FATIGUE EFFECTS ON MANUAL LIFTING ACCELERATION

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ABSTRACT

The objective of this study was to investigate the effects of fatigue, caused by frequent manual lifting, on lifting velocity and lifting acceleration. Ten male volunteers performed lifting at a rate of 4 times per minute, continuously, for two hours using the free-style posture. A box (30cm x 30cm x 20cm) with a fixed weight (15.9 kg) was used as the load for lifting. Heart rate, oxygen consumption, and EMG were also measured to estimate the level of fatigue. The posture as well as acceleration was recorded. The results show that the lifting acceleration at the end of two hour increased significantly (20%, $p < 0.001$) compared to the accleration after fifteen minutes of lifting. It was also found that subjects changed their lifting postures as the result of fatigue. All subjects also indicated pain in their upper legs and the lower back at the conclusion of the experiment.

Key words: Manual lifting, lifting acceleration, muscular fatigue.

I. INTRODUCTION

It is commonly assumed that when workers get tired, they tend to lift loads slowly in order to reduce the overall work rate. At the same time, however, they must maintain the task pace set by production requirements (e.g., conveyor belt speed). It was hypothesized in this study that the onset of overall muscular fatigue, resulting from increasing task duration, and the need to maintain the pace set by production demands would lead a subject to increas acceleration. Should this happen, the consequences on the imposed spinal stresses could be severe. Since, by definition, force is equal to the product of the mass lifted and the load acceleration, excessive force may result when lifting the same mass with an increased acceleration. Conversely, low accelerations will reduce the extent of the imposed external forces.

The objective of this investigation, therefore, was to study the effect of overall muscular fatigue on load acceleration during manual lifting of a load.

II. METHOD

An experiment involving lifting a load was conducted to examine changes in load acceleration.

1. SUBJECTS

Ten male college students voluntarily participated in the experiment. Their age ranged from 22 to 31 years. All subjects were inexperienced in manual lifting and were monetarily compensated for their participation in the experiment; Mital (1985) has shown that the response pattern of experienced and inexperienced workers to manual lifting job demands is similar. To familiarize the subjects with the experimental task, a practice session of five minutes was conducted before the experiment. The experimental setup for the practice session was the same as that used in the experiment.

2. EXPERIMENT

Prior to the lifting experiment, each subject's back and arm strengths were measured using a strength monitor. The methodology specified by Caldwell et al. (1974) was employed for this purpose. In the lifting experiment, each subject lifted a box (30cm x 30cm x 20 cm), filled with metal pieces, using a free lifting posture. The box weighed 15.9 kg and had cut-out handles.

Each subject lifted the load continuously for two hours. This duration is typical of industrial work where a break (either a coffee break or lunch break) usually follows. No rest was provided during the 2-hour work period. The response measures (load acceleration, compressive force at $L_{5/S1}$, Oxygen consump-

tion rate, EMG's at lower back, arm, and leg, and heart rate) were recorded during the lifting cycle every 30 minutes. Load acceleration was obtained using the Peak Performance 2D system in which the lifting motion and the load movement were videotaped and the tape was analyzed to calcualte the acceleration. The compressive force was calculated using the Michigan's Biomechanical 2D model by revising it for acceleration.

Heart rate, oxygen consumption rate and EMG were used as measures of the fatigue. As indicated by Mital (1983) and Mital and Asfour (1983), in the absence of muscular fatigue, the heart rate remains unchanged. As the overall fatigue builds-up, the increased circulatory strain causes the heart rate to increase. In inexperienced male workers, performing only manual lifting jobs that do not cause muscular fatigue, the average working heart rate is approximately 85 beats per minute (Mital, 1985). Any further increase in the average heart rate is an indication of overall muscular fatigue onset.

Ⅲ. RESULTS

All data were analyzed using Statistical Analysis System. It was found that in a typical lifting cycle initially the value of acceleration increased fairly quickly to reach the peak level. After this point, it steadily reduced until reaching a zero value. Then, the subjects actually decelerated (negative part of the cycle plot) so that the load could be stopped at the terminal point of the lift.

Mean acceleration was computed for each subject during the acceleration portion of the lifting cycle. The deceleration portion of the cycle was excluded for computing the average acceleration; deceleration does not increase the compressive force on the back. Figure 1 shows the mean acceleration changes with time. ANOVA shows that the mean load acceleration increased significantly ($p < 0.001$), by 20%, from $0.72 m/sec^2$ after 30 minutes of lifting to $0.85 m/sec^2$ by the end of two hour of lifting. During the same period the average peak compressive force for all subjects increased by 13% from the 2180 newtons to 2470 newtons.

Heart rate, oxygen consumption rate and EMG level showed the existence of fatigue due to lifting. The heart rate increased significantly ($p < .01$), by 21% on the average, from 95 bpm to 115 bpm during the experiment. The oxygen consumption rate was remained at 14.5ml/min/kg. The median frequencies of EMG's were reduced from 110Hz. to 80Hz. for arm, 90Hz. to 70Hz. for lower back and 78Hz. to 61Hz. for leg muscles. This increase is a definite indicator of the overall muscular fatigue build-up.

Ⅳ. DISCUSSION

This work investigated changes in load acceleration with the working duration in a manual lifting task. It was hypothesized that as the overall muscle fatigue builds up due to the increased

working time, the load acceleration will increase. As mentioned in the results section, the average starting heart rate of the subjects was 95 bpm. This was higher than the average starting heart rate in Mital's (1985) study (85 bpm). As the overall muscular fatigue builds up, the starting heart rate increased by almost 21% at the end of the 2-hour working period. Since the load acceleration increased over the same period as the heart rate increased, the hypothesis that load acceleration would increase with muscular fatigue was proven correct.

The increase in acceleration is believed to be goal related. The overall muscular fatigue tends to slow down worker movements while the need to maintain the work tempo (forced pace in this case - 4 lifts per minute) forces him to attempt to continue at the set pace. We believe that the perceived need to makeup for the loss of time in picking up the box forces the subject to accelerate the load during the lift. It was also noted that there was significant sudden changes in force exertion as indicated by the magnitude and extent of jerking.

The increased acceleration resulted in higher spinal compressive force. The general expectation that people would jerk the load to reduce the compressive load on the spine after prolonged lifting, was substantiated in this work.

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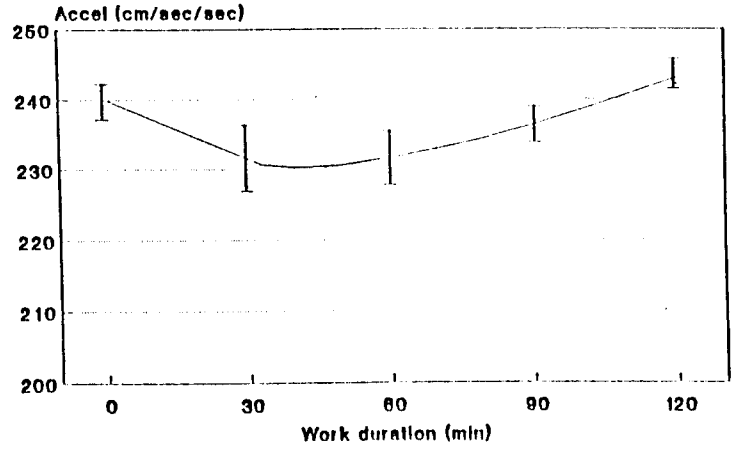

Figure 1. Mean Acceleration averaged for all subjects during the two hours of lifting.