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ACCEPTABLE LOADS AND PHYSIOLOGICAL STRESSES WHEN LIFTING A CRIB BLOCK

by

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Twelve male subjects with mining experience participated in an investigation of the acceptable weights and physiological stresses while lifting a crib block. The independent variables were posture, symmetry, and lifting height. The dependent variables were the maximum acceptable weight of lift (MAWL), heart rate (HR), absolute and normalized oxygen utilization ($A\dot{V}O_2$ and $N\dot{V}O_2$), ventilation volume ($\dot{V}_E$), and the respiratory exchange ratio (R). HR, $N\dot{V}O_2$, $A\dot{V}O_2$, and $\dot{V}_E$ were all significantly higher in the stooped posture than in the kneeling posture, and R was higher in restricted postures than in the unrestricted posture. $N\dot{V}O_2$, $A\dot{V}O_2$, and $\dot{V}_E$ were higher when lifting to a higher shelf. MAWL was a function of posture, symmetry, and lifting height. The data indicate that the weight of crib blocks are often above acceptable weight limits for the tasks tested.

INTRODUCTION

Back injuries are the leading cause of lost work time in the U.S. coal mining industry, accounting for approximately 30% to 40% of worker compensation payments made by the industry. One frequently handled material in underground mining is the crib block. Crib blocks are wooden blocks, approximately 15 cm wide, 15 cm deep, and anywhere from 30 cm to 180 cm long. The weight of a crib block can be anywhere from 9 to 28 kg (Bobick, 1987), depending on the size of the block and the amount of water in the wood. Crib blocks are stacked to support roof in places where it may be unstable. Miners often must lift these items in severely restricted postures since, in many cases, the height of the mine roof is low (frequently less than 1.2 meters). The two most common postures used for lifting in low seam coal mines are stooping or kneeling on two knees (Bobick, 1987).

Previous researchers have examined some aspects of lifting in restricted postures. Several studies have been performed using intra-abdominal pressure (IAP) as a measure of spinal stress when lifting in restricted headroom conditions (Davis and Troup, 1966; Davis and Ridd, 1981; Ridd, 1985; Sims and Graveling, 1988). Biomechanical aspects of restricted postures have been examined by Gallagher *et al.* (1990, 1991a, 1991b). Physiological demands of performing manual lifting tasks in low-coal mines have also been documented (Humphreys and Lind, 1962; Ayoub *et al.*, 1981). Gallagher *et al.*

(1988) examined lifting capacity, metabolic costs, and electromyography of trunk muscles while lifting in stooped and kneeling postures and observed decreased psychophysical lifting capacity and increased metabolic stress and internal load on the spine in the kneeling posture. Similar results were reported by Gallagher (1991) and Gallagher and Unger (1990). The current study was undertaken to determine the effects of the material being lifted (ie. the crib block) and the effects due to varying seam heights on physiological costs and lifting capacity.

METHOD

Subjects

Twelve healthy male subjects (μ = 41.9 years of age, σ = 5.7) participated in an investigation of the acceptable weights and physiological stresses while lifting a crib block. All subjects were paid volunteers and received a physical examination and graded exercise tolerance test prior to taking part in the testing. All subjects were experienced underground coal miners who operated under terms of informed consent.

Experimental Design

Two independent variables were manipulated in this experiment: four levels of posture (kneeling, stooping under a 1.2 meter roof height [Low Stoop], stooping under a 1.5 meter roof height [High Stoop], and unrestricted standing) and four levels of lifting conditions (symmetric to 35 cm lifting height, symmetric to 70 cm, 90° asymmetric to 35 cm, and 90° asymmetric to 70 cm). A Graeco-Latin square design was used, whereby each subject performed four of the sixteen possible treatments; thus, three subjects were assigned to each treatment. The dependent measures were the psychophysical maximum acceptable weight of lift (MAWL), heart rate (HR), normalized oxygen utilization ($N\dot{V}O_2$), absolute oxygen utilization ($A\dot{V}O_2$), ventilation volume ($\dot{V}_E$), and the respiratory exchange ration (R). A priori orthogonal contrasts were specified for both independent variables. These contrasts are presented in Table 1. All dependent variables were analyzed using an analysis of variance (ANOVA) procedure, and a five percent significance level was used for each contrast.

Apparatus

An Arlyn[1] Model 300-D digital scale was used to determine the weight of the lifting box before and after periods of lifting. The subjects' heart rates were determined using a Beckman Dynograph Recorder (Model 511-A), and respiratory measurements were collected using the Beckman Metabolic Measurement Cart I.

The lifting tasks were performed under a roof that restricted the subject's posture. A wooden box in the shape of a standard crib block (76.2cm x 15.2cm x 15.2cm) with three covered compartments was used in the lifting tasks. The box was lowered automatically by a hydraulic cylinder attached to a shelf. The shelf height could be set to either 35 cm or 70 cm. The lifting frequency was controlled using a computer generated voice prompt.

Experimental Procedure

After informed consent was obtained, each subject received a training period where they performed the lifting task to be described for the unrestricted standing condition at a

[1]Reference to specific products does not imply endorsement by the Bureau of Mines.

lifting height of 70 cm. This was to ensure that each subject understood the methodology and did not experience extreme muscle soreness during the actual lifting tests.

On a later day, each subject returned and was read the lifting task instructions. The subjects lifted the box at a rate of four lifts per minute. Immediately after the block was placed on the shelf, the block was automatically lowered to the starting position on the floor. Then, in accordance with the standard psychophysical methodology (Snook, 1978), each subject adjusted the weight to a level that he could lift "without strain or undue fatigue" for the duration of the lifting task by putting in or taking out steel weights. The subject was not informed of the amount of weight in the lifting box during the test, and the experimenters varied the starting weight by placing different amounts of weight in the covered compartments. The subject performed two lifting periods for each condition; one period would begin with a light box (approximately 9.6 kg) to which the subject would add weights, and the other period would begin with a heavy box (approximately 36.5 kg) to which the subject would take away weights. It must be noted that regardless of the starting weight, the subject was free to add or subtract weight at any time during the test. Each lifting test lasted fifteen minutes. Heart rate data were collected every minute during the last ten minutes of the test. Physiological measures were collected every thirty seconds during the last five minutes of testing.

Upon completion of the test, the subject rested (ten minutes between lifting periods and fifteen minutes between lifting conditions), after which the next test would be run. This procedure was repeated until the subject had completed all four tests.

Data Analysis

The MAWL for each lifting condition was determined to be the average of the two lifting periods for that condition. Physiological variables were also taken as the average observed for the two lifting periods in each posture. The data were then analyzed using an ANOVA procedure.

RESULTS

A summary of significant effects is presented in Table 1, and cell means are given in Table 2.

Maximum Acceptable Weight of Lift

The MAWL was affected by symmetry of lift ($F_{1,24}$=6.02, p=0.022); more weight could be lifted asymmetrically than symmetrically. This difference, although significant, was not large (an average of 0.89 kg). Also significant was the posture by lifting condition interaction ($F_{6,24}$=3.15, p=0.020). Thus, the main effect of symmetry cannot be interpreted since MAWL was a complex function of posture, symmetry, and lifting height.

Heart Rate

The only factor to influence the heart rate was posture. Namely, the heart rate was higher in the stooped postures than in the kneeling posture ($F_{1,24}$=11.76, p=0.002).

Oxygen Utilization

$A\dot{V}O_2$ and $N\dot{V}O_2$ were affected by identical factors. Both were higher in the stooped postures than in the kneeling posture ($A\dot{V}O_2$:$F_{1,24}$=61.43, p<0.001; $N\dot{V}O_2$:$F_{1,24}$=62.16, p<0.001). In addition, both were higher when lifting to a 70 cm shelf height than when lifting to a 35 cm shelf height ($A\dot{V}O_2$:$F_{1,24}$=7.18, p=0.013; $N\dot{V}O_2$:$F_{1,24}$=7.37, p=0.012).

Table 1. Summary of significant effects.

	MAWL	HR	$N\dot{V}O_2$	$A\dot{V}O_2$	$\dot{V}_E$	R
Posture		**	***	***	***	*
Standing vs. Restricted						*
Low Stoop vs. High Stoop						
Kneeling vs. Stooped		**	***	***	***	
Lifting Conditions	*		**	*	*	
Symmetric vs. Asymmetric	*					
Height: 35cm vs. 70cm			*	*	*	
Symmetry x Height						
Posture x Lifting Conditions	*					*

* p<=0.050
** p<=0.010
*** p<=0.001

Table 2. Cell means.

	MAWL (kg)	HR (bpm)	$N\dot{V}O_2$ (ml/kg/min)	$A\dot{V}O_2$ (l/min)	$\dot{V}_E$ (l/min)	R
Kneeling	20.5	103.6	10.1	0.835	22.25	0.854
Low Stoop	20.6	107.9	12.6	1.037	27.47	0.878
High Stoop	20.7	108.7	12.7	1.037	26.97	0.865
Standing	21.1	104.8	12.0	0.984	25.13	0.846
Symmetric	20.3	105.6	11.6	0.955	25.14	0.863
Asymmetric	21.1	106.9	12.1	0.991	25.77	0.859
35 cm Lift	21.0	105.2	11.5	0.945	24.79	0.862
70 cm Lift	20.4	107.3	12.2	1.001	26.12	0.860

Ventilation Volume

Both posture and lifting height affected $\dot{V}_E$. Like heart rate and oxygen utilization, $\dot{V}_E$ was higher when stooped than when kneeling ($F_{1,24}$=55.64, p<0.001) and was higher when lifting to a 70 cm shelf height than when lifting to a 35 cm shelf height ($F_{1,24}$=5.98, p=0.022).

Respiratory Exchange Ratio

R was significantly higher in restricted postures than when standing ($F_{1,24}$=4.52., p=0.044). Furthermore, there was a significant posture by lifting condition interaction ($F_{6,24}$=2.65, p=0.041). Thus, the main effect of symmetry cannot be interpreted since R was a complex function of posture, symmetry, and lifting height.

DISCUSSION

Maximum Acceptable Weight of Lift

A previous Bureau of Mines research study (Gallagher, 1991) found increased lifting capacity in asymmetric lifting postures when compared to symmetric lifting. This differs from the findings of other researchers' work in unrestricted postures. For example, Garg and Badger (1986) found that lifting capacity is decreased 6% to 25% with asymmetric lifts. Similar results have been obtained by others (Asfour, *et al.*, 1984; Mital and Fard, 1986; Kumar, 1980; Kumar and Magee, 1982). We believe the discrepancy illustrates an important difference between unrestricted and restricted lifting situations. The reason that more weight was lifted in asymmetric lifts in restricted postures may be because asymmetric movements are not restricted in constrained headroom conditions; however, symmetric (or sagittal plane) movements are limited under these circumstances.

This study, however, revealed that a complex interaction between posture and lifting conditions was significant for these lifting tasks; thus, the MAWL is dependent upon posture, level of symmetry, and lifting height. For example, while kneeling or while stooped under a 1.2m roof, the MAWL is greater in the symmetric conditions. However, while stooped under a 1.5m roof or while standing, the MAWL is greater for the asymmetric conditions.

The results of this study differ from those of previous Bureau of Mines studies (Gallagher, et al., 1988; Gallagher and Unger, 1990) in that neither posture alone nor lifting height alone were found to be a significant factor in the determination of the MAWL. Perhaps due to the awkward size of the crib block and the lack of handles, the lifting capacity was limited by the initial force required to lift the crib block from the ground. Thus, posture may no longer be the predominant factor in limiting lifting capacity under these circumstances.

It is thus apparent that the size of an object plays a considerable role in the determination of the MAWL. This has been stated previously by Snook (1978), Garg and Saxena (1980), Genaidy *et al.* (1990), and many others. Any models that are developed to predict risk of back injury, then, should include the size of the object as a parameter.

Physiological Cost

These results indicate that the stooped postures appear to be more physiologically stressful than the kneeling posture, as also reported by Gallagher (1991). This finding differs from some previous Bureau of Mines studies (Gallagher, *et al.*, 1988; Gallagher and Unger, 1990) which found significant increases in metabolic cost in the kneeling posture, despite the fact that significantly less weight was being lifted in the kneeling posture. The disparity between these two studies can be explained by examining the tasks involved; the previous studies examined lifting tasks which used a lateral lift across the body. This lateral lifting motion generated a relatively small moment on the shoulder and elbow when lifting in the stooped posture, and required little trunk motion. The current lifting tasks, on the other hand, required subjects to lift the load up and away from the body, thereby increasing the moment experienced by the shoulder and elbow joints, as well as on the back, when stooped. The increased moments would have to be counteracted by increased muscle forces about the affected joints, and the heightened muscle activity would result in increased oxygen uptake and heart rate.

Furthermore, $N\dot{V}O_2$, $A\dot{V}O_2$, and $\dot{V}_E$ were significantly higher when lifting to a higher shelf height, as expected. This increased physiologic cost is certainly a result of the increased work performed against the force of gravity when performing the lift to a greater height.

The respiratory quotient was significantly lower when standing than in the restricted postures; this indicates that the body is burning more fat and fewer carbohydrates when performing work in the standing posture. Thus, lifting in the restricted postures is physiologically more taxing than lifting in an unrestricted posture.

On the average, subjects in this experiment selected a workload that kept the absolute oxygen utilization rate near or below recommended physiological eight hour workload limits of five kilocalories per minute, or an absolute oxygen consumption rate of approximately one liter per minute (NIOSH, 1981). In addition, the heart rates observed in the experiment were, on average, below the recommended eight hour limit of 115 beats per minute.

CONCLUSIONS

The data presented in this paper indicate that for the lifting task examined in this study there are several physiological disadvantages associated with lifting in stooped postures. The stooped lifting tasks require a greater energy expenditure, as seen through increased heart rate, oxygen utilization, and ventilation volume. Furthermore, the respiratory quotient indicates that the restricted postures are more physiologically demanding than the unrestricted standing posture. The psychophysical lifting capacity, on the other hand, was found to be a complex function of posture, symmetry, and lifting height. This significant interaction indicated that crib block lifting capacity was dependent upon the specific nature of the lift being performed. Since the actual differences were relatively small and for the sake of simplicity, the following recommended weight limits are based upon the pool of all lifting conditions that were examined.

Using the criterion of Snook and Ciriello (1974), which uses the mean and standard deviation to determine work loads that are acceptable to 90% of the population, a weight limit of 14.5 kg (approximately 33 lbs.) can be recommended for lifting a crib block. It must be noted that this limit applies only to repetitive handling of crib blocks and was based on data from healthy, male subjects. Bobick (1987) determined through informal observations that actual crib blocks weigh between twenty and sixty pounds (approximately 9 to 28 kg). It appears, then, that crib blocks are often above acceptable weight limits for the tasks studied. Consequently, careful consideration should be given to the design of materials handling systems associated with crib blocks.

The increased metabolic data in the stooped postures indicate that if crib blocks are to be handled repetitively in these postures, more frequent rest breaks may be needed to prevent the onset of fatigue when assuming this posture. Since most materials handling in coal mines is self-paced, workers should be advised not to rush lifting tasks. The authors encourage miners who work in low coal to heed the advice given by Andersson (1985); prolonged work in any posture should be avoided.

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