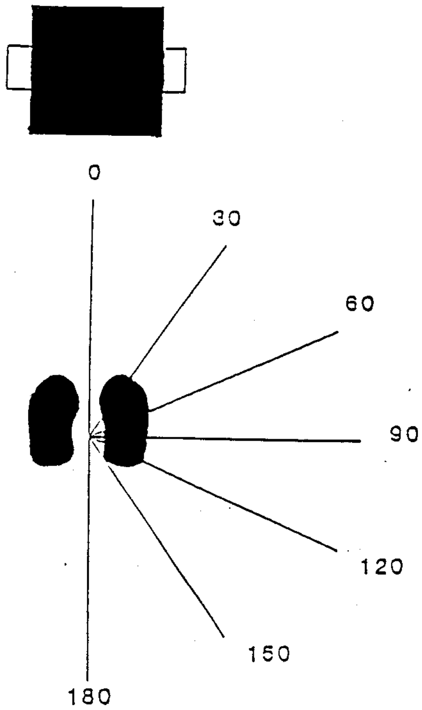

Figure 2. Floor plan.

difference between the maximum position and the minimum position during the lift for each plane. Peak velocity was the maximum rate of change in position during the lift (i.e., a single point). The average velocity was defined as the average rate of change in position throughout the lift. The peak acceleration was the maximum rate of change in velocity during the lift.

Table 1. Dependent measures.

Dependent measure	Abbreviation
1. Frontal range of motion	FROM
2. Frontal peak velocity	FPV
3. Frontal average velocity	FAV
4. Frontal peak acceleration	FPA
5. Sagittal range of motion	SROM
6. Sagittal peak velocity	SPV
7. Sagittal average velocity	SAV
8. Sagittal peak acceleration	SPA
9. Transverse range of motion	TROM
10. Transverse peak velocity	TPV
11. Transverse average velocity	TAV
12. Transverse peak acceleration	TPA

2.5. *Procedure*

The subjects were given the following instructions prior to the practice session.

1. You will perform 43 randomized lifting tasks.
2. Lifts will be done at 1 min intervals.
3. Begin each lift with your feet on the foot prints.
4. Once you initially lift the box you may move your feet to accommodate the lift.
5. Lift the box at a comfortable pace (speed).
6. The instructions to lift the box are: ready set go.

All the asymmetry and weight conditions were practised prior to placing the LMM on the person.

2.6. *Statistical analysis*

Each repetition of a condition was entered into a data base. The three repetitions for each condition were averaged prior to statistical analysis. An average was used in order to reduce the effects of individual outliers. The first step in the statistical analysis was to perform a multivariate analysis of variance (MANOVA) to determine the significance of asymmetry, weight, and their interaction on the entire group of dependent variables. This was followed by an individual analysis of variance (ANOVAs) for each dependent measure. Finally for significant back motion factors, mathematical regression models were developed to predict back motion characteristics for a given task asymmetry and weight.

3. Results

The results of the MANOVA in table 2, performed by blocking on subjects, indicated that the two main effects (asymmetry and weight) and their interaction were all statistically significant. This analysis indicated that asymmetry, weight, and their interaction significantly affected trunk motion components, collectively.

Table 2. MANOVA *p* values for the lifting experiment

Main effect or interaction	Significance
Asymmetry	0·0001*
Weight	0·0001*
Asymmetry × weight	0·0049*

*indicates the statistically different variables using a 0·05 level of significance.

3.1. *Asymmetry × weight interactions*

Individual ANOVAs were performed on each back motion parameter found significant in the MANOVA. Table 3 lists a summary of the significant effects for each back motion parameter. The asymmetry × weight interaction was most often significant in the sagittal plane. The sagittal plane dependent variables of range of motion, peak velocity, peak acceleration, as well as the transverse variable range of motion, all had a significant interaction term.

Table 3. ANOVA *p* values for back motion parameters in the lifting experiment.

Motion parameters	Significance ASY	Significance WT	Significance ASY × WT
Frontal range of motion	*0·0008	0·9749	0·1269
Frontal peak velocity	0·1147	0·5228	0·2660
Frontal average velocity	*0·0309	0·5395	0·1760
Frontal peak acceleration	0·5413	0·6144	0·4521
Sagittal range of motion	*0·0001	*0·0003	*0·0121
Sagittal peak velocity	*0·0001	*0·0018	*0·0075
Sagittal average velocity	*0·0001	*0·0001	0·9687
Sagittal peak acceleration	*0·0001	*0·0007	*0·0277
Transverse range of motion	*0·0001	0·0985	*0·0007
Transverse peak velocity	*0·0001	0·0638	0·1344
Transverse average velocity	*0·0001	*0·0068	0·1236
Transverse peak acceleration	*0·0001	0·1158	0·6714

*indicates the statistically different variables using a 0·05 level of significance.

Figures 3, 4, and 5 display the sagittal plane asymmetry × weight interaction for sagittal range of motion, sagittal peak velocity, and sagittal peak acceleration, respectively. Generally, as the lifting condition became more asymmetric the sagittal range of motion decreased, whereas the velocity and acceleration characteristics increased. The 14 lb task weight displayed the most reactive response to asymmetry and the 42 lb task weight showed the least reactive response under the experimental conditions. This difference was most apparent for sagittal peak acceleration. The *post hoc* analysis showed that differences among the weight levels were significant for conditions greater than 90° of asymmetry for both sagittal peak acceleration and

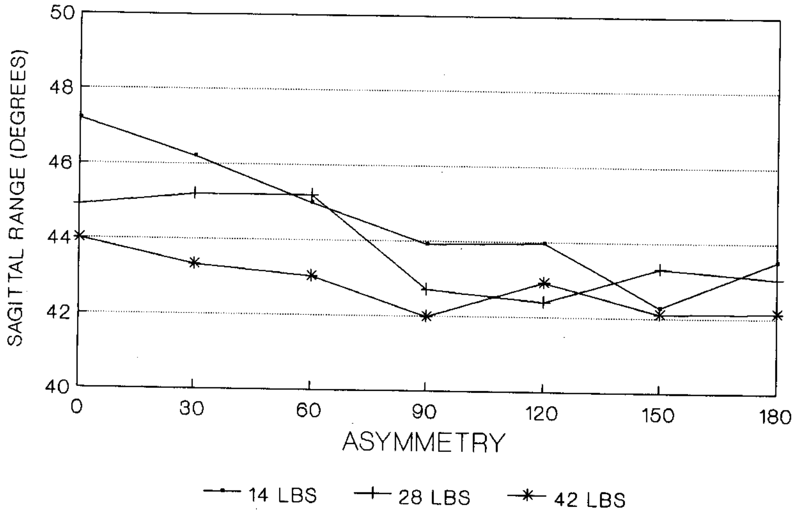

Figure 3. Interaction of asymmetry and weight for sagittal range of motion.

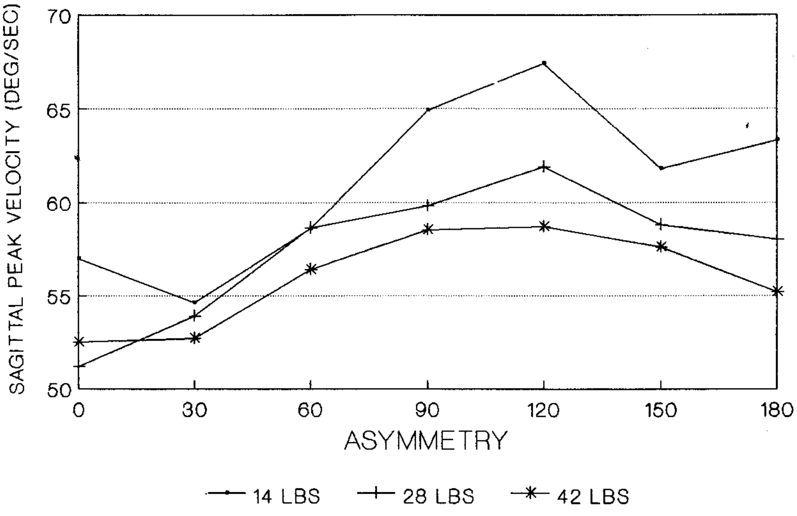

Figure 4. Interaction of asymmetry and weight for sagittal peak velocity.

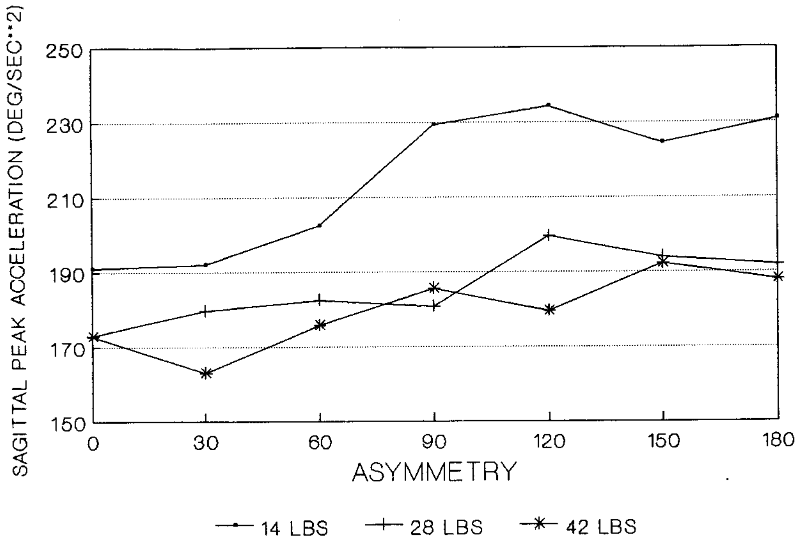

Figure 5. Interaction of asymmetry and weight for sagittal peak acceleration.

sagittal peak velocity. The differences among the weight levels were significant for task asymmetries less than or equal to 60° for sagittal range of motion.

The interaction of weight and asymmetry for the transverse range of motion is illustrated in figure 6. This shows that the transverse range of motions of all three weights were similar. Table 3 shows the transverse range of motion was significant for asymmetry but not for weight. At *T0*, the transverse range of motion was approximately 5° for all three weight levels, which shows that even sagittally symmetric lifts involve some degree of asymmetry. The differences in the transverse range of motion among the three weight levels were only statistically significant at

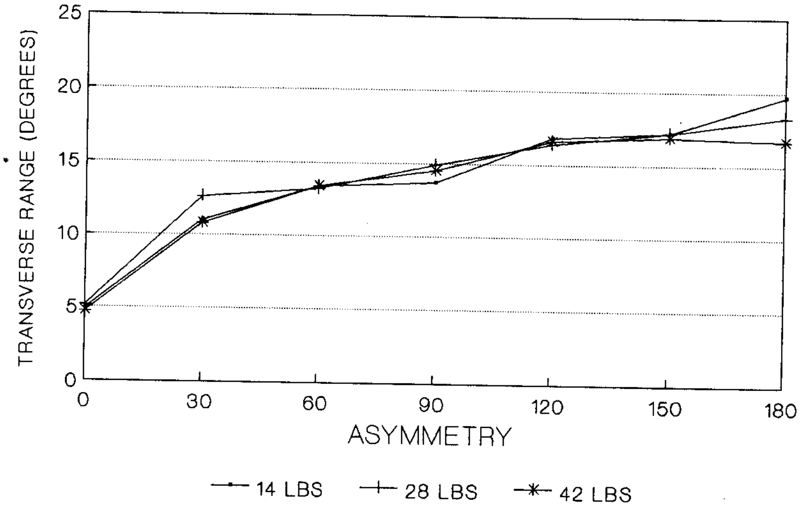

Figure 6. Interaction of asymmetry and weight for transverse range of motion.

*T*30 and *T*180. Significant increases in transverse range of motion due to asymmetry occurred between *T*0 and *T*30 for all three weight levels.

3.2. *Effects of asymmetry*

Table 3 also shows the motion parameters and their respective significance values for each main effect. All the sagittal and transverse plane, motion parameters responded significantly to changes in task asymmetry. However, in the frontal plane only the range of motion and average velocity responded significantly to changes in asymmetry. Figures 7, 8, 9, and 10 show average values and best fit curves for range of motion, peak velocity, average velocity and peak acceleration, respectively, as a function of asymmetry for the significant parameters in each plane.

3.2.1. *Sagittal plane:* As shown in Figure 7, the sagittal range of motion decreased slightly as a function of increasing task asymmetry. However, the sagittal peak velocity (figure 8) and sagittal average velocity (figure 9) both significantly increased as task asymmetry increased to 120 degrees. The increase in sagittal peak velocity and sagittal average velocity as a function of increasing asymmetry was opposite the sagittal range of motion response to increasing asymmetry. Figure 10 shows that sagittal peak acceleration increased as a function of increasing task asymmetry. It is important to recognize that the range of motion, peak velocity, average velocity, and peak acceleration in the sagittal plane did not follow similar response patterns to asymmetry. This was particularly true at task asymmetries beyond 120°. This, emphasizes the need to examine range of motion as well as all motion parameters.

3.2.2. *Transverse plane:* Figures 7, 8, 9 and 10 also show the transverse range of motion, transverse peak velocity, transverse average velocity, and transverse peak acceleration as a function of asymmetry, respectively. From *T*0 to *T*30, all four transverse motion parameters had dramatic increases, whereas the sagittal and frontal plane motion parameters changed only slightly. At task asymmetries beyond 30°, the transverse range of motion (figure 7), transverse peak velocity (figure 8), transverse average velocity (figure 9), and transverse peak acceleration (figure 10)

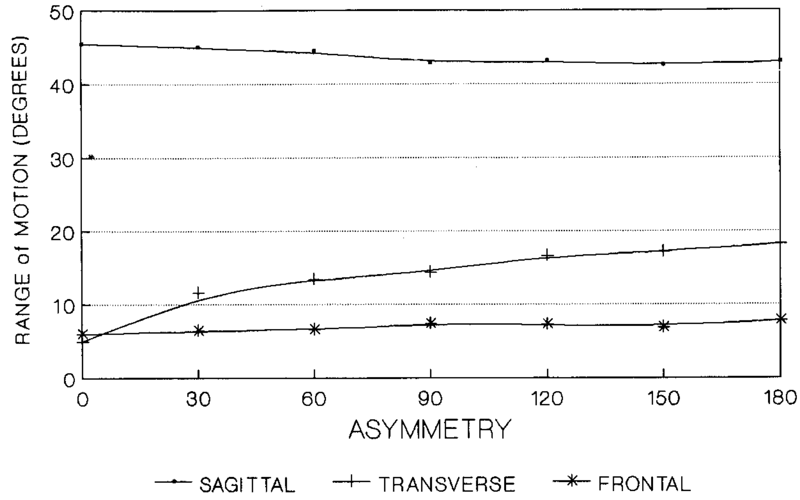

Figure 7. Sagittal, transverse, and frontal range of motion as a function of asymmetry.

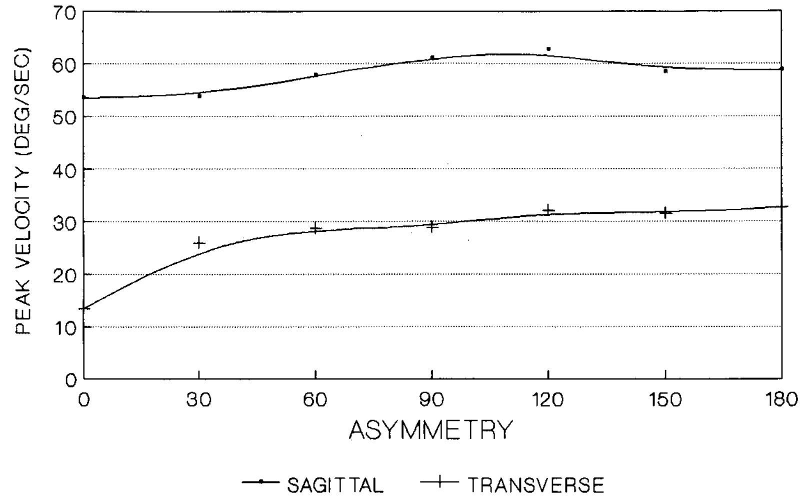

Figure 8. Sagittal and transverse peak velocity as a function of asymmetry.

generally increased but at a much reduced rate compared to the increase between 0 and 30° of task asymmetry. This may indicate a threshold of twisting that is reached with very little task asymmetry.

3.2.3. *Frontal plane:* As shown in figures 7 and 9, the frontal plane parameters changed only slightly due to asymmetry, even though they were statistically significantly.

3.3. *Effects of weight*

The individual ANOVA results in table 3 indicate that five motion parameters responded significantly to weight changes. All four sagittal plane motion parameters

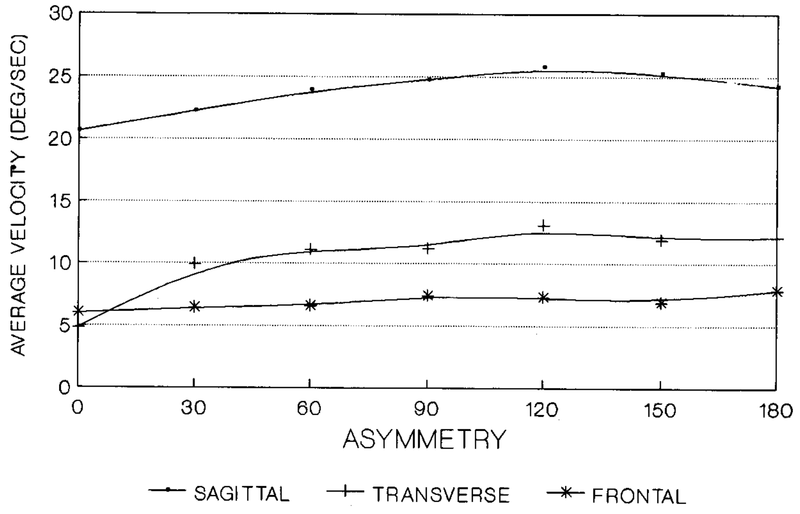

Figure 9. Sagittal, transverse, and frontal average velocity as a function of asymmetry.

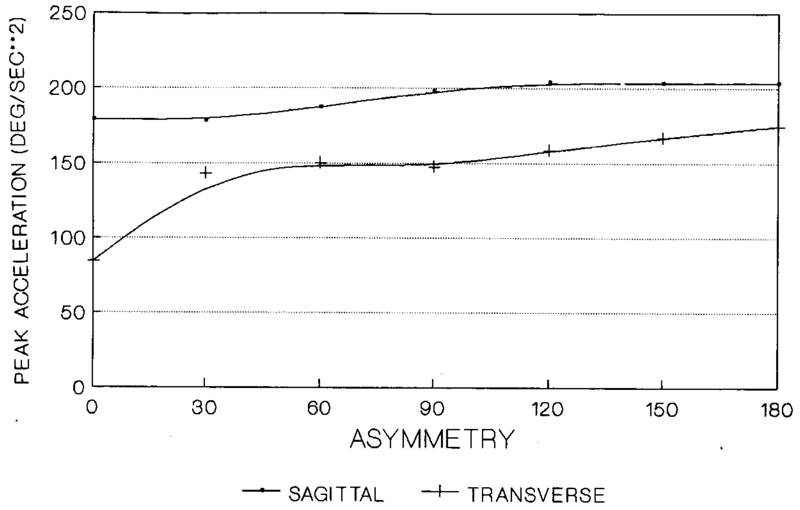

Figure 10. Sagittal and transverse peak acceleration as a function of asymmetry.

decreased significantly and consistently with increasing task weight. Also, in the transverse plane the average velocity decreased significantly due to increases in task weight. The frontal motion parameters showed increased response with increasing task weight, however these changes were not statistically significant.

3.4. *Predictions of trunk motions*

Regression models were developed for each significant motion parameter. Models were developed based on the significant terms in the ANOVA table for each motion parameter. Table 4 lists the models with their *y*-intercept and weighting coefficients for each term in the model. Notice that the transverse and sagittal plane models had exponential asymmetry components. These models may be used to predict the motion parameters at any task asymmetry and any weight level within the extreme conditions of this study. The sagittal and transverse plane motion parameter models have high R^2 values indicating these motion parameter models have good predictability. It is important to point out that these model parameters were developed based on the vertical lift height and horizontal distance factors used in this experiment. Applying these models to other vertical lifting heights or horizontal distances may affect the model predictability.

Table 4. Lifting models.

Motion parameter	*y*-int.	ASY linear	ASY exp	WT	ASY × WT	R^2
FROM	6·2	0·007				0·63
FAV	5·5	0·001				0·66
SROM	48·4	−0·03		−0·11	−0·0005	0·83
SPV	55·9	1·14	0·439	−0·12	−0·0007	0·67
SAV	23·3	0·84	0·338	−0·10		0·87
SPA	202·2	0·29		−0·86	−0·0040	0·81
TROM	5·23	1·12	0·495		−0·0003	0·98
TPV	16·4		0·567			0·98
TAV	6·36	0·94	0·402	−0·03		0·87
TPA	106·5		0·834			0·98

Note: All R^2 significant at the 0·05.

4. Discussion

This study has, for the first time quantitatively documented the changes in trunk motion characteristics that occur with asymmetric lifting tasks. This has permitted us to predict the expected trunk motion necessary to complete a free dynamic lift.

The results have shown that the range of motion, velocity, and acceleration parameters in the sagittal and transverse planes responded differently to changes in task asymmetry and task weight. It is also important to note that velocity and acceleration parameters may reveal information not found in the range of motion. Therefore, all three motion parameters need to be measured. For example, the sagittal range of motion decreased but the transverse range of motion increased as a function of task asymmetry. Thus, a trade-off in range of motion occurred from the sagittal plane to the transverse plane as a function of task asymmetry. The velocity and acceleration parameters increased in both the sagittal and transverse planes as a function of increasing task asymmetry. The need to measure all three motion parameters is emphasized by the fact that trade-offs occurred in the range of motion parameter and not the velocity or acceleration parameters.

The interaction of weight and asymmetry was significant in the sagittal and transverse planes. In general, the sagittal plane range of motion, peak velocity, and peak acceleration had decreased levels of response at increased weight levels. However, the rate of decrease changed as a function of increasing task asymmetry. This indicates that safe or acceptable task asymmetries may be dependent upon the task weight. Hence, it may be necessary for lifting guidelines to have more than one asymmetry factor. However, further research in this area is necessary.

The transverse range of motion in the back was far below the actual asymmetric angle of the task for all three weight levels. Explanations for the differences might include any combination of the following: movement of the feet, twisting with the legs or hips, using the arms to reach instead of twisting with the back, or locking of the facet joints.

Overall, changes in task asymmetry and task weight lead to responses in the transverse and sagittal plane motion parameters. The frontal plane parameters showed little response to the changes in task weight or task asymmetry. Future research to determine which task design changes cause responses in frontal plane motion parameters may be useful in the development of lifting guidelines.

The results of this study can be compared to those of Marras and Mirka (1989), Mital and Fard (1986), and Garg and Badger (1986). Marras and Mirka, who defined asymmetry with respect to L5/S1, as was done here, found that trunk strength decreased 8·5% of maximum for every 15 degrees of trunk asymmetry. Mital and Fard, who defined asymmetry in terms of hand vs feet position, found that maximum acceptable weight decreased 8·5% at 90° task asymmetry. In the current study, the L5/S1 trunk asymmetry was measured at each task asymmetry and task weight. Therefore, the percentage of maximum trunk strength can be determined at each task asymmetry and task weight based on the transverse range of motion measured and the ratio of 8·5% decrease per 15° from the Marras and Mirka results. Table 5 shows the predicted percentage decrease of maximum trunk strength (from a sagittally symmetric condition) as a function of task asymmetry for each task weight. This table indicates that once a task requires a lift of 30° or more, a substantial drop in trunk strength would be expected. Note that strength does not decrease smoothly as a function of increasing task asymmetry. This decrease in strength would be of particular concern in repetitive, fatiguing work.

Table 5. Percentage decrease of maximum trunk strength based on transverse range of motion.

Task asymmetry	% Decrease of max trunk strength (14 lb)	% Decrease of max trunk strength (28 lb)	% Decrease of max trunk strength (42 lb)
0	2·8%	2·9%	2·7%
30	6·2%	7·1%	6·1%
60	7·6%	7·5%	7·6%
90	7·8%	8·4%	7·8%
120	9·5%	9·3%	9·4%
150	9·7%	9·7%	9·6%
180	11·2%	10·4%	9·5%

Table 5 shows that at 90° and 28 lb. the decrease in maximum trunk strength was 8·4%. Indicating that at 90° of task asymmetry the trunk asymmetry was approximately 15° depending on task weight. The 8·4% decrease in maximum trunk strength at 90° corresponds to the Mital and Fard results of an 8·5% decrease in maximum acceptable weight at 90°. However, the Garg and Badger results showed 22% decrease in maximum acceptable weight at 90°. The difference in the Garg and Badger results are probably due to the restriction of foot movement to the sagittal plane. It is hypothesized that restricting foot movement would increase the amount of transverse motion in the back, which results in the increased reduction in maximum acceptable weight.

Marras and Mirka also found that maximum concentric trunk strength decreased approximately 0·33% for every degree-per-second increase in sagittal constant velocity. Therefore, the sagittal peak velocity may also be used to determine the percentage of decrease in maximum trunk strength. Table 6 shows the percentage decrease of maximum trunk strength as a function of task asymmetry and task weight. It is important to note that these peak velocities were measured while subjects were lifting at a comfortable pace. This table indicates that compared to static strength estimates, dynamic exertions reduce available strength in these lifting situations between 17 and 21%.

Table 6. Percentage decrease of maximum trunk strength based on sagittal peak velocity.

Task asymmetry	% Decrease of max trunk strength (14 lb)	% Decrease of max trunk strength (28 lb)	% Decrease of max trunk strength (42 lb)
0	18·8%	16·9%	17·3%
30	18·0%	17·8%	17·4%
60	19·4%	19·3%	18·6%
90	21·4%	19·7%	19·3%
120	22·2%	20·4%	19·4%
150	20·4%	19·4%	19·0%
180	20·9%	19·1%	18·2%

Tables 5 and 6 could be applied, with good judgement, to industrial lifting situation, now. However, it should be noted that the percentages of decrease in maximum trunk strength were determined using the trunk motion characteristics of the lifting task described in the methods section. Changes in the vertical and horizontal distances of the lifting task may effect the transverse range of motion or sagittal peak velocity, therefore changing the percentage decrease in maximum trunk strength. Future research using weight levels lower than 14 lb and more than 42 lb may elicit different biodynamic responses. Thus changing the percentage decrease of maximum trunk strength as a function of the weight lifted. This is a promising area of research, which may help in the development of future lifting guides to reduce the risk of low back injuries.

5. Conclusions

Epidemiological studies have indicated that bending and twisting are occupational factors associated with an increased risk of LBP. However, no studies have shown how much bending and twisting occurs in the low back with specific task designs. This study quantifies free dynamic back motion characteristics necessary to perform typical industrial tasks. Generally, there was a trade-off between the sagittal and transverse planes as a function of increasing task asymmetry. The most significant finding of this research project was the quantification of transverse back motion for specific task asymmetries under free dynamic lifting conditions. The weight factor was significant mainly in the sagittal plane of the body. All trunk motion characteristics in the sagittal plane and the transverse average velocity significantly decreased with increased task weight, while other parameters were unaffected.

The results of this research project determined the work station designs that cause increased levels of back motion that may put a person at higher risk of LBP. Future research should include similar studies investigating the effects of different weight levels and horizontal and vertical distances. Knowledge of the workplace design parameters that increase back motion characteristics provides ergonomists with the information to design the workplace to reduce back motion which may prevent LBP.

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