An investigation of the effect of ergogenic corsets on biomechanical, physiological and psychophysical parameters during manual lifting

by Amarnath R Duggasani

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Industrial and Management Engineering
Montana State University

Abstract:
Spinal supports have been used for many centuries to reduce low back pain. The most popular of these available in industry is ergogenic corset. The effect of the corsets and their interaction with other lifting conditions such as frequency and load was not studied in terms of metabolic, postural or psychophysical variables.

A laboratory experiment using 8 male subjects was conducted to document the effect of ergogenic corsets bn various parameters for a set of manual lifting conditions. The manual lifting conditions included three frequencies at 3, 6 and 9 lifts per minute and two loads of 7 kg and 14 kg. The major parameters studied' were oxygen consumption, energy expenditure, angular displacements at hip and knee, and psychophysical rating of perceived exertion. This study is unique in terms of the application of three major approaches available in ergonomics viz physiology, biomechanics and psychophysics within the same experimental environment. The analysis of the data collected was performed using ANOVA techniques to find the impact of corsets and their interaction with other lifting variables on the physiological, postural and psychophysical parameters.

Results indicate that ergogenic corsets had no significant effect on any of the physiological, postural or psychophysical variables under study except for increased blood pressure. It is also proved that these orthotic devices had no significant ergonomic benefit. And no significant interactions were found between corset and frequency and/or load except for angular displacement at hip. Finally, it was recommended that corsets should be avoided due to the following: 1. Long-term health effects of corset use by workers with hypertension or other cardio-vascular conditions in which increased blood pressure is contraindicated.

2. Lack of effect (positive or-negative) in. physiological, biomechanical, or psychophysical parameters thus bringing into question the economic validity of purchasing these corsets in quantity for ergonomic purposes.

3. Based on this study as well as the evidence from previous studies which studied the singular effects, there seems to be no ergonomic justification for the use of ergogenic corsets, particularly on long-term basis.

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A thesis submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Industrial and Management Engineering

MONTANA STATE UNIVERSITY
Bozeman, Montana

August 1993

APPROVAL

of a thesis submitted by

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This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

8/18/93
Date

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To my parents who taught me how to learn

ACKNOWLEDGEMENTS

It would be nearly impossible to thank all of the individuals who have assisted me in the completion of this study. I would, however, like to particularly recognize the members of my thesis committee. First, Dr. Robert Marley has been a very enthusiastic and encouraging advisor and I am deeply appreciative of the confidence he has shown in my abilities. Second, Dr. Donald Boyd and Dr. Paul Schillings, who gave advice whenever I needed and it has been a great honor to have them in my thesis committee. And, of course, to Dr. Ellen Kreighbaum, who was there on many occasions offering valuable advice as well as her laboratory equipment.

I would like to offer a hearty thank you to those who served as subjects. If not for the eager participation of these individuals, this study would have been quite impossible.

I certainly want to express great appreciation to my parents for their love and encouragement and I dedicate this work to them. Finally, I wish to express my love and gratitude to my wife Madhavi, who was always there helping me in achieving this goal. Thank You !

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ABSTRACT

Spinal supports have been used for many centuries to reduce low back pain. The most popular of these available in industry is ergogenic corset. The effect of the corsets and their interaction with other lifting conditions such as frequency and load was not studied in terms of metabolic, postural or psychophysical variables.

A laboratory experiment using 8 male subjects was conducted to document the effect of ergogenic corsets on various parameters for a set of manual lifting conditions. The manual lifting conditions included three frequencies at 3, 6 and 9 lifts per minute and two loads of 7 kg and 14 kg. The major parameters studied were oxygen consumption, energy expenditure, angular displacements at hip and knee, and psychophysical rating of perceived exertion. This study is unique in terms of the application of three major approaches available in ergonomics viz physiology, biomechanics and psychophysics within the same experimental environment. The analysis of the data collected was performed using ANOVA techniques to find the impact of corsets and their interaction with other lifting variables on the physiological, postural and psychophysical parameters.

Results indicate that ergogenic corsets had no significant effect on any of the physiological, postural or psychophysical variables under study except for increased blood pressure. It is also proved that these orthotic devices had no significant ergonomic benefit. And no significant interactions were found between corset and frequency and/or load except for angular displacement at hip. Finally, it was recommended that corsets should be avoided due to the following:

1. Long-term health effects of corset use by workers with hypertension or other cardio-vascular conditions in which increased blood pressure is contraindicated.
2. Lack of effect (positive or negative) in physiological, biomechanical, or psychophysical parameters thus bringing into question the economic validity of purchasing these corsets in quantity for ergonomic purposes.
3. Based on this study as well as the evidence from previous studies which studied the singular effects, there seems to be no ergonomic justification for the use of ergogenic corsets, particularly on long-term basis.

CHAPTER 1

INTRODUCTION

Manual Material Handling (MMH) makes up a significant percentage of work performed in modern business and industry despite the obvious trends towards automation. MMH activities include lifting, lowering, pushing, pulling, holding, and carrying. Not only are MMH activities an important part of modern industry, but they also have been long recognized as the major hazard to the industrial workers. The majority of material handling related over-exertion injuries in industry are caused by lifting (NIOSH, 1981).

In United States, approximately 35% of all compensation claims are related to back injuries (NSC, 1983) and an estimated 14-billion dollars are paid annually in direct financial compensation (Taber, 1982). The indirect costs may be as much as four times this amount (Asfour, Khalil, Moty, Steele, and Rosomoff, 1983).

Low back pain and injury risk is a special concern during the performance of MMH tasks. Lifting is a particularly stressful material handling activity to the lower back (Rowe, 1969; and Ayoub, Bethea, Deivanayagan, Asfour, Bakken, Liles, Mital and Sherif, 1978). Klein, Jensen, and Sanderson (1984) report that 48.1 percent of workers compensation claims initiated because of back pain or strain were a result of lifting objects.

Low back injuries due to lifting can obviously result in substantial costs, both economically as well as in terms of human anguish.

Therefore, the elimination, or at least reduction in the number, severity and the resulting costs of these injuries is of serious concern to researchers and health related agencies.

The total compensable costs for 1986 low back pain cases in the United States increased 241% when compared with 1980 statistics and the total workers compensation costs for the same period increased 184% (Webster and Snook, 1990).

CHAPTER 2

REVIEW OF LITERATURE

Back Pain

Manual Material Handling has been recognized as the major hazard to health and safety in business and industry, particularly in terms of low back pain (Rowe, 1969; Ayoub, et al., 1978). Low back injuries bring substantial costs, both economically as well as in human anguish (Jones, 1971; Accident Facts, 1980).

Back injury, particularly to the low back, occurs with alarming frequency (Ayoub, 1992). Troup (1965) stated that in the United Kingdom, about 19% of all reported accidents affect the spine and trunk, and approximately 40% of back injuries result from lifting, and 33% are from twisting movements of the spine. At some time during their working lives, 50 to 80 percent of workers in Scandinavian countries will have back complaints (Svensson and Andersson, 1982). They further stated that between 9 and 19.5 percent of worker absence is due to the diagnosis of back problems. Similarly, Lundgren found that 60 percent of the population in Sweden suffer from pain during their working years (Grandjean, 1980).

In the United States, approximately 35% of all compensation claims are related to back injuries (NSC, 1983), over 25 million work days are lost (NIOSH, 1981), and an estimated 14-billion dollars are paid annually in direct, financial compensation (Taber, 1982).

Klein, Jensen, and Sanderson (1984) report that 48.1 percent of all workers compensation claims initiated because of low back pains or strains were the result of lifting objects. According to Khalil, Genaidy, Asfour and Vinciguerra (1984), low back pain is the second largest pain problem, headaches are the first.

Therefore, the study of factors leading to back or other forms of injury resulting from MMH activities is obviously important to researchers and practitioners in many disciplines (Marley, 1987). Traditionally, three approaches have emerged to reduce the number and severity of industrial, over-exertion injuries caused by manual lifting (Snook, Campnelli and Hart, 1978). The three approaches are: (1) selective screening of workers for differing tasks, (2) proper training in safe lifting, and (3) designing tasks to fit within the capacities of workers.

For the development of safe and permissible lifting capacity, four approaches are traditional. The remainder of this chapter will be directed to discussing and comparing the various approaches used in measuring lifting capacity as well as to examining the variables that affect lifting capacity.

The Science of Lifting

There are four basic methodologies for studying lifting capacity of individuals. The National Institute for Occupational Safety and Health (NIOSH, 1981) has outlined these four measures which are: (1) the epidemiological approach, (2) the biomechanical approach, (3) the psychophysical approach, and (4) the physiological approach. The following is a more detailed discussion of these different approaches.

Epidemiological Approach

Epidemiology refers to the identification of the frequency, distribution and possible controls of illness and injuries for a given population. Factors that can influence injury can be divided into work-related or personal factors (Marley, 1987). Examples of work-related factors are weight of load, size of load, height of lift, and frequency of lift. Personal factors include, gender, age, anthropometric variables, lifting style, attitude, amount of training, and strength variables.

Thorough epidemiological studies are time consuming and expensive. Furthermore, the relationship between health problems and MMH tasks is unclear. This is due to the fact that additional confounding variables, such as outside work tasks, sports, or other stressful activities, enter into the picture.

Biomechanical Approach

Biomechanics uses laws of physics and engineering concepts to describe motion undergone by the various body segments and the forces acting on these body parts during normal, daily activities (Franked and Nordin, 1980). The biomechanical approach attempts to determine the forces imposed upon the musculoskeletal system during a lifting task, and, thereby, is considered appropriate for predicting the maximal, low frequency lifting capacity of an individual (Smith, 1980). The forces in a biomechanical model include reaction force and torque on various joints of the body as well as compression and shear forces on the low back (Ayoub, Selan, Karwoski and Rao, 1983).

One of the approaches in biomechanics states that acceptable load limits be a function of back strength. Although there is a disagreement as to the cause of low back pain, the compressive force on the lumbar spine, especially on L5/S1 segment, has been accepted now as one of the primary means of stress on the spine during MMH activities (Garg, 1979). In the development of lifting limits, compressive force has been used as a criterion, and a limit of 650 Kg has been set for this criterion based on a study by Chaffin and Park (1973). This value was adopted by NIOSH (1981) for the maximum permissible limit (MPL). Data compiled by Evans and Lissner (1959) and Sonada (1962) show large variation in the compressive strength of the L5/S1 segment. Thus, distributions of compressive force of lumbar vertebral segments for both males and females under "typical conditions of MMH activities" are badly needed to provide a better basis for the design of MMH tasks and to enhance the performance of biomechanical models (Ayoub, 1992). There are two types of biomechanical approaches, static and dynamic models.

Static Models. Static models assume either a static situation or movement slow enough to be considered a series of static positions. Chaffin (1969) developed a computerized static model that can predict the forces and torques at various joints of articulation. This model assumed a seven link configuration (wrist, elbow, shoulder, hip, knee, ankle, and L5/S1 joint) to represent the human musculoskeletal system. Compression and shear forces on the lower spine (L5/S1 joint) could, therefore, be calculated.

This model, sometimes called the Static Sagittal Plane model (SSP), indicates that the maximal strength of a major muscle or muscle group does not necessarily reflect the maximal lifting capacity of an individual. The SSP model had been revised to include eight, solid links along with strength variables (Chaffin and Baker, 1970; Martin and Chaffin, 1972).

Dynamic Models. Unlike static models, dynamic models analyze forces at various articulations during the lifting motion, as a function of time. For example, El-Bassoussi

(1974) developed a dynamic biomechanical model that calculated the compressive and shear forces on the spine at the L4/L5 and L5/S1 joints during a lifting task.

This task involved lifting a box of varying size and weight from the floor to a height of 30 inches (approximately knuckle height). The model examined the differences between leg lifts and back lifts, also called "stoop" versus "squat" lift.

El-Bassoussi showed that the back experienced higher compressive forces during a back lift than with a leg lift. Ayoub, Asfour and Bethea (1980) showed that this particular model could also be used to predict the compressive forces generated by the task since the model contained data on force and torque at various joints. Park and Chaffin (1974) added acceleration of load into their previous model and also recommended the Straight Back/Bent Knee method of lifting over the Back Lift method.

Muth, Ayoub, and Gruver (1978) developed a non-linear programming model that included anthropometric measurements, size and weight of object lifted, starting and ending points of lift motion, and time performance as constraints. The objective function to be minimized was an integral of the square of the ankle torque function including the action of the torques occurring at the other joints. They found the time to perform a given task was critical in the model.

Smith (1980) as well as Smith, Smith, and McLaughlin (1982) documented an acceleration factor utilizing high speed photography to analyze lifting motion. They report statistically higher forces and moment values in dynamic models as opposed to static models.

Ayoub, Chen, and Coss (1986) developed a model which calculates the linear and angular velocities, acceleration, force, and torque at various joints of articulation. These joints were the hand, wrist, elbow, shoulder, hip, knee, and ankle.

Following are the two other widely used biomechanical techniques seen in the literature:

Intra-abdominal Pressure Measurements. The idea that pressures within the trunk might assist with its mechanical efficiency was suggested in the 1920's (Keith, 1923). The underlying theory is that when, for example, a weight is lifted, a flexion moment develops about the spine. This moment is counter balanced by the posterior back muscles. The pressure in the trunk cavities assist in this respect, producing an extension moment. The muscle contraction force needed for equilibrium is reduced and as a result the stress on the vertebral column is reduced (Chaffin and Andersson, 1984). Davis, in 1956, found that the intragastric pressure increased when the trunk moment was increased; and, his findings were later confirmed by Bartelink (1957). Morris, Lucas and Gruver (1961) using a mathematical model of forces acting on the spine, concluded that the load on the spine was reduced by 30% on the lumbosacral disc because of the support from the pressures within the trunk.

The relationship between the trunk moment and the increasing pressures found in the laboratory prompted the use of intragastric pressure measurements to assess load during work (Chaffin and Andersson, 1984). Stubbs (1973) and Davis and Stubbs (1978b) found some indication that workers in occupations with peak pressures of 100 mm of mercury within the trunk were more likely to report back injuries.

Intra-abdominal pressure recording is a safe and simple measurement method causing little discomfort to the subject being investigated. One single value or curve emerges, simplifying the data handling and evaluation procedures. The main obstacle to using the technique to estimate the load on the spine is the uncertainty about the relationship of pressure and spine compression. There is ambiguity in the studies made so far. The pressure apparently rises in parallel with the load increased over a force range when the load is static and the position is symmetrical. Asymmetry in load and posture influences the relationship, however. Moreover, the pressure response is not continuous, but rather divided during the lift into an initial response and sustained response. The relationship of the initial response and the trunk moment is not understood. Knowledge of the factors that control the intra-abdominal pressure is very limited. The situation is further complicated by the uncertainty about how well intragastric and intra-intestinal pressure measurements actually reflect the true intraperitoneal pressure (Chaffin and Andersson, 1984).

When a lift is initiated, the intra-abdominal pressure is assumed to yield its major support to the spine when the trunk moment is at its maximum. This does not seem to be the case. To what degree voluntary and reflex-triggered contractions of the abdominal muscles relieve the spine by increasing the intra-abdominal pressure is uncertain. When this relief occurs is uncertain (Chaffin and Andersson, 1984). And, also, the asymmetrical loading of the trunk can create large stresses on some component structures without simultaneous intra-abdominal-pressure increases being observed. Thus, the use of intra-abdominal pressure to develop safe levels of manual handling is debatable.

Electromyography. Electromyography (EMG), the recording of myoelectric signals which occur when a muscle is in use, can be used to assess the level of activity occurring over a period of time. It can also be used to show the presence of muscle fatigue, a state when a skeletal muscle is unable to maintain a required force of contraction (Hagberg, 1981). A high correlation has been shown between EMG activity and muscular force, for both static and dynamic activities (Hagberg, 1981). This relationship was once thought to be linear, but is now proposed as exponential (Lind and Petrofsky, 1979; Hagberg, 1981). The EMG values can be normalized, and thus, can be expressed as linear functions.

When a muscle begins to fatigue, an increase in the amplitude in the low frequency range and a reduction in the amplitude in the high frequency range of EMG activity are observed (Petrofsky, Glaser and Phillips (1982). And, a shift in the frequency spectrum towards the lower end of the spectrum as fatigue occurs is also observed (Corlett, 1990).

Although needle electrodes, entering specific muscles, are used for medical research, occupational EMG records are usually taken from surface electrodes. These are stuck over the central part of the muscle and leads taken, via preamplifiers, to amplification and recording equipment (Corlett, 1990).

Psychophysical Approach

Psychophysics constitutes one of the oldest areas of psychological research. It primarily deals with physical stimuli and the associated human sensations. In terms of MMH activities, the psychophysical approach estimates an individual's lifting capacity by quantifying his/her subjective tolerance to the stresses of manual material handling (Ayoub, 1987).

Stevens (1960) defines the relationship between the intensity of a physical stimulus and strength of a sensation by the following function:

$$S = K * I^n$$

where,

S = strength of sensation,

I = intensity of physical stimulus,

K = constant representing a function of the particular units of measurements,

n = the slope of the line representing the power function when plotted in log-log coordinates.

Research has shown the exponent of many types of stimuli. For example, electric shock = 3.5, taste (salt) = 1.3, loudness (binaural) = 0.6, and lifting weights = 1.45.

Snook (1978) states that the relationship between the perception of muscular effort and stimulus force required to lift an object obey the power function. Psychophysical methods have been applied to many practical problems including effectiveness, temperature, and comparative loudness and brightness scales.

One of the first to apply psychophysics to MMH problems were Snook and Irvine (1967). In general, the psychophysical approach calls for the subject to be in control of (adjust) a task variable (either weight of load or frequency of lift). Subjects can then monitor their own feelings of exertion and fatigue and make appropriate adjustments in their workloads. As described in Asfour (1980), subjects attempt to perform to their maximum capacity without strain and discomfort.

Several researchers have attempted to use psychophysical models in order to develop prediction models for lifting capacities. Ayoub, et al. (1978), studied males and females lifting a box over the frequencies of 2, 4, 6, and 8 lifts per minute, six different lifting ranges (height of lift), and three container sizes. They achieved R-square values ranging from 0.85 to 0.877.

Garg, Mital, and Asfour (1980) developed linear equations that attempted to predict the maximum acceptable weight of lift (MAWOL). Three regression equations were derived using three measures of static strength. However, the achieved R-squared values were relatively low (0.23, 0.31, and 0.62). The authors concluded that the maximum voluntary strength measures used should be revised, and, in general, should be used with extreme care.

Pytel and Kamon (1981) developed equations to predict maximum dynamic lift capacity (MDL) of males and females based upon dynamic strength measures from the Mini-Gym Model 101. They then developed an equation to predict MAWOL for 4 lifts per minute (dynamic strength, in newtons, and gender, male or female, were the only independent variables). They reported an R-square of 0.941. Furthermore, MAWOL was 22 percent of the MDL estimate for both the genders.

Asfour (1980) developed four different models using frequency, box size, height of lift (or lowering), and angle of twist in the body. Furthermore, he validated the equations and found correlation coefficients between 0.62 and 0.79.

Physiological Approach

The physiological approach is concerned with the physiological stresses placed upon the body during lifting. The biomechanical models are considered appropriate for low frequency lifting when the capacity of an individual is defined by either strength or limits of compressive and shear forces exerted on key joints. Conversely, physiological models are applied to repetitive lifting where it is presumed that the load is well within maximal physical strength. In such repetitive tasks, capacity is primarily limited by the oxygen transport system.

The physiological approach may use several dependent measures. Variables such as oxygen consumption, heart rate, pulmonary ventilation, energy expenditure, blood pressure, lactic acid accumulation, and percent physical work capacity are examples of measures used in these models. Snook and Irvine (1967) and Ayoub et. al. (1978), recommend oxygen consumption, heart rate, and energy expenditure as the primary physiological measures for dynamic activities.

Another difference between physiological approaches and biomechanical approaches is in the study of lifting technique. Research has shown that the Straight Back/Bent Knees (squat) method of lifting is more physiologically fatiguing than the Bent Back (stoop) method (Brown, 1971; Garg and Saxena, 1979). This is primarily due to the increase of muscle mass involved. It follows that, when the lifting load is relatively heavy, the squat method was shown to require more energy (Das, 1951; Asfour, 1980).

Muller (1953) proposed that maintaining certain postures and the excessive use of one group of muscles could limit the work capacity even at a lower rate of energy expenditure. Muller recommended that 5 Kcal/minute be the limit of energy expenditure for an 8-hour work day.

Frederik (1959) developed the following model to estimate appropriate energy usage during a lifting task:

$$E = (f * a * w * c) / 1000$$

where,

E = total energy expenditure (kcal/hour),

f = frequency of lifts per hour,

a = vertical lifting ranges (feet),

w = weight of lift (pounds),

c = energy consumption (gram-calories/ft. lbs.).

By this model Frederik recommended that energy expenditure should not exceed 3.33 kcal/min for an average work day (based on lifting as a singular performance).

Micheal, Hutton, and Horvath (1961) conducted cycle ergometer and treadmill tests at various speeds and loads for a continuous 8-hour day. They report that 35 percent of the maximum aerobic capacity (or PWC) should be the limit of work that could be performed without experiencing undue fatigue.

Bink (1962) reasoned that physical work capacity has two major factors: (1) the capacity for oxygen uptake, and (2) the capacity for food intake. Bink found that the mean food intake of a 35-year old man in the Netherlands to be 4100 kcal. He, therefore, developed the following formula for expressing PWC as a linear function of the log of working time:

$$A = [(\log 5700 - \log t) * a] / 3.1$$

where,

A = physical work capacity (kcal/minute),

t = working time (minutes),

a = aerobic capacity (kcal/minute).

Based upon this equation, the allowable energy expenditure over an 8-hour day for an average 35-year old male (from the Netherlands) should be 5.2 kcal/minute.

In examining average heart rate as a criterion for energy expenditure, Suggs and Splinter (1961), and Brouha (1967) state that 115 beats per minute (bpm) should not be exceeded. Snook and Irvine (1967) cited a range of 110 to 130 bpm as appropriate for continuous work. Furthermore, Snook and Irvine recommend a mean heart rate of 112 bpm for leg tasks and 99 bpm for tasks involving arm movements.

Astrand (1967) determined maximal oxygen uptake (VO_2 max) via bicycling. She reports that 50 percent of the VO_2 max was the upper limit for an 8-hour working day. She further stated that this level may not be attainable for all workers as the mean level of her subjects was 39 percent (ranging from 25 to 55 percent).

Aquilano (1968) compared a carton handling task using physiological criteria and time-study criteria. Calculating 4 kcal/min as 128 percent performance, he concluded that traditional predetermined time-standards (determined by stopwatch) were unacceptable in work physiology terms.

The association between lifting and oxygen consumption has been established. Hamilton and Chase (1969) defined the linear relationship of lift frequency and load upon O_2 consumption and heart rate.

Validated in actual industry in Sweden, Aberg, Elgstrand, Magnus and Lindholm developed a model for predicting oxygen uptake in manual tasks (1969). The model is dependent upon the fact that oxygen uptake is based on a series of changes analogous to the positional energy of a mass, a change of the mass velocity, a change of the compressional energy of a spring, and frictional loss. The following is the Aberg, et al., (1969) formula:

$$VO_2 = (BWn * k1) + (BWcl * k2) + BWcl * (GCBh * k3 + GCBv * k4) + (WWP + WT) * (Lha * k5 + u * Lhc * k6 + Lvu * k8 + Lvd * k8)$$

where,

VO_2 = computed oxygen uptake (liters/min),

BWn = body weight, naked (kgs),

BWcl = body weight, with clothing (kgs),

GCBh = horizontal displacement per time unit of the body's center of gravity, up plus down (m),

GCBv = vertical displacement per time unit of the body's center of gravity, up plus down (m),

WWP = weight of work piece (kgs),

WT = weight of tool (kgs),

Lha = horizontal displacement per time unit of tool and work piece (kgs),

Lhc = horizontal displacement per time unit of tool and work piece, carrying or dragging (m),

Lvu = upward vertical displacement per time unit of tool and work piece, lifting (m),

Lvd = downward vertical displacement per time unit of tool and work piece, lifting (m),

u = coefficient of friction in horizontal move,

kl,8 = constants.

Garg, Chaffin, and Herrin (1978) developed regression equations to predict energy expenditure for MMH tasks. They operated on the assumption that complex tasks could be broken down into several, more easily defined, sub-tasks.

Therefore, if energy usage of each sub-task were known, summing these values would give the expenditures for the entire task.

Mital (1980) studied the effect of load lifted, frequency of lift, vertical height of lift, and container size. He noted that oxygen consumption and heart rate increased in a linear relation with these variables. He also found that oxygen consumption decreased slightly when handles were used on the container.

Asfour (1980) found similar relationships. He also stated that, for a given fixed output, it is physiologically preferable to lift a heavier load at a slower pace than a lighter load at a faster pace. Furthermore, he developed a regression model to predict energy costs for lifting and lowering tasks. These two models are stated as:

For floor to 30 inches:

$$
\begin{aligned}
VO_2 = {} & 545.7538 - 106.4477 * TA \\
& + BB * F * F * (31856.54 \\
& - 2332.8*F)/1000000 \\
& + 12684.91 * F * L * L/1000000 \\
& + 12.31 * F * H * L * WB * LB * ANG/1000000
\end{aligned}
$$

where,

VO_2 = oxygen consumption (mL/min),

TA = task type (1 = lift; 2 = lowering),

BW = body weight (lbs),

F = frequency of lift/min,

H = height of lift (inches),

L = weight of lift (lbs),

WB = box width (inches),

LB = box length (inches),

ANG = angle of twist (1 = 0 degrees; 2 = 90 degrees).

Bakken (1983) found an interaction between range of lift and frequency of lift. This interaction, along with range and frequency separately, had a significant effect upon heart rate during a lifting task.

Intaranont (1983) developed models to predict anaerobic threshold (AT) for lifting tasks. He found no statistically significant difference for AT values in two ranges of lift or the frequency of lift (6, 7.5, and 9 lifts/min.). Four models were presented to predict AT and lifting capacity:

Lifting from floor to knuckle height:

$$AT = (471892.555 + 1.439 * WT * F * F - 3461.837 * PB - 11.744 * WT * WT - 3771.16 * WT^{R} + 24.964 * LBW * LBW) * 10^{-5}$$

$$L90 = (1044206.996 - 764422.134 * F + 229233.277 * AK + 86454.21 * PWB) * 10^{-5}$$

Lifting from knuckle to shoulder height:

$$AT = 157396.895 - 21.615 * WT * F - 1611.729 * PA + 2.113 * WT * WT) * 10^{-5}$$

$$L90 = (3018662.771 - 616833.995 * F + 330678.86 * AKB + 10152.833 * LBW) * 10^{-5}$$

where,

AT = anaerobic threshold (l/min.),

L90 = lifting capacity at 90% of AT (lbs.),

WT = body weight of a subject (lbs.),

LBW = lean body weight of subject (lbs.),

R = LBW/WT,

PB = PWC * 1000 * 2.2046/LBW (ml/kg(LBW)-min.),

PWCB = PWC determined by bicycling (l/min.),

AK = 0.9 * AT * 1000 * 2.2046/LBW (ml/kg(LBW) -min.),

PA = PWCA * 1000 * 2.2046/LBW (ml/kg(LBW)-min.),

PWCA = PWc determined by arm cycling (l/min.),

AKB = 0.9 * ATB * 1000 * 2.2046/WT (ml/kg(WT) -min.),

ATB = anaerobic threshold for arm lift (l/min.).

Mital and Shell (1984) developed a computerized model to determine rest allowances for physical tasks. The model was based upon eleven inputs: (1) worker sex, (2) worker age, (3) body weight, (4) hours of sleep per day, (5) shift duration, (6) number of tasks performed during work shift, (7) time duration of each task, (8) metabolic energy requirements for each task, (9) worker's general physiological condition, (10) worker's aerobic capacity, and (11) average energy requirement for non-working or sleeping periods.

Physical Work Capacity

The term physical work capacity (PWC) is synonymous with the terms maximal oxygen uptake (VO_2 max), aerobic capacity and maximal aerobic power. Astrand and Rodahl (1977) define PWC as the highest oxygen uptake an individual can attain during a physical activity.

PWC varies greatly between individuals. The value depends upon individual variables (such as age, gender, body mass, and training), environmental variables (equipment, test protocol, etc.) and genetic variables (Astrand and Rodahl, 1977).

Determination of PWC

Exercise. Traditionally, PWC has been determined by any one of the three methods of exercise: (1) treadmill exercise, (2) bicycle ergometer exercise, and (3) bench stepping. Astrand and Rodahl (1977) note that there are advantages and disadvantages to all three of these methods. For example, treadmill exercise is often preferred in studying younger individuals but older subjects sometimes have difficulty keeping their balance. Also, the supporting handrail often interfaces with the work load.

Bicycle ergometry lends itself to accurate work load measurement because physiological responses, such as ECG and blood pressure, are easily monitored. However, the bicycle ergometer stresses the leg muscles and subjects are often forced to stop due to local muscle fatigue before reaching their true PWC.

A stepping bench exercise is often utilized many times in field studies because it is inexpensive and very portable. The stepping bench exercise loses reliability with active or well-trained subjects because the work rate and height of step become so great as to impede performance.

Kamon and Ayoub (1976) classify the methods of measuring PWC as either direct or indirect.

Direct Methods. The direct methods call for the administration of work loads that will tax the cardiovascular system to limit. Measured values, thus, yield VO_2 max and maximum heart rate and establish a linear relationship between oxygen uptake and work load. Many protocols use this relationship between VO_2 max and maximum heart rate to predict VO_2 directly in terms of workload.

Indirect Methods. The indirect method assumes two factors: (1) the linear relationship between steady-state heart rate and PWC at submaximal work loads, and (2) an age-dependent, expected, maximal heart rate. Assessment of VO_2 max is carried out by recording heart rate and oxygen consumption at two to three work loads for which steady state is achieved. A regression line for this relationship is generated and PWC is then extrapolated to the maximal heart rate. This method is not as accurate as the direct method. Kamon and Ayoub (1976) report that 10 to 15 percent errors in estimated VO_2 max can be the result of variation in maximum heart rate within age groups. However a major advantage of the submaximal technique is that the risk of extreme physiological stress is reduced.

Other researchers have noted differing age-dependent parameters used in simple submaximal techniques. For example, Hakki, Hare, Iskandrian, Lowenthal and Segel (1983) found that the acceptable maximum heart rate (Max HR) for women to be 220 - age, but for men the formula 205 - (age/2) was more appropriate.

Hellerstein, Hirsch, Ades, Greenslott and Segel (1973) proposed that VO_2 max could be predicted by calculation of % VO_2 max for the final work load from the following formula:

$$\% \ VO_2 = -42 + 1.41 * \% \ \text{Max HR}$$

Pitetti, Vaugh, and Snell (1987) found this model to be an accurate method for determining actual VO_2 max from submaximal heart rates in the general population when using an arm-leg ergometer. This equation was dependent upon the estimated maximum heart rate, equal to 205 - (age/2).

Studies on Physical Work Capacity

Many studies have been completed regarding estimates of PWC for a variety of tasks (Issekutz, Birkhead, and Rodahl, 1962; Hermiston and Faulkner, 1971). Table 1 shows a comparison of PWC determined by three different activities for 12 males and 11 females (Kamon and Pandolf, 1972).

TABLE 1
Comparison of PWC (L/min.) During Laddermill Climbing, Uphill Running, and Cycling. Expressed as Mean(S.D.)

Activity	Males	Females
Climbing	3.92(0.52)	2.68(0.26)
Running	4.08(0.60)	2.58(0.30)
Cycling	3.62(0.54)	2.40(0.26)

Source: Kamon and Pandolf (1972).

McKay and Banister (1976) also found that treadmill running was a more effective mode for testing maximal aerobic capacity compared to bicycle ergometry. They noted, further, that there was no significant impact of speed on treadmill running when incline was used as a loading factor. However, there were significant differences between pedalling speeds in the bicycle tests. Frequencies between 60 and 80 rpm seemed to be optimal.

Petrofsky and Lind (1978a) compared VO_2 max of two lifting tasks and a bicycling ergometer task. Their subjects lifted and lowered 4 different box weights (floor to 60 cm.) with lower frequencies of up to 70 lifts/minute. With the bicycle ergometer they pedalled at a rate of 50 rpm for work loads up to 1500 kpm/minute. Results showed that the average maximum oxygen uptake for the bicycle ergometer was 3.71 L/min. By comparison, the highest value for lifting task was 19 percent lower (with the 80 lb. box). Furthermore, as the weight of the box reduced, VO_2 max declined until it was 47 percent of the bicycle ergometer (2 lb. box).

In another study, Petrofsky and Lind (1978b) compared VO_2 max for bicycle ergometry and lifting tasks for extended work (1 to 4 hours). Maximal oxygen uptake for lifting was always lower than for the work on the bicycle ergometer. They noted that for 1 hour, all subjects could perform lifting tasks at 70 percent of VO_2 max achieved on the bicycle ergometer. However, some subjects perceived extreme fatigue. The 4-hour session revealed that fatigue was evidenced at 50 percent of VO_2 max. Petrofsky and Lind concluded that an acceptable level of work load an individual can lift for an extended period should be 50 percent of VO_2 max. They warn, however, that VO_2 max should be determined by the particular task being performed rather than some other form of work or exercise, such as bicycle ergometry.

In the development of their model, Mital and Shell (1984) determined that energy demands for 8 hours of work should not exceed 28 and 29 percent (for females and males, respectively) of aerobic capacity and 23 to 24 percent of 12 hours of work. This was, as they stated, lower than a widely accepted limit of 33 percent proposed by Bink (1962). Marley (1987) determined that the estimates of lifting PWC is frequency specific and show a curvilinear trend as a function of frequency.

Cunningham, Goode, and Critz (1975) compared PWC attained on a rowing ergometer with a bicycle ergometer. They found no significant differences between the two exercises. It was concluded that, because of restricted abdominal muscle use during portions of the motion, rowing PWC could have been limited.

Petrofsky and Lind (1978b) observed that the trunk movement involved in lifting with repeated abdominal compression may well restrict the ability to move larger volumes of air in and out of the lungs. They also stated that such a factor might be abetted by some chest fixation due to the lifting and holding of the box. Equally, the intermittent static effort with its restrictive effort on the circulation to muscles may cause, or contribute to the limitations placed on work capacity.

Back Support

Spinal supports have been used for many centuries to reduce low back pain. Recent rationale for their application is that a support raises the intra-abdominal pressure which provides stability to the back and reduces pain (Kumar and Godfrey, 1986). The application of orthotic devices is employed to (1) provide support or immobilize a body segment, (2) correct or prevent deformity, and (3) assist or restore function (Jordon 1963). Pain is usually present and in clinical practice it has been observed that, despite incomplete immobilization, low back bracing generally results in symptomatic reduction of pain. Partial immobilization and/or support to the lumbar region are the two likely factors leading to relief (Kumar and Godfrey, 1986). A significant mechanical support to the spine is provided by the raised intra-abdominal pressure (Bartelink, 1957; Davis, 1959; Morris, Lucas, and Bresler, 1961; Davis and Troup, 1964; Morris and Lucas, 1964; Kumar, 1971; Grillner, Nilsson, and Thorstensson, 1978). This support is provided by the tensed abdomen. The phenomenon has been variously assigned to reflex (Bartelink, 1957) or conditioned reflex activities. However, the existence of such a reflex has been debated as there does not appear to be an identifiable neuropathway (Kumar and Davis, 1973). Anatomically, it has been suggested that the transverses abdominis belongs to the same group as the diaphragm and transverse thoracic muscle. These muscles together with the pelvic floor surround the abdominal cavity, and by their coordinated contraction, create a high pressure area anterior to the spine. This high pressure "balloon" has a force vector which acts parallel to the spine in the upward direction on the anterior side. This force tends to resist flexion and assist extension of the spine. It acts on a long lever arm, relative to the extensors of the spine and is of greater magnitude during initiation of extensor movement (Kumar and Godfrey, 1986). The described support has been calculated by Morris, Lucas, and Bresler (1961) to reduce 30 percent of compression stress at the lumbosacral junction, a frequent site of low back disorder. Most low back pain patients have weak abdominals (Hemborg and Moritz, 1985). Empirically strengthening these muscles reduces the forces which cause pain. It is suggested that the provision of an extrinsic support increases the resultant abdominal pressure, adding to the efficiency of the system (Kumar and Godfrey, 1986).

The studies by McGill, Norman and Sharratt (1990), and Harman, Rosenstein, Fryman, and Nigro (1989) showed that wearing of a lifting belt resulted in higher intra-abdominal pressure. McGill, et al., speculated that this could be due to the fact that their subjects were handling loads which were 10 times heavier and produced intra-abdominal pressure which was 2 to 3 times higher.

Hermong, Moritz, and Lowing (1985) demonstrated a decrement in the electromyographic activity of erector spinae with elevated intra-abdominal pressure. McGill, et al., (1990) reported that wearing an ergogenic corset resulted in lower abdominal EMG activity when compared with lifting belts. But, they also stated that the interpretation of the above with the limited information they had was difficult.

They also speculated that in an industrial environment, an ergonomic corset would hinder any axial twisting of the trunk, forcing a worker to pivot by moving the feet. The avoidance of twist while lifting has been advocated by industry safety associations to reduce over-exertion injury for some time. They also stated that the belt might support anterior-posterior shear loads as the upper body tends to shear anteriorly on the pelvis due to the forward inclination of the trunk. While the rib cage and pelvis tend to be more rigid structures, hence better able to support shear, the abdomen might benefit from additional external constraints to prevent shear.

Kumar and Godfrey (1986) anticipated that, due to the difference in immobilization from different braces, braces will likely have a different physiological cost of wearing. Therefore, the choice of spinal support should be based on criterion other than abdominal support.

Asundi, Purswell, Schlegel and Bowen (1993) showed that back belts were of significant value in reducing the time to onset of an initial injury, but not in the prevention of a reinjury. They also stated that workers who used a back belt were at a significantly reduced risk of a back injury compared with workers who did not use a belt when performing regular lifting. But this theory was based on the rationale of a back belt acting over a period of time to prevent injury, rather than acting during a single lifting episode that may have resulted in an injury. Thus the conclusion is highly debatable. They also speculated that the belt may have acted to relieve back pain for previously injured workers, thus allowing them to lift more than they would have without the belt and, thereby, increasing the likelihood of a reinjury.

Individual Factors

There are several individual (within-subject) factors that can have an effect upon lifting capacity. The following section discusses some of these.

Age

It is well documented that maximal oxygen uptake (VO_2 max) decreases with age (Astrand and Rodahl, 1977). They report that by age 65, the mean PWC value is 70 percent that of 25-year olds. Other research has shown, however, that for given submaximal loads, VO_2 max is unaffected by age (Muller, 1962; and Shepard, 1974).

Strength

Maximal strength also varies from one individual to another. Generally, maximal strength is realized for most individuals between 20 and 30 years of age and by age 65, is about 80 percent of maximum (Astrand and Rodahl, 1977). This, however, does not affect the determination of one's maximal acceptable weight of lift (Ayoub, et al., 1978). With regard to strength and gender, female lifting strength is on the average 60 percent of that for males (Fox and Mathews, 1981).

Gender

There exists several significant differences between males and females regarding anthropometrics, mean heart rate, and risk of injury (Herrin, Chaffin, and Mach, 1974; Garg, 1976; Astrand and Rodahl, 1977; and Grasley, Ayoub, and Bethea, 1978).

Astrand and Rodahl (1977) found that VO_2 max for women was approximately 70 to 75 percent of that for men. Other researchers have claimed that female lifting strength is 60 percent of males on the average (Asmussen and Heeboll-Neilson, 1962; Snook and Ciriello, 1974; Burke, 1977; and Petrofsky and Lind, 1978a).

Body Weight

There is a linear relationship between body weight and energy expenditure in men (Asfour, 1980). Increases in body weight results in increases for energy usage. The relationship holds true for women but with a lower slope (NIOSH, 1981).

Training

In general, improvement of PWC values can be expected as a result of training. Astrand and Rodahl (1977) stated that regular training increased individual PWC, in most cases, by 10 to 20 percent. Ready and Quinney (1982) documented the effects of training and detraining of male subjects. With a Beckman Metabolic Measurement Cart and a progressive exercise test, they found a 36-percent increase in PWC (L/min.) after 9 weeks of training. PWC decreased by 11 percent after a 9-week detraining period.

At submaximal work loads, the effect of training is unclear. Tzankoff, Robinson, Pyke and Brown, (1972), and Fox, Bartell, Billings, O'Brien, Bason and Mathews (1975) reported no increase in oxygen consumption at submaximal loads.

Task Factors

The American Industrial Hygiene Association has stated that weight of lift, frequency of lift, height and range of lift, and container size are all significant factors in lifting tasks (1970).

Weight of Load

It is well documented that increases in weight of lifting load results in increases in metabolic energy cost for the worker (Frederik, 1959; Mital, 1980; and Asfour, 1980).

Frequency of Lift

As the frequency of lift is increased, lifting capacity decreases (Snook and Irvine, 1967; Bakken, 1983). Van Wely (1961), Aquilano (1968), Hamilton and Chase (1969), and

Mital (1980) have all documented increases in physiological responses due to increases in lifting frequency.

Height and Range of Lift

Mechanical work is proportional to height of lift; therefore, metabolic energy expenditure increases with an increase in vertical height of lift (NIOSH, 1981). This follows the basic formula:

Mechanical Work = Load * Frequency * Height of Lift

However, Aquilano (1968) and Garg (1976) observed that lifting capacity is dependent upon the range of height. For example, lifting from floor to knuckle height is different than lifting from shoulder to reaching height as these involve different muscle groups. Since the squat lift involves more muscle mass, Snook (1978) and Ayoub, et al., (1978) state that the maximum acceptable weight of lift, from the psychophysical approach, was highest in the floor to knuckle lift.

Container Size

Ayoub, et al., (1978) concluded that the amount of weight lifted was inversely proportional to the container size in the sagittal plane when using a psychophysical approach. These results are similar to Martin and Chaffin (1972), Aghazaden (1974), and Asfour (1980).

Handles

Garg and Saxena (1980) concluded that the maximum acceptable weight of lift for containers with handles was greater than for those without handles. Appropriate handles facilitate reduced risk of injury (Mital, 1980).

Environmental Factors

Factors most affecting physiological responses in workers are temperature, humidity, air circulation, and atmospheric constituents (Brouha, 1967). Heart rate increases approximately 7 to 10 bpm for every 10-degree (Celsius) rise in ambient temperature (Kamon and Belding, 1971).

CHAPTER 3

RATIONALE AND OBJECTIVES

The human, manual lifting capacity is affected by many factors. Age, gender, body composition, task, environment, physical work capacity, and task parameters, all have an influence upon the ability of an individual to perform repetitive activities, including lifting tasks.

Much of the research in the area of manual material handling is concerned with reducing the risk of injury and undue fatigue during task performance for extended periods. Different approaches were used to suggest limitations for performance during these tasks.

The trunk movement involved in lifting with repeated abdominal compression may well restrict the ability to move large volumes of air in and out of the lungs and such a factor might be abetted by some chest fixation associated with lifting and the holding of box (Petrofsky and Lind, 1978a). Kumar and Godfrey (1986) anticipated that, due to the difference in immobilization from different braces, braces will likely have a different physiological cost of wearing. Considering the above two studies, it was believed that there will be a significant effect of corsets on the oxygen transport system of the human body. Thus it is of great importance to study the physiological costs of wearing the corsets and their interaction with other lifting conditions such as frequency and load.

Researchers showed that wearing of a lifting belt resulted in higher intra-abdominal pressure (McGill, et al., 1990, and Harman, et al., 1989). But the use of intra-abdominal pressure to develop safe levels of manual handling is highly debatable. Researchers believe that wearing a corset would remind the worker to lift with his legs rather than with his back thereby reducing the chances of injury. But there has been no systematic study to validate this theory. So data on the effect of the corsets and their interaction with other lifting parameters on lifting posture are critically needed.

The feelings about the corsets in industry are divided. Some workers feel strongly for the corset and some think it is not useful. But no systematic study has been done to report these data. Thus the effect of the corsets and their interaction with other lifting parameters on perceived exertion are of great importance in the psychophysical analysis.

On the overall, there have been no systematic investigations into the effects of corsets and their interaction with the major lifting conditions of frequency and load. Therefore, the objectives of this study were:

1. To document and compare major physiological and biomechanical variables during selected lifting activities

with and without an ergogenic corset and also to examine the interaction of the corsets with frequency and load.

2. Document the psychophysical variable (RPE) for selected lifting activities with and without an ergogenic corset and to examine the effects of corsets and interaction of these with frequency and load.

3. Develop recommendations for the use of ergogenic corsets during manual lifting activities.

CHAPTER 4

METHODS AND PROCEDURES

Subjects

Eight male subjects were selected from the student population at Montana State University for participation in this study. Students were used primarily because of their flexibility in scheduling.

Subjects were screened as to not allow those with personal or familial history of heart disease or low back problems to participate in this experiment. This was accomplished through a questionnaire (Appendix A) that was given to prospective subjects. After initial screening, some baseline measurements were taken. Subjects with basal (resting) heart rates greater than 95 or with basal blood pressure greater than 140/90 were excluded from any participation.

Apparatus

A Sensormedics Breath-By-Breath Metabolic Measurement System (2900c) was used for analysis of physiological variables. A two-way valve, coupled with a mouthpiece and noseclip, was used to direct the expired gases from the subject to the 2900c.

Heart rate was measured by the Polar Vantage XL heart rate monitor. The blood pressure was monitored using the

Marshall Deluxe Desk Model Mercurial Sphygmomanometer (Model 100).

Biomechanical variables were measured via digitized video with a six-link model on the Ariel Performance Analysis System (APAS).

The ergogenic corset made by ProFlex was used in this experiment. The container that was used in this experiment will be a Rubbermaid plastic storage unit with preformed hand-holds. It is 21-inches long, 15-inches wide, and 9-inches deep.

The total weight of the container was adjusted by using a predetermined and unmarked load of lead shot. The container weight was, thus, manipulated using these combinations of weights.

Procedures

Experimental Design

The experimental design for documenting the biomechanical, physiological, and psychophysical variables for the frequencies of 3, 6, and 9 lifts per minute with and without wearing the ergogenic corset at two loads of 7 kg and 14 kg was a completely-randomized, multifactor experiment with three factors and subjects as blocks. The order of task presentation was randomized.

Experimental Variables

A summary of the independent, dependent, and controlled variables is given in Table 2.

TABLE 2
Independent, Dependent, and Controlled Variables in Experiment.

Class	Variables
Independent	* Lifting - Frequency of lift - Weight of lift * Ergogenic Corset
Dependent	* Physiological - Tidal volume - Respiratory quotient - VO_2 - VCO_2 - Heart rate - Blood pressure - Energy expenditure * Biomechanical (for hip and knee) - angular displacements at origin - peak angular velocities - peak angular accelerations * Psychophysical - Rate of perceived exertion (on Borg's scale)
Controlled	* Population (college male students) * Height of lift (floor to knuckle i.e., 0 to 30 inches) * Container size * Coupling (with handles) * Lifting plane (sagittal)

The Task

Once the subject was hooked to the metabolic system the experiment was started. The subject was requested to lift at the fixed frequency, load, and belt condition for 15 minutes, and the metabolic parameters were monitored throughout the task. The subject was continuously filmed during the final 5 minutes of the task. Then the subject was requested to give his rating of perceived exertion (RPE). All the data were recorded using Data Collection Form shown in Appendix B.

Physiological Measures

Resting Parameters. The resting heart rate (RHR), resting $\dot{V}O_2$ (mL/min.) and resting blood pressure for each subject were taken at the conclusion of a 10-minute interval of sitting upright in a chair.

The physiological parameters under study were tidal volume (TV), respiratory quotient (RQ), oxygen consumption (VO_2), carbon dioxide expiration (VCO_2), heart rate (HR), systolic and diastolic blood pressure (SBP and DBP respectively), and energy expenditure (EE). All, except SBP and DBP, were measured throughout the task and averaged during the final 5-minute period. SBP and DBP were measured at the end of the task.