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Lumbar Motion Response to a Constant Load Velocity Lift

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An experiment was performed to evaluate the motions of the lumbar spine during a constant load velocity lift. For the purposes of this study, a constant load velocity refers to the linear vertical velocity of the load. This vertical load velocity was controlled using a modified angular isokinetic dynamometer, which produced linear isokinetic motion during a lift. A lumbar monitor was used to observe the position, velocity, and acceleration changes that occurred in the lumbar spine during the lifting task. The results indicate that under constant load velocity conditions, significant angular accelerations occur at the lumbar level. The nature of these accelerations was found to depend on several variables associated with a lifting task, such as the load velocity and the asymmetry of the lift. The physical significance of these results would be increased spinal loading above that which would be predicted using a static model.

INTRODUCTION

The NIOSH *Work Practices Guide to Manual Lifting* (1981) employs a static, two-dimensional, biomechanical model to calculate the resultant compressive forces experienced by the spine during a lift. This compressive force is the sum of the external load and the internal muscle forces required to counterbalance the external load. Because of their mechanical disadvantage, the muscles that supply the internal forces must exert many times as much force as the external load in order to stabilize the trunk. It is generally accepted that these compressive forces can eventually lead to degeneration of the intervertebral discs.

One of the assumptions associated with many static biomechanical lifting models is that if a person performs a smooth, controlled lift, the effects of the dynamics of the trunk on the internal forces are minimized. This assumption is an integral part of these models because linear accelerations of the load and angular accelerations of the body segments would dramatically change the compressive forces experienced by the spine. These additional compressive forces are attributable to an increase in muscle force needed to produce linear and angular accelerations. By using a static model to estimate spinal compressive forces in the workplace, the muscle force above that which is required to hold a weight statically is ignored. The angular acceleration of the trunk is a critical component that needs to be quantified if one is to create an accurate dynamic model of lifting.

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Dynamic Studies

There have been several attempts to understand and quantify the dynamic component of a lifting task. Marras, Rangarajulu, and Wongsam (1987) performed a dynamic trunk exertion analysis that investigated the electromyographic (EMG) response of the trunk muscles under different angular velocity conditions. They showed that force production capabilities decreased as a function of increasing trunk velocity and that the EMG activity associated with the dynamic movement was significantly different from that of the static exertion.

The NIOSH manual (1981) cites research done by Park (1973), who investigated the effect of load acceleration on the amount of force needed to lift the load. It was found that the amount of force required to lift a box was 115–120% that of the static load. Freivalds, Chaffin, Garg, and Lee (1984) also investigated a dynamic lift and found the ground reaction forces during a lift to be 40% greater than those occurring under static loading conditions. They performed their study using a stroboscopic light, camera, and reflective discs placed over the major joints of the body to obtain an estimate of the two-dimensional motion component during a lift. Mirka (1988) showed that the motion characteristics of the lumbar spine in three planes (sagittal, coronal, and transverse) were affected by two lifting variables studied: load velocity and asymmetry of the lifting stance. All of these researchers have recognized the vital dynamic component of a lift and have attempted to quantify some aspect of it.

The goal of the present research was to quantify the velocity and acceleration profiles that occur during a highly controlled lift. A better understanding of the relationship between load motion and trunk motion will permit a critical evaluation of the "smooth, controlled lift" assumption of many static lifting models and allow for development of models that take into account this aspect of workplace biomechanics.

METHODS

Subjects

Sixteen male volunteers with no history of back pain were tested in this study. A summary of anthropometric characteristics of the subject population is presented in Table 1. Material handling experience among the subjects varied.

Equipment

A Kin/Com isokinetic dynamometer modified to produce linear motion, a lumbar motion monitor (LMM), and a Compaq portable microcomputer connected to a Lab Master analog-to-digital (A/D) board were used to perform this study. The linear isokinetic motion was achieved by attaching a large wooden wheel to the rotating axis of the Kin/Com. Wound around this wheel was a cable that was attached through a series of pulleys

TABLE 1

Means and Standard Deviations for Anthropometric Data

Dimension	*Mean*	*Standard Deviation*
Age	27.1 (yrs)	4.81
Height	185.0 (cm)	14.0
Weight	80.5 (kg)	9.6
Shoulder height	152.36 (cm)	9.63
Elbow height	114.38 (cm)	6.20
Upper-arm length	37.45 (cm)	3.12
Lower-arm length	50.45 (cm)	3.21
Upper-leg length	43.90 (cm)	3.00
Lower-leg length	51.81 (cm)	4.54
Trunk length	61.04 (cm)	3.83
Trunk breadth	33.06 (cm)	2.722
Trunk depth	22.90 (cm)	1.61
Trunk circumference	93.29 (cm)	8.41

to a load cell, which was mounted in a handle arrangement. The force exerted by the subject was read by the load cell and instantaneously plotted on a computer monitor placed in front of the subject. These force data were continuously plotted throughout the lift. Also plotted on this screen was a line that designated the constant force level for this particular trial. This feedback system allowed the subjects to control their lifting force throughout the trial (see Figure 1).

The LMM is a device designed and built in the Biodynamics Laboratory at Ohio State University which monitors the position of the lumbar spine in three planes. The LMM is essentially an exoskeleton that spans the lumbar spine and uses a series of sensors to reflect relative angular displacement of the top of the lumbar spine relative to the pelvis. The data from the LMM, as well as the force and position data from the Kin/Com, were sent to the Lab Master (A/D) board, where they were digitized and sent to a Compaq computer for storage.

Independent Variables

The independent variables in this study are variables associated with lifting which have been identified in previous research as important factors in quantifying the internal forces on the lumbar spine and their association with low back injury (Marras et al., 1987; Seroussi and Pope, 1987; Troup, Leskinen, Stalhammar, and Kuorinka, 1983). In the present research these variables were studied for their effects on the motions of the spine. These variables include load weight (90, 135, and 180 N), load velocity (37.5 and 75.0 cm/s), lifting style (bent leg and straight leg), and asymmetry of lift (0 and 90 deg).

Various levels of control were placed on the subjects during the experiment to try to balance the freedom that occurs in real lifting conditions and the control needed to perform an experiment. All subjects used an overhand lifting grip on the handle as they lifted it from ankle to shoulder height. The horizontal location of the load throughout the lift was not physically controlled, but subjects were instructed to lift with as little horizontal deviation as possible. The load velocity was tightly controlled by the Kin/Com while the force output was controlled by the subject. The asymmetry of the lift was defined as the angular displacement of the feet with respect to the foot position during a normal, sagit-

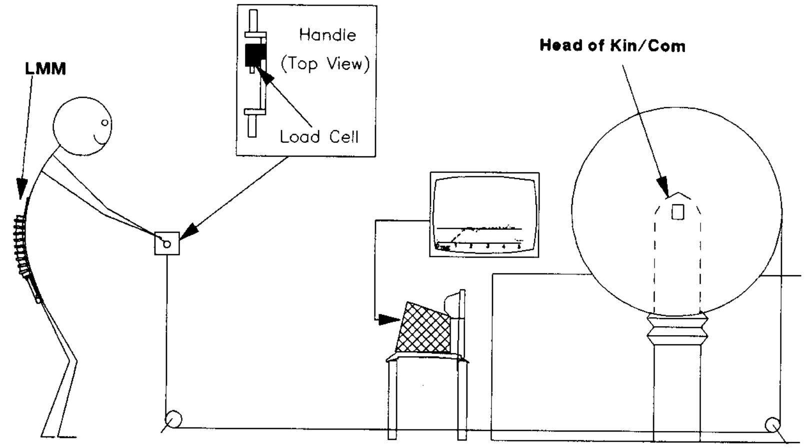

Figure 1. *Experimental apparatus.*

tally symmetric lift. Subjects were allowed some freedom under the asymmetric conditions as long as they did not move their feet. The straight-leg lift and the bent-leg lift differed only in the position of the legs at the beginning of the lift. After the lift began, no control was placed on lifting style. By controlling some variables and not controlling others, a balance was struck between experimental control and real-life lifting which was acceptable and comfortable to most subjects tested.

Dependent Variables

The dependent variables in this analysis were limited to the variables that describe the accelerations that occurred during a concentric lift in the sagittal plane as it is in this plane that the greatest moments around the spine are expected. Therefore the accelerations in this plane would render the greatest muscular forces and, in turn, the greatest levels of spinal compression.

Quantification of sagittal acceleration involved choosing several variables that characterize the acceleration profiles that occurred during a lift. These components of sagittal motion were (1) the magnitude of the peak acceleration, (2) the sagittal angle at which the peak acceleration occurred, (3) the vertical height of the load at which the peak acceleration occurred, and (4) the number of local acceleration maxima (peaks) that occurred during the lift. These dependent variables are referred to as *magnitude, angle, height,* and *peaks,* respectively.

Procedure

Subjects were asked to perform the lifting task under every combination of independent variables. They had to maintain the designated level of force within a tolerance of 20 N (using the video feedback system described earlier) throughout the duration of the trial in order for the trial to be accepted. The experimenter also monitored starting position (lifting style) and foot position (asymmetry) throughout the trial to ensure that those criteria were met. A rest period of 1 min was given between exertions.

Data Conditioning

The position data taken from the sensors were collected at 50 Hz. These data were then smoothed using two points before and after the point in question and then differentiated using the adjacent points to obtain the angular velocity and angular acceleration profiles. An example of these velocity and acceleration profiles is shown in Figure 2. Each acceleration profile was then evaluated for the dependent variables of interest.

An analysis of variance (ANOVA) was performed on the data to find those lifting variables that affected the dependent variables. The results of this analysis showed two significant factors influencing the acceleration components. These results are summarized in Table 2.

A change in asymmetry (0 to 90 deg) caused a change in two dependent measures. First, there was an increase in the sagittal angle of the trunk at which the peak acceleration occurred (18 to 22 deg, 0 being vertical). Second, there was an increase in the number of peaks (3.3 to 3.6 peaks). An increase in load velocity (37.5 to 75 cm/s) caused a decrease in the number of peaks (4.6 to 2.3 peaks) and an increase in the magnitude of the peak acceleration (70 to 130 deg/s/s). An example of these load velocity effects is shown graphically in Figures 3 and 4. Figure 3 contains a sample of the velocity acceleration profiles that exist under the low-velocity conditions; Figure 4 illustrates those found under the high-velocity conditions. These figures illustrate the differences that occurred in both the

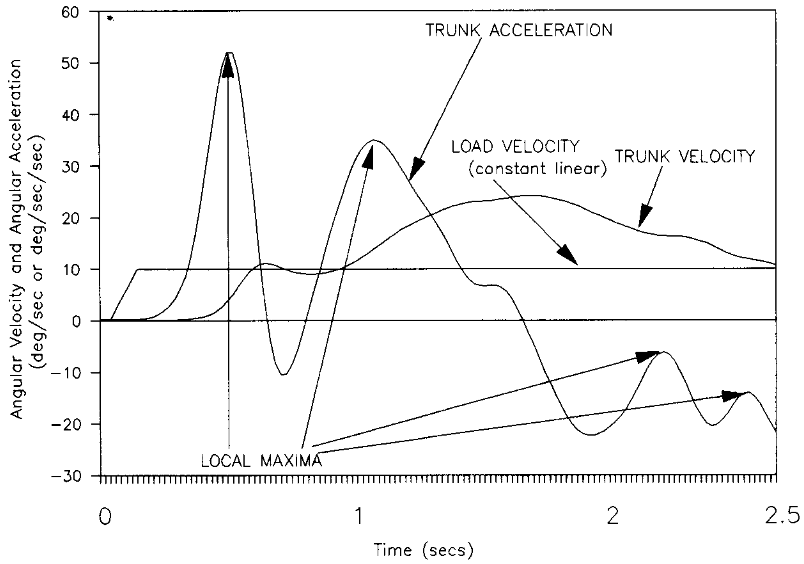

Figure 2. *Example of the angular velocity and angular acceleration profiles associated with a constant load velocity lift.*

magnitude of the peak accelerations and the smoothness of the lift.

DISCUSSION

The goal of this research was to find the relation between the motion of a load and the motion of the trunk. The quantification of this relation and how it is affected by changes in lifting parameters will add to our ability to create an accurate model of dynamic lifting. One component of trunk motion, and the focus of this study, was the sagittal acceleration profile during a lift.

Many factors associated with an acceleration profile could add insight into the risk of injury for a given task. These might include (1) the magnitude of the greatest acceleration during the lift, (2) the number of accelerations that occurred during the lift, (3) the length-strength relationship of the muscles at

TABLE 2

ANOVA Table for Main Effects and Two Factor Interactions

Acceleration Components	*Lifting Variables*									
	V	*S*	*F*	*A*	*VS*	*VF*	*VA*	*SF*	*SA*	*FA*
Magnitude	X									
Angle				X						
Height										
Peaks	X			X						

Note: X's denote significance at the $p < 0.05$ level. V = load velocity; S = lifting style; F = force level; A = asymmetry of stance.

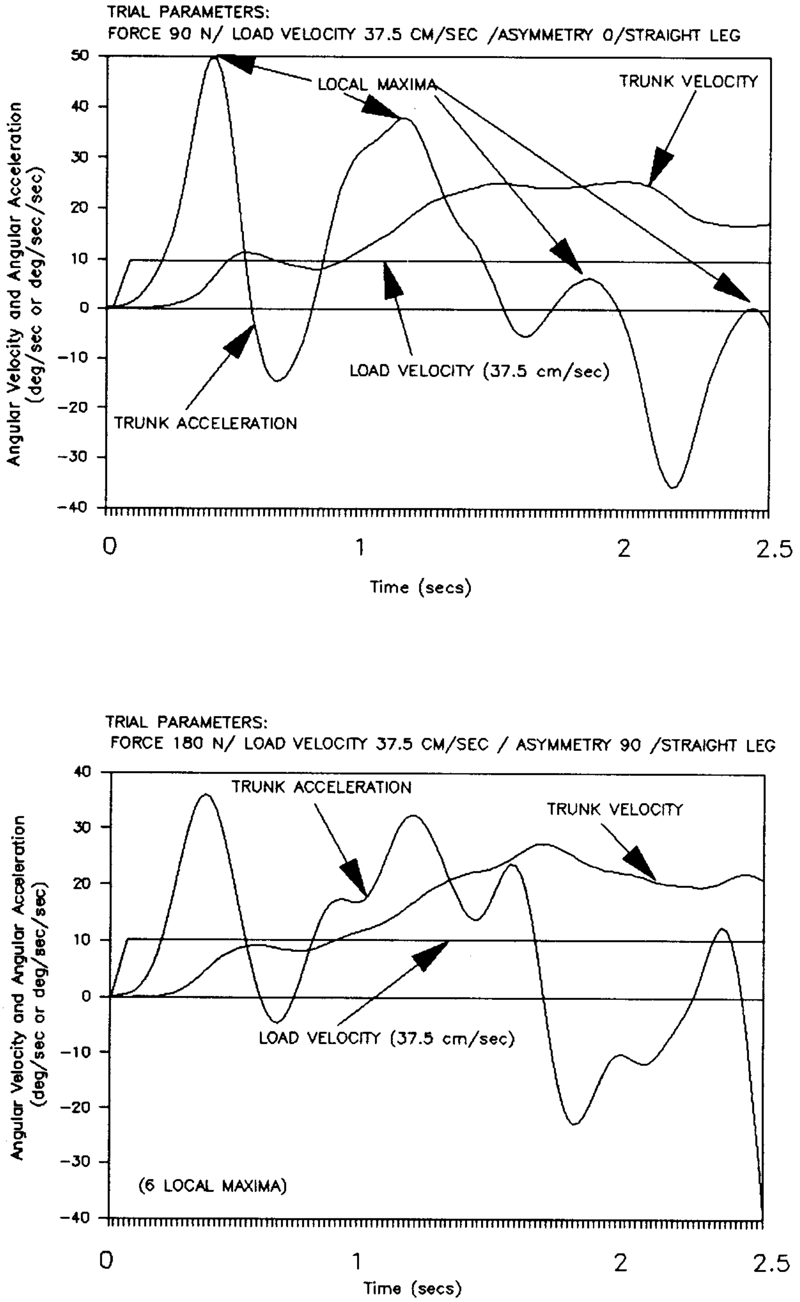

Figure 3. *Examples of the lumbar motion profile of a low-load velocity lift.*

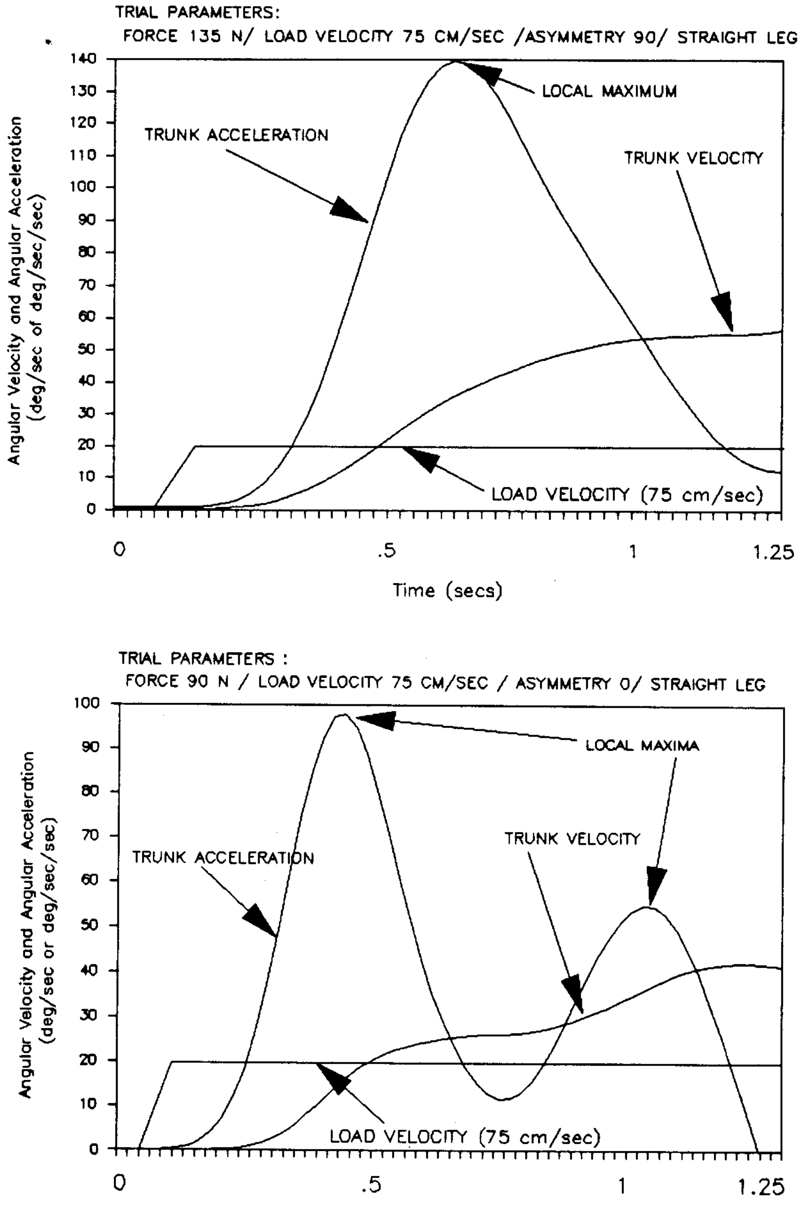

Figure 4. *Examples of the lumbar motion profile of a high-load velocity lift.*

the point of the peak acceleration, and (4) the moment arm of the trunk and external load around the L5/S1 joint at the time of the peak acceleration. Each of these factors has an effect on the internal forces exerted by the trunk musculature during a lift. In defining the dependent variable components in this study an attempt was made to find variables that best described these issues.

In this study it was found that the higher load velocity caused a higher peak angular acceleration in the sagittal plane. At a load velocity of 37.5 cm/s, the angular acceleration in the sagittal plane was 70 deg/s/s, whereas under the 75 cm/s condition, the angular acceleration in the sagittal plane was 130 deg/s/s. This type of effect would be one associated with acute physical trauma because an acceleration of this magnitude coupled with a significant external load might overcome some tissue tolerance of the back during a single lift.

The dependent variable *peaks*, which was defined as the number of local maxima, was found to have a greater value under the low-velocity conditions. The alternating compression/decompression of the spine that would result from the illustrated acceleration profiles might lead to a gradual deterioration of the intervertebral disc and other tissues of the back. This type of deterioration would be considered cumulative because it would create problems over an extended period.

It is hypothesized that the increased number of peaks under the low-velocity conditions and the increased magnitude of the peak acceleration under the high-velocity conditions are the result of a change in the lifting control strategy employed by the subject. Under the low-velocity conditions, the results showed an increase in the number of local maxima of the acceleration profiles, and the figures illustrate that these peaks occur throughout the lift. This motion profile would indicate that the subject controlled the external force with the trunk musculature for the duration of the lift. Because the subjects were using their trunk musculature to control their force output, a significant amount of antagonistic muscle activity would be applied to control external force and stabilize the trunk. This antagonistic muscle force is supplied by the flexor muscles of the trunk and would add to the total spinal load.

Under the high-velocity conditions, subjects' control strategy involved beginning the lift with a ballistic motion of the trunk (which would render the high acceleration values) and then controlling the external force output for the remainder of the exertion with their arms. In a completely unrestricted lift the ballistic motion of the trunk would have been coupled with a significant amount of force exerted by the lower limbs. The fact that these subjects elected to attempt a ballistic motion of the trunk in order to perform even this highly controlled activity seems to indicate that this is the preferred lifting technique. Asking workers to change their lifting technique to conform to the slow, controlled lift guidelines might reduce the compressive force resulting from lower accelerations but may also require the development of new training techniques.

The effects of asymmetry on the motions of the trunk during lifting include, but are not limited to, factors that influence compression of the spine. Other issues include lateral shear forces and rotational stresses that occur at the lumbar level. These internal forces are the result of asymmetric loading on the spine as well as awkward trunk postures.

The asymmetry effects that were found to influence compression in this study include the sagittal angle at which the peak acceleration occurs and the number of local maxima during a single lift. An increase in the sagittal angle at which peak acceleration occurs would imply an increase in the moment arm of the load at peak acceleration, which would increase the resultant compressive force on the spine. The increase in the number of peaks of the acceleration profile during asymmetric lifts would indicate that there was a decrease in the stability of this position and also might indicate increased coactivation of the agonist/antagonist groups during this type of lift; again, this coactivation would lead to increased compression. The changes in spinal compression which result from changes in asymmetry are significant, but these forces are only part of the risk associated with asymmetric lifting.

These results indicate that it is difficult to say, from the standpoint of motion components, that one set of lifting conditions is better than another. In order to be able to make that judgment, many variables—such as compressive forces, shear forces, and cumulative trauma effects—must be weighed against one another to create the best lifting conditions.

CONCLUSIONS

It has been shown that a slow, controlled lift does not imply a constant angular velocity around the lumbar spine. This means that a model that relies on a constant angular velocity lift assumption, and therefore considers the spine a static system, will underestimate total spinal load. In addition, it was shown that asymmetry also affects the motion characteristics of the lumbar spine in the sagittal plane. These two areas—asymmetry and dynamics—need to be investigated in future research to build a more accurate lifting model that will eventually lead to more realistic lifting standards.

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