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규칙적 들어올리기 작업에 있어서의 들기 가속도와 피로도와의 관계연구

Fatigue Effect On Lifting Acceleration During Frequent Liftings

Youngjoun Kim*

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 × 30cm × 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 showed that the lifting acceleration at the end of two hour increased significantly (20%, $p<0.001$) compared to the acceleration 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.

Keyword: Manual lifting, lifting acceleration, muscular fatigue.

* Department of Industrial Engineering
Korea Air Force Academy
POB No. 335-1, Sangsuri, namilmyun
Choongbuk 363-840
Tel : 043-290-6493
E-mail : kimyj@afa.ac.kr

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1. 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 increase acceleration. Should this happen, the stress imposed on the spinal column could be severe. Since, by definition, force is equal to the product of the mass lifted and the load acceleration, the excessive force can be generated even when lifting the same mass with an increased acceleration. Conversely, low acceleration will reduce the extent of the external forces imposed on the spine.

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

2. METHOD

An experiment was conducted to examine the load on the spine as the load acceleration changes.

2.1 Subjects

Ten male college students voluntarily participated in the experiment. Their age raged from 22 to 31 years. All subjects were inexperienced in manual lifting and were monetarily compensated for their participation in the experiment. Based upon the results by Mital (1985) who has shown that the response patterns between experienced and inexperienced workers to manual lifting job demands are 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.

2.2 Experiment

Prior to the lifting experiment, each subject's back and arm strength 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 × 30cm × 20cm), filled with metal pieces, using a free lifting posture. The box weighed 15.9 Kg and had cut-out handles. Figure 1 shows the experimental layout.

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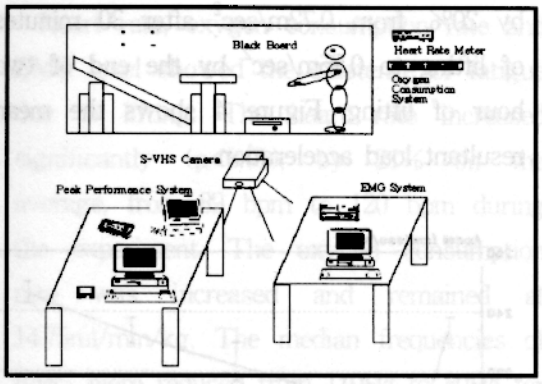

Figure 1. Experimental set-up

Each subject lifted the load continuously for two hours. This duration was in typical in industry where a break (either a coffee break or lunch break) usually follows. No rest was provided during two hours work period. The response measures (load acceleration, compressive force at L_5/S_1, Oxygen consumption 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 load movement were videotaped and the tape was analyzed to calculate the acceleration. The compressive force was calculated using the Michigan's Biomechanical 2D model that was revised to compute acceleration.

Heart rate, oxygen consumption rate and EMG were used as measures of 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 increases the heart rate. Inexperienced male workers who performed only manual lifting jobs did not experience muscular fatigue, the average working heart rate was approximately 85 beats per minute (Mital, 1985). Any further increase in the average heart rate is an indication of overall muscular fatigue onset.

3. RESULTS

All data were analyzed using Statistical Analysis System. It was found that in a typical lifting cycle, the value of acceleration increased fairly quickly to reach the peak level as shown in Figure 2. After this point, it steadily reduced until it reached to 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.

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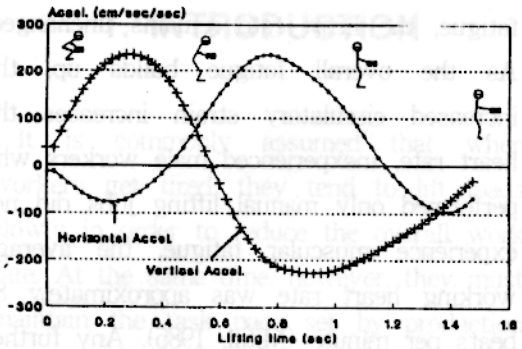

Figure 2. Typical acceleration/deceleration profile over time during one cycle of lifting.

Mean acceleration was computed for each subject during the acceleration portion of the lifting cycle. The deceleration portion of the cycle was excluded to compute the average acceleration. Deceleration did not increase the compressive force on the back. Figure 3 shows the change in mean acceleration with time.

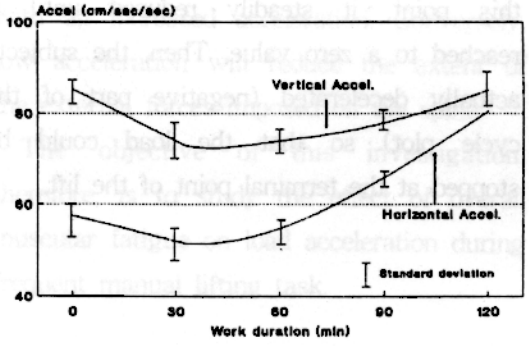

Figure 3. Mean Load Acceleration vs. Elapsed Time (Lifting).

ANOVA showed that the mean load acceleration increased significantly ($p<0.001$), by 20%, from 0.72m/sec^2 after 30 minutes of lifting to 0.85m/sec^2 by the end of two hour of lifting. Figure 4 shows the mean resultant load acceleration.

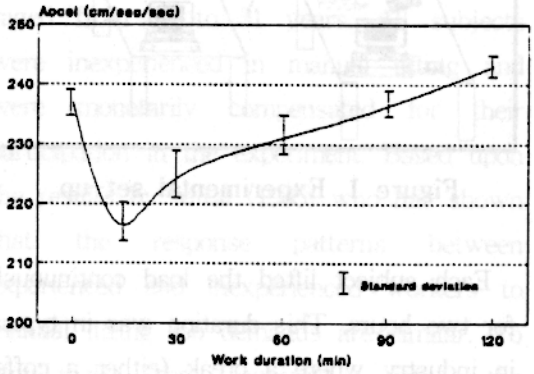

Figure 4. Mean Resultant Load Acceleration.

It also increased significantly ($p<0.001$) from the minimum value of 2.17m/sec^2 to 2.43 m/sec^2. During the same period the average peak compressive force for all subjects increased by 13% from the 2180 newtons to 2470 newtons as shown in Figure 5.

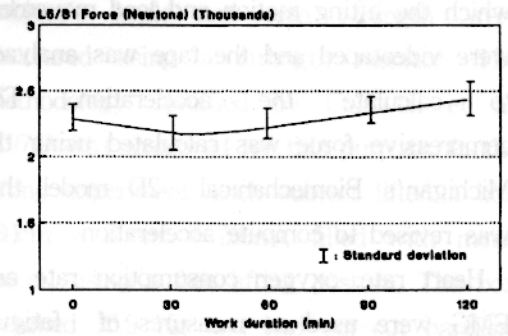

Figure 5. Compressive Force vs. Elapsed Time (Lifting).

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Heart rate, oxygen consumption rate and EMG level showed the existence of fatigue due to lifting. The heart rate increased significantly ($p<0.01$), by 21% on the average, from 89 bpm to 120 bpm during the experiment. The oxygen consumption rate was increased and remained at 14.75ml/min/kg. The median frequencies of EMG were reduced from 110Hz to 80Hz for arm, 90Hz to 70Hz for lower back and 78Hz to 61Hz for leg muscles, respectively. Such physiological and neuromuscular changes are definite indicators of the overall muscular fatigue build-up.

4. DISCUSSION

This work investigated changes in load acceleration during frequent manual lifting tasks. It was hypothesized that if the overall muscle fatigue builds up due to the increased working time, the load acceleration increases. As mentioned in the results section, the average starting heart rate of the subjects was 89 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 35% at the end of two hours working period. The median frequency of EMG were also reduced significantly. Since the load acceleration increased over the same period as the heart rate increased, the hypothesis such that "the load acceleration would increase with muscular fatigue" was proven correct.

The increase in acceleration is believed to be a goal oriented behavior. The overall muscular fatigue tends to slow down worker movements whereas the need to maintain the work pace (forced pace in this case - four lifts per minute) forces him to attempt to continue at the set pace. It was believed that the perceived need to makeup for the loss of time in picking up the box forces the subject to increase the load acceleration 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 a higher spinal compressive force. Therefore, the increased load acceleration with a fatigued muscle could increase the risk of low back injury during frequent and prolonged lifting task.

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Author Profile

◈ Youngjoun Kim

Received the Ph.D. in Industrial Engineering in Louisiana State University. He is a member of Korean Ergonomics Society, and Korean Institute of Industrial Engineering. He is currently a faculty member in department of Industrial Engineering in Korea Air Force Academy.

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