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THE EFFECTS OF LIFTING FREQUENCY ON THE DYNAMICS OF LIFTING

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The goal of this study was to quantify the effects of different lifting frequencies (3, 6 and 9 lifts/minute) at different lifting heights (30 and 60 cm) on the kinematics of the lumbar region. Each of these lifting tasks was performed for twenty minutes. The time dependent traces of the both the mean and standard deviation of sagittal acceleration showed subject dependent trends over time. Averaged across time, the results of this study reveal that there is a non-linear increase in the sagittal acceleration with greater frequency of lifting.

INTRODUCTION

The frequency multiplier found in the NIOSH equation (Waters et al, 1993) is based on data from psychophysical studies (Snook and Ciriello, 1991) and physiological studies (Garg, 1976, Garg et al, 1978). The psychophysical approach was used to develop the multiplier for frequencies up to four lifts/minute while the physiological results were used to find the multipliers for frequencies greater than four lifts/minute. These studies were useful in predicting preferred workload of an individual (psychophysical) or the cardiovascular cost of lifting (physiological), but they did not discuss the biomechanical implications of variable lifting frequency. Given that frequency of lift does not fit well into a static description of a work environment, trunk kinematics during manual lifting tasks need to be considered in order to get a more complete picture of the risk associated with frequency of lift in free dynamic MMH tasks. The goal of the current study was to better understand the effects of lifting frequency on these trunk kinematic parameters.

METHODS

Subjects

Five male and five female college students volunteered for this study. The subjects had no history of a low back disorder. Written informed consent was given by all of the subjects at the beginning of the experiment.

Equipment

Motion analysis and heart rate monitoring equipment were utilized for this experiment. A telemetry-based Lumbar Motion Monitor was placed on the back of the individual to measure the angular position, velocity, and acceleration of the lumbar spine in three-dimensional space. The heart rate of the subjects was measured using an Accurex II Heart Rate Monitor.

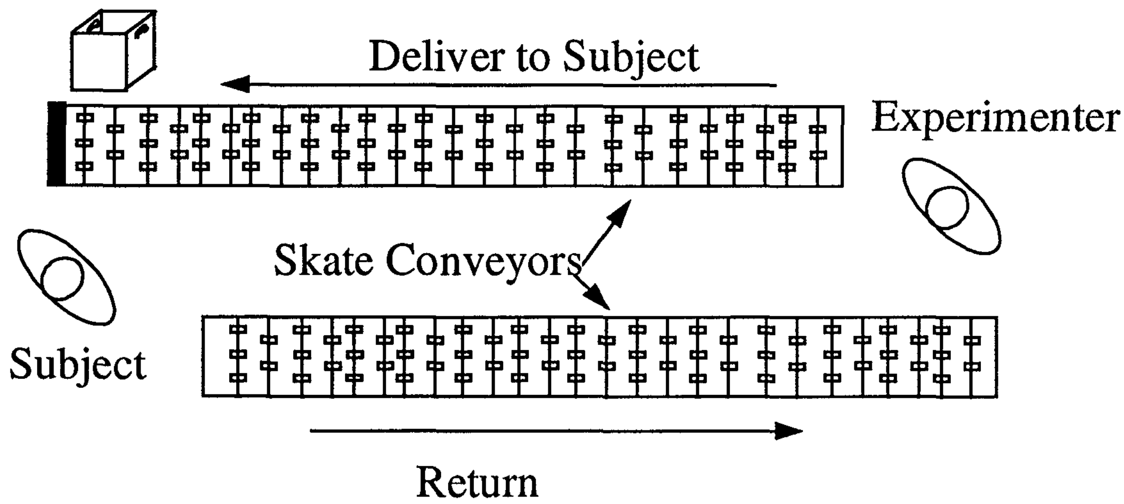

Figure 1. Overhead view of experimental environment

Experimental Setup and Task

Wooden boxes with handles ("good" coupling as defined by the 1991 Lifting Equation) were delivered to the subjects via gravity-fed passive skate-wheel conveyers at approximately 5° slope. The mass of the boxes were 11.4 kg for men and 7.4 kg for the women. The conveyors were placed parallel to each other 2 feet apart and were offset by 2 feet. This resulted in a 90° rotation requirement for transferring the boxes from the first to the second conveyer (Figure 1). Subjects worked for twenty minutes and then were given a five minute rest period.

The boxes were placed on the conveyer at the prescribed frequencies to simulate equally spaced packages from an automatic conveyer system. Each box was sent to the subject with the handles in line with conveyor to standardize the initial lifting posture. The subjects were then asked to lift the box after it reached the box stop and place it on the top of the return conveyer with the handles perpendicular to the midline of the conveyor. The subjects were given no instructions as to the lifting style to be used. Research has shown that this free-style lift allows for the greatest psychophysical lifting capacity (Garg and Saxena, 1979) while providing data which would be most representative of industrial data.

Experimental Design

The independent variables for this study were frequency of lift and the height of the handles as the box was lifted. The starting heights were 30 and 60 cm from the floor, while the height of the handles while placing the box on the return conveyer was 70 cm. The three lifting frequencies chosen for this study were 3, 6, and 9 lifts/minute. These frequencies were chosen for comparison with the data from previous research (Garg and Saxena, 1979) and to cover the range of frequencies typically seen in industry (Marras et al, 1993). The duration of each experimental condition was twenty minutes. Data was collected on each of the lifts for the 3 and 6 lifts/minute condition while computer limitations only allowed for data collection on every other lift for the 9 lifts per minute condition

The dependent variables were the kinematic parameters describing the motion of the lumbar spine (range of motion, velocity, and acceleration) in the three planes (sagittal, coronal, and transverse). This kinematic data was collected at a rate of 60 samples per second. Heart rate was collected as the instantaneous value at one minute intervals. Sagittal acceleration is the only dependent variable which will be discussed in the current paper.

Data Analysis

The peak value of sagittal acceleration was extracted from each of the data files. This peak value was computed as the average of the peak value and one data point on each side of this peak value. This was done to reduce data processing induced variability. This resulted in one peak value per trial. The time dependent standard deviation was then calculated from seven consecutive trials.

RESULTS

The results of this study are shown graphically in Figures 2-5. Figure 2 shows the response of sagittal acceleration to the different levels of starting height and lift frequency. A statistical analysis revealed a significant effect for both starting height and lift frequency ($p<.001$). Figure 3 shows an example of a time dependent response of the peak sagittal acceleration. The data in this part of the analysis was highly variable from subject to subject. In fact when these were averaged across subjects no significant trends resulted. It was only when the data was plotted by subject did the analysis reveal these interesting results. Finally, Figures 4-5 shown how the variability in the peak sagittal acceleration changed as a function of time. Again these trends were highly subject dependent.

DISCUSSION

The results of the present study suggest that in addition to the increase in some of the physiologic parameters which have been shown previously, there are some critical biomechanical parameters which are affected by increased frequency of lifting.

It should be noted that the frequency levels chosen in this experiment were not so high as to require continuous work from the subject. If the frequency levels chosen had been at these excessive levels, it would not have been surprising for the frequency levels to be highly correlated with some of these kinematic parameters because the subjects' trunk dynamics would have to increase to keep up with the incoming work. The results of this study have shown, however, that under the conditions which do not require continuous work there still was an increase in most kinematic parameters with increased lifting frequency. Even under the highest work rate (9 lifts per minute) there still was between 3 and 4 seconds of rest wherein the subject was standing erect and waiting for the next box to arrive. This result indicates that instead of a required increase in trunk kinematics, as would be the case under conditions of high lift rates (>15/minute), there appears to some other mechanism at work.

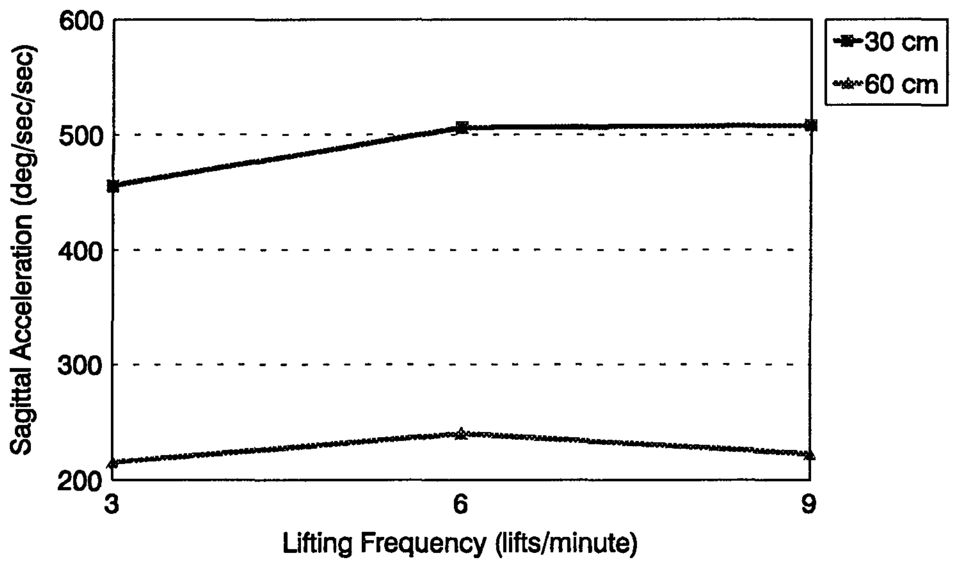

Figure 2. Response of sagittal acceleration to different levels of lifting frequency and starting heights. Note non-linear trend in these graphs.

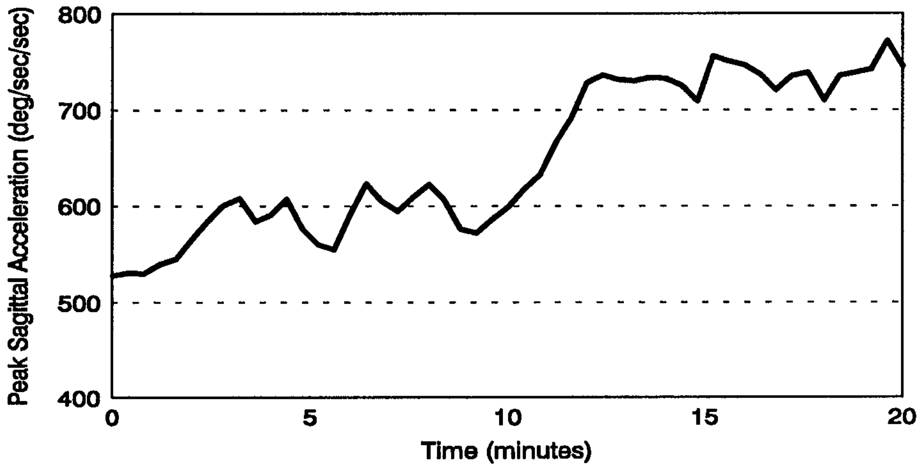

Figure 3. Time dependent response of the peak sagittal acceleration. Condition: Frequency = 9 lifts/minute, starting height = 30 cm.

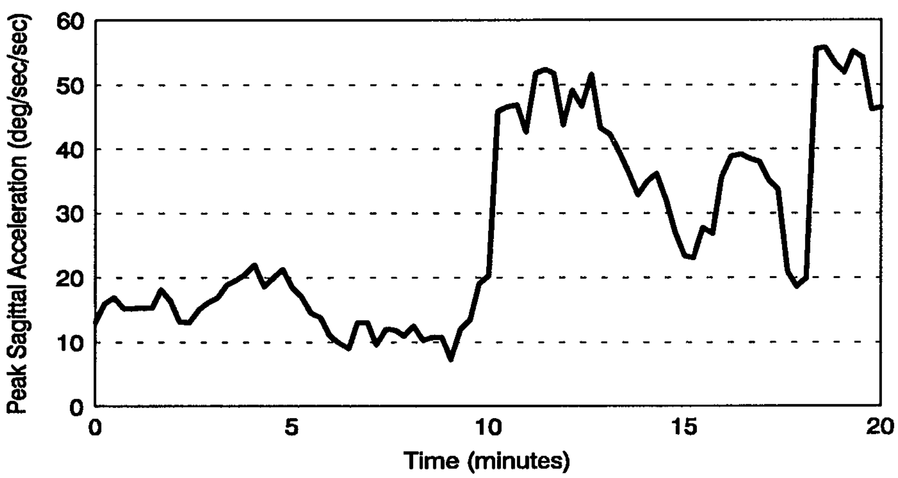

Figure 4. Time dependent response of the standard deviation of the peak sagittal acceleration. Condition: Frequency = 9 lifts/minute, starting height = 30 cm.

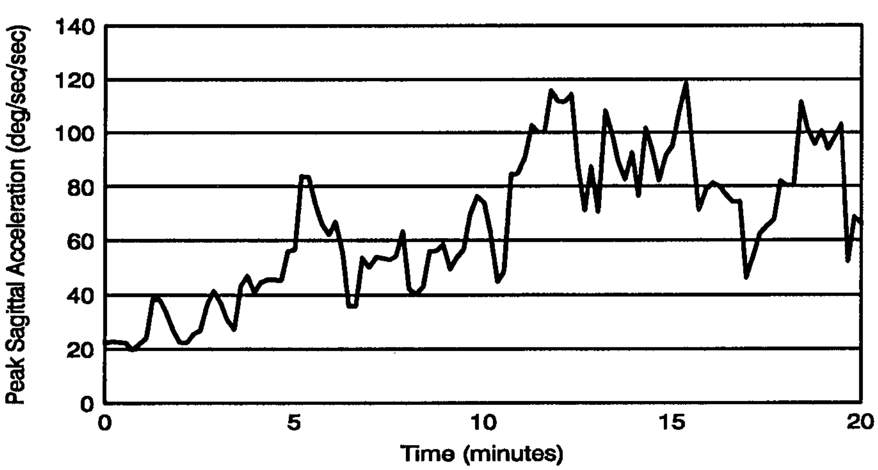

Figure 5. Time dependent response of the standard deviation of the peak sagittal acceleration. Condition: Frequency = 9 lifts/minute, starting height = 30 cm.

There has quite a bit of work done in the area of the effects of frequency during lifting. Much of the work has been in the area of psychophysics and cardiovascular physiology. Of particular relevance to the current study is a paper by Garg and Saxena (1979) which described a psychophysical study wherein subjects performed lifts at constant frequencies (3, 6, 9, and 12 lifts/minute) and were asked to find their maximum acceptable weight of lift. They found an interesting energy minimization at a frequency of 9 lifts/minute. The metabolic cost per unit work curve (i.e., Kcal/Kg*m or HR/Kg*m ratio) was parabolic with the minimum point occurring at the frequency of 9 lifts/minute (Garg and Saxena, 1979; Garg and Banaag, 1988). These studies were very useful in predicting the weights and workloads that subjects would choose as a function of the lifting frequency, but they did not discuss any change in the lifting biomechanics, a limitation which has been overcome somewhat with the current study. It is interesting to note that there does seem to be a sort of leveling off of the sagittal acceleration, a results consistent with that of the studies mentioned above.

The time dependent data shown in Figures 3-5 showed some very interesting subject dependent trends. Of particular interest is data presented in Figures 3 and 4. At about the ten minute mark there is an abrupt change in the variability of the subjects performance and an increase in the peak sagittal acceleration. Reviewing written notes taken during subject data collection it was noted that it was around this point that the subject changed from a squat lift to a stoop lift. This would explain the trends shown in these figures. Figure 5 shows a gradual increase in the variability of the data. This may be attributed to the gradual onset of fatigue. Not shown in this paper are data which show fairly high levels of variability early in the twenty minute period which tended to level off as the subject progressed through the experiment. This might indicate a short adjustment period as the subject became acclimated to the lifting task. Taken as a whole, the time dependent data suggests that it may be important for ergonomists to consider the changes over time of the human performance aspect of manual material handling. These parameters could become markers describing variables such as fatigue or warm-up periods which could be useful in designing and monitoring workplace design and evaluation.

ACKNOWLEDGMENTS

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REFERENCES

Garg, A. 1976, "A Metabolic Rate Prediction Model for Manual Materials Handling Jobs," PhD Dissertation, University of Michigan.

Garg, A. and Banaag, J. "Maximum acceptable weights, heart rates, and RPEs for one hour's repetitive asymmetric lifting," *Ergonomics*, 31: 77-96 (1988).

Garg, A. and Saxena, U. "Effects of lifting frequency and technique on physical fatigue with special reference to psychophysical methodology and metabolic rate," *American Industrial Hygiene Association Journal*, 40: 894-903 (1979).

Marras, W., Lavender, S., Leurgans, S., Rajulu, S., Alread, G., Fathallah, F. and Ferguson, S. "The Role of Dynamic Three-Dimensional Trunk Motion in Occupationally Related Low Back Disorders: The Effects of Workplace Factors, Trunk Position and Trunk Motion Characteristics," *Spine*, 18: 617-628 (1993).

Snook,S.H. and Ciriello, V.M. "The Design of Manual Handling Tasks: Revised Tables of Maximum Acceptable Weights and Forces," *Ergonomics*, 34, 1197-1213 (1991).

Waters, T.L., Putz-Anderson, V., Garg, A. and Fine, L.J. "Revised NIOSH Equation for the Design and Evaluation of Manual Lifting Tasks," *Ergonomics*, 36, 749-776 (1993).