EFFECTS OF LIFTING IN FOUR RESTRICTED WORK POSTURES

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ABSTRACT

The purpose of this study was to examine the lifting capacity of low-seam coal miners in four restricted work postures (roof heights of 36", 40", 44", and 48"), investigate the associated metabolic costs, and to examine electromyographic (EMG) data from eight trunk muscles during the lifting procedure. Subjects were thirteen underground miners accustomed to handling materials in restricted work postures. Each subject performed two twenty-minute periods of asymmetric lifting in each of four postures during the day of testing. The frequency of lifting was 10 lifts per minute. A specially designed lifting box incorporated microswitches in one handle of the box and another in the bottom of the box, in order to examine the trunk muscle function at specific points during the lfting cycle. The data collected will be used by the Bureau of Mines to make recommendations for lifting materials in low-seam coal mines.

INTRODUCTION

Statistics obtained from the Mine Safety and Health Administration's Health and Safety Analysis Center (HSAC) files for the years 1981 through 1986 have shown back injuries as being a significant and continuing problem in the underground mining industry. During this six-year period there have been a total of over 12,500 back injuries in underground coal mines. HSAC statistics also indicate that the rate of back injuries per 200,000 man-hours worked is higher the lower the seam of the coal mine (see Table 1). One reason for the increased incidence in low seams is that underground miners must perform lifting tasks in restricted working positions.

Previous Bureau research has indicated that underground miners have a reduced lifting capacity when lifting in an unrestricted kneeling position (i.e., a roof height of 48 inches), as compared to lifting in the stooped position at the same roof height (Gallagher, 1987). This research also demonstrate that myoelectric activity of the trunk muscles is significantly affected by the posture assumed when lifting (i.e., stooped or kneeling). Furthermore, the metabolic cost of lifting was found to be significantly elevated in the kneeling posture compared to stooped. The purpose of the present investigation was to examine the effects of lifting using restricted kneeling postures (i.e., roof heights of 36" and 40"), and stooped postures

TABLE 1.- Incidence of Back Injuries in Underground Coal Mines, 1981-1986. Incidence rates are expressed in terms of the number of back injuries per man-year (200,000 hours). Low-seam coal mines are defined as those with a roof height of $\leq$ 48 inches, while medium and high seam mines have a roof height > 48 inches.

	All underground coal mines	Low-seam coal mines	Medium/high-seam coal mines
1981	3.96	5.76	3.62
1982	3.74	5.08	3.51
1983	3.28	4.54	3.00
1984	3.25	4.44	2.99
1985	1.30	2.01	1.18
1986	3.13	5.67	2.71

(at roof heights of 44" and 48") on psychophysical lifting capacity, electromyography of eight trunk muscles, and the metabolic cost of performing the lifting activity.

METHOD

Subjects were 13 underground miners accustomed to handling materials in restricted work postures. Informed consent was obtained from each participant, and the subject was then prepared for the lifting tests. The eight trunk muscles investigated were identified and the skin above the muscle was prepared by shaving and cleaning the skin thoroughly with alcohol. Bipolar surface electrodes filled with an electrolyte gel were attached to the skin above the muscle (3 cm apart center to center), and a ground electrode was attached. Surface electrocardiographic electrodes were also placed for determination of heart rate during the lifting tests. Each subject performed two twenty-minute periods of lifting in each of four postures during the day of testing. In each posture, one period of lifting started with heavy box (approximately 95 pounds), and one started with a light box (approximately 25 pounds). The frequency of lifting was 10 lifts per minute.

A specially designed lifting box was used for this study. This box incorporated microswitches in one handle of the box and another in the bottom of the box (see figure 1). These switches allowed researchers to determine the following events during the lifting cycle: a) when the subject grasped the box, b) when the subject lifted the box, c) when the subject placed the box back down, and d) when the subject released his grip on the box. In addition, the collection of integrated EMG data (at minutes 2 and 18 during the test) was triggered when the subject grasped the handle of the box. However, EMG data from all eight trunk muscles was obtained starting two seconds prior to the time the handle trigger was activated (by means of the memory buffer in the ISAAC[1] 5000 high speed data acquisition system) to assure that all EMG data associated with the lift was collected. Metabolic data was obtained during the last five minutes of every test using a Beckman Metabolic Measurement Cart I. Heart rates were taken every minute during the lifting tests. EMG data for each muscle was expressed as a percentage of the overall maximum observed for that muscle during all of the lifting tests. The MAWL data, average heart rate, oxygen consumption, ventilation volume, and respiratory exchange ratio data were analyzed using an analysis of variance (ANOVA) on repeated measures statistical package. Both mean and maximum EMG data were analyzed using a multivariate analysis of variance (MANOVA) on all muscles followed by separate ANOVAs and post hoc Duncan Range Tests performed on each separate muscle.

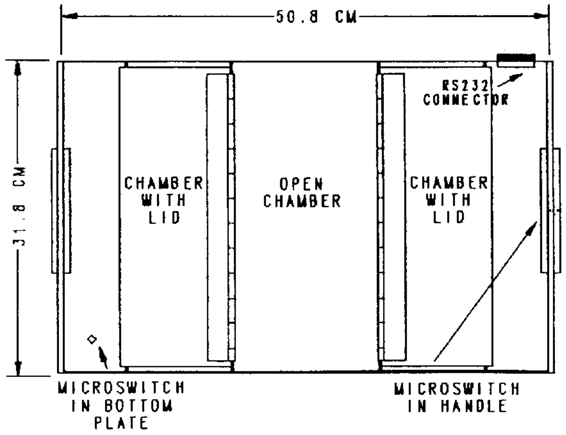

FIGURE 1. Schematic of the lifting box used in this experiment.

Lifting Box and EMG Instrumentation

EMG data during the MAWL experiments were collected using a system of surface electrodes coupled with and EMG amplifier and integrator, an analog/digital (A/D) converter, and microcomputer (figure 2). Collection of EMG data was triggered by the lifting box, which contained microswitches built into one handle and the bottom of the box to allow the marking of specific events during the course of a lift.

The lifting box was made using a welded aluminum construction and weighed approximately 19.5 lb. when empty. The box was divided into several compartments where weights could be added or removed according to the purposes of the test. Two compartments had hinged covers in which the experimenters randomly varied weight prior to the start of the test. A microswitch was built into one of the box handles, which was activated when the subject grasped the box at the start of the lift. This switch was armed by a second switch at the microcomputer to prevent false triggering due to vibration or incidental contact. When the switch was closed a +10 volt direct current (VDC) signal was sent from the lifting box to the A/D converter, triggering the collection process.

A second microswitch was attached to the bottom of the lifting box and was activated as

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[1] Reference to specific brands, equipment or trade names in this report is made to facilitate understanding and does not imply endorsement by the Bureau of Mines.

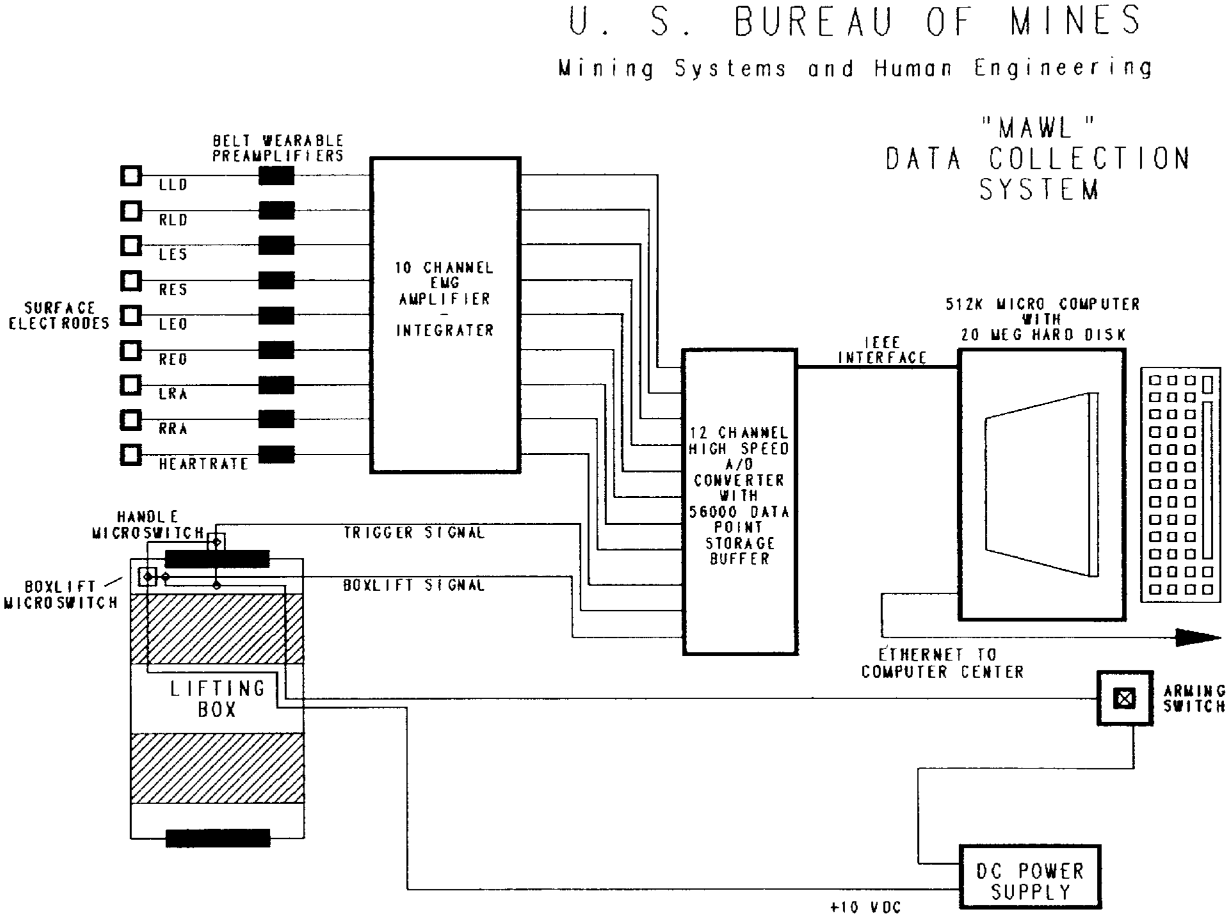

FIGURE 2. U. S. Bureau of Mines Electromyographic Data Acquisition System.

long as the box was resting on its base. When the box was lifted, the switch opened and the signal dropped from +10 VDC to zero.

A micro-computer was used to control the entire data collection process. Custom software was developed to activate the A/D converter and store the data collected. When the researcher wanted to collect EMG data the microcomputer sent the proper commands to the A/D converter, which then would collect data output from the EMG amplifier/integrator and the lifting box. The data are allowed to pass through the converter's buffer until a +10 VDC signal was recieved from the box handle microswitch, indicating that the handle has been grasped in preparation for a lift. At this point, the A/D converter stored a preset number of data points prior to the +10 VDC signal and began to store data points at the rate and duration specified by the researcher through the software. In the present study, integrated EMG data was collected at a rate of 100 Hertz (Hz) for a seven second period of time; two seconds of data were stored prior to the lifting box handle signal being received by the A/D converter, and five seconds of data were collected after the signal was received.

The box microswitches enabled the investigators to analyze EMG data at the following points: when the box handle was grasped, when the box was lifted, when the box was set down, and when the handle was released. The EMG data described in this paper were analyzed from the time that the subject grasped the handle of the box until the handle of the box was released. After the data had been stored in the buffer of the A/D converter, the microcomputer stored the information on disk, cleared the buffer of the A/D converter, and reset the system for

TABLE 2. - Mean acceptable weights of lift and metabolic costs of lifting in the four restricted postures (N = 13)

	Kneeling		Stooped	
	36"	40"	44"	48"
MAWL (lbs)	54.2	53.5	63.5	66.0
HR (bpm)	141	133	126	126
V_E (L/min)	34.0	31.8	29.6	28.8
VO_2 (mL/kg/min)	15.8	15.3	13.7	13.8
R	0.92	0.90	0.89	0.87

another test. This data was later transferred to a mainframe computer for plotting and statistical analyses.

RESULTS

Analysis of the data indicates that restricting the posture of underground miners has a significant effect on lifting capacity ($F_{3,36} = 9.000$, $p < .001$). Table 2 lists the psychophysical lifting capacity for each of the experimental conditions along with data on the metabolic cost of performing at each roof height. The greatest amount of weight lifted by these miners was at the 48" roof height (mean = 66.0 pounds), and the least at the 40" roof height (mean = 53.5 pounds). Heart rate ($F_{3,36} = 9.543$, $p < .001$), oxygen consumption ($F_{3,33} = 8.05$, $p < .001$), and ventilation volume ($F_{3,33} = 4.880$, $p < .01$) were all significantly affected by roof height with the higher physiological values occurring in the kneeling postures. The respiratory exchange ratio ($F_{3,33} = 3.825$, $p < .05$) was also significantly affected by posture.

The results of the MANOVA for maximum EMG indicated that seam height has a significant effect on muscle activity ($F = 5.115$, $p < .001$). Similarly, the MANOVA for mean EMG during the lifting tasks demonstrated a significant effect due to seam height ($F = 6.395$, $p < .001$). Neither initial box weight (light or heavy) nor time of the data collection (minute 2 or minute 18 of the test) demonstrated a significant main effect on muscle activity in the multivariate analysis ($p > .05$). Table 3 presents a summary of significant results using the Duncan Multiple Range Test describing the effects on percentage of maximum EMG activity for the eight trunk muscles due to lifting in the four seam heights.

DISCUSSION

This study confirms the findings of an earlier investigation by the Bureau of Mines which demonstrated that underground miners have a reduced lifting capacity in the kneeling posture, while the metabolic costs of lifting in the kneeling position are greater. These findings indicate that muscular fatigue due to materials handling may occur more quickly in this posture, and that lifting heavier weights in low-seam coal mines might be better accomplished in the stooped posture (due to the higher lifting capacity in this position).

The analysis of the electromyographic data indicates that the function of the back muscles studied are quite different in the kneeling posture than when stooped. The erector spinae muscles are much more active when lifting in the kneeling posture. It seems reasonable to assume that these muscles must bear much more responsibility for the lift in this posture due to the fact that several muscle groups typically called upon for lifting are not available for use in this position. As a result, there may be an increased compressive load on the lumbar region of the spine when lifting in this position. The greater metabolic demand of lifting in this posture is likely due to an increased demand for oxygen by the back muscles.

In the stooped posture, the latissimus dorsi muscles were significantly more active during the lifting tasks than when kneeling; however, the erectores spinae were more quiescent when lifting in this posture. Many studies have shown that the erectores spinae demonstrate much less activity when the trunk is flexed, and it is assumed that the posterior group of ligaments (i.e., the posterior longitudinal, the ligamentum flavum,

TABLE 3. - Duncan range test significance for maximum EMG activity during lifting tasks. Conditions with the same letter are not significantly different at the 0.05 level. Numbers in parentheses represent the mean percentage of maximum EMG activity for the cell (N = 7). The subjects were kneeling at 36 and 40 inches, and were stooped at 44 and 48 inches.

	LLD	RLD	LES	RES	LEO	REO	LRA	RRA
36 inches	A (34.86)	A (36.63)	A (72.83)	A (77.21)	A (56.75)	A (46.91)	A (45.05)	A (33.64)
40 inches	A (26.77)	A (32.85)	A (67.01)	A (72.37)	A (56.26)	A (37.18)	A (51.99)	A (46.09)
44 inches	C (62.51)	B (60.69)	B (40.69)	B (39.39)	B (41.33)	A (48.13)	A (41.41)	A (33.37)
48 inches	B (47.98)	B (58.22)	B (30.10)	B (42.40)	A B (42.65)	A (37.90)	A (33.01)	A (35.19)

NOTE: LLD = Left Latissimus Dorsi; RLD = Right Latissimus Dorsi; LES = Left Latissimus Dorsi; RES = Right Latissimus Dorsi; LEO = Left External Oblique; REO = Right External Oblique; LRA = Left Rectus Abdominis; RRA = Right Rectus Abdominis.

the interspinous, and the supraspinous) are primarily responsible for supporting the vertebral column when the trunk is bent forward. It is likely that the subjects in the present study were dependent upon their ligaments for support during the lifting tasks, and were therefore placing those ligaments under considerable stress. Unfortunately, it is difficult to determine such stresses.

The results of the electromyography indicate that, in the stooped posture, the latissimus muscle is working at a higher percentage of its' maximum capacity than the erectores during the lift. The Bureau of Mines is currently examining the biomechanical stresses of lifting in these two postures using a model by Schultz (Schultz and Andersson, 1981; Schultz *et al.*, 1982), in order to determine the compression and shear forces experienced by the spine when lifting in restricted working conditions.

The data presented in this paper (along with data collected in previous studies) will be used by the Bureau of Mines to make recommendations for lifting materials in the low-seam coal mining environment. The results of this study may also be valuable information for other industries where workers must handle materials in restricted work spaces.

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