



The effect of an upper-extremity activity on maximum acceptable weight of lift in a combined manual materials handling task
by Bheem Prakash Kattel

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

Despite various efforts through research and studies to make manual materials handling tasks safer and less stressful, statistical data, on the cases of back injury and the amount of compensation paid, indicate that manual materials handling is the leading cause of back injuries.

Biomechanical, physiological and psychophysical approaches have been used for the determination of safe loads for static and dynamic or repetitive tasks. The psychophysical approach requires individuals to adjust either the frequency of handling or the weight of load being handled according to their perception of physical strain. In the actual industrial setup various combinations of manual materials handling activities involving upper-extremity are encountered.

This study aimed at determining the effect of an upper-extremity activity on Maximum Acceptable Weight of Lift (MAWOL) in a combined manual materials handling task by using psychophysical approach. A combined manual materials handling / task (lifting, carrying and shearing) often found in labor intensive steel furniture manufacturing industries was chosen for the study. The task was simulated using LIDO Workset under laboratory conditions. Eight college students served as human subjects for the study. A metabolic measurement cart, a heart rate monitor, a frequency counter and an anthropometric measuring kit were other pieces of equipment used in the study to record various physiological and anthropometric data.

MAWOL was determined for each task using psychophysical approach and energy expenditure rate during each experiment was estimated by using the increase in heart rate above resting heart rate value.

The results of the analysis of the data recorded during the study showed that MAWOL values for different tasks were higher at low frequency of handling than those at high frequency (14% lower for 4/min than for 2/min for lifting, carrying and combined lifting and carrying; 24% lower for combined lifting, carrying and shearing). Mean heart rate was higher for higher frequency of handling than that for lower frequency.

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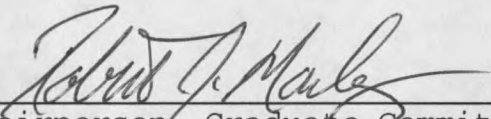
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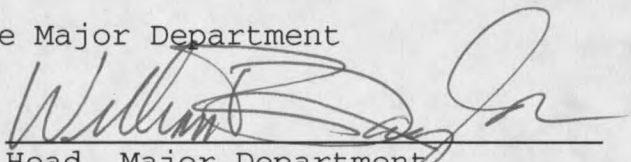
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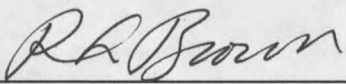
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ABSTRACT

Despite various efforts through research and studies to make manual materials handling tasks safer and less stressful, statistical data, on the cases of back injury and the amount of compensation paid, indicate that manual materials handling is the leading cause of back injuries.

Biomechanical, physiological and psychophysical approaches have been used for the determination of safe loads for static and dynamic or repetitive tasks. The psychophysical approach requires individuals to adjust either the frequency of handling or the weight of load being handled according to their perception of physical strain. In the actual industrial setup various combinations of manual materials handling activities involving upper-extremity are encountered.

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CHAPTER 1

INTRODUCTION

Despite various technological innovations and efforts to automate the materials handling tasks, involvement of humans for the materials handling tasks has been on the rise over the years. The situation in the third-world countries has been still more serious due to economic conditions and the surplus manpower available to be employed. Thus, manual materials handling tasks are the forces to reckon with, in any industrial scenario, throughout the world. The back injuries, associated with manual materials handling activities, have necessitated research works to be conducted for the determination of the maximum acceptable weight of lift (MAWOL). Even after numerous research works leading to the significant reduction in the back injury problems, the compensation costs associated with it are still severe (NIOSH 1981).

Caillet (1981) estimated that 70-million Americans have been inflicted by back injuries and that the number will increase by 7-million annually. The cost associated with this problem is extremely high. Klein, Jensen, and Sanderson (1984) estimated that between 19% and 25.5% of all workers'

compensation claims are due to back pain. The summary from the National Safety Council's Work Injury and Cost Statistics (1972-1984) show that while injury frequency declined slightly between 1981 to 1984, the cost remained about the same.

Many research studies have been carried out, utilizing various methodologies, for the determination of maximum acceptable weights for manual materials handling activities in the past years (Stevenson, et al., 1989; Dutta, et al., 1989; Gallagher, 1991; Ayoub, et al., 1980; Ayoub, et al., 1980; Mital, et al., 1980; Garg, 1980; Mital, et al. 1983; Chaffin, et al., 1983; Drury, et al., 1989; Nicholson, 1989; Mital, 1984; Garg, et al., 1980; Ciriello, et al., 1983; Kroemer, 1983).

Psychophysical method of determining the maximum acceptable weights for manual materials handling tasks has been used by many researchers in the past many years. However, most of these research studies relate only to individual tasks such as lifting, carrying, lowering (Ciriello, et al., 1993; Fernandez, et al., 1988; Ciriello, et al., 1990; Ciriello, et al., 1983; Mital, 1983; Garg, et al., 1980; Ciriello, et al., 1991; Jiang, et al., 1986; Ciriello, et al., 1993; Ayoub, et al., 1980).

Very little research work has been done to determine the maximum acceptable weights for combined manual materials handling activities. In the actual industrial set-up, various combined manual materials handling activities are carried out

and it has been necessary to determine if the combination of activities produce any significant effect on the maximum acceptable weight in relation to the individual activities making the combination. Designing the manual materials handling tasks based on this, would certainly be beneficial in reducing the back injury cases and hence, the ever increasing compensation costs for such injuries. The research works carried out on the maximum acceptable weights for the combined tasks involved only the combination of different manual materials handling tasks (Jiang, et al., 1986; Gallagher, 1991; and Ciriello, et al., 1993). However, in the real case industrial scenario, workers may have to perform a sequence of operations involving manual materials handling tasks as well as some other tasks of different nature such as the involvement of upper extremities or lower extremities.

The present study is intended to determine if a combination of upper extremity activities, in a sequence of manual materials handling activities, produces any significant effect on the maximum acceptable weight of lift, using Psychophysical methodology.

CHAPTER 2

LITERATURE REVIEW

Overexertion Injury

Compensation costs of over 1 billion per year and the 12-million lost workdays due to overexertion on account of manual materials handling activities, speak for themselves on the seriousness of the situation. The seriousness is more reflected by the report that injuries of overexertion due to manual materials handling activities account for 25% of all the overexertion injuries (NIOSH, 1981).

Low back pain continues to account for approximately one third of all workers compensation costs. Manual materials handling tasks are associated with 63% of low back disorders (Ciriello, et al., 1993).

Overexertion, musculoskeletal, and back injuries occur due to a mismatch between the strength abilities of the workers and strength demands of their jobs. Strength capabilities of the working population and the methods for matching individual worker to the job's physical requirements are needed to reduce such injuries. Making such a match provides a permanent engineering solution (Garg, et al., 1980).

Design Approaches to Solving MMH Problems

The following approaches have been used over the years to determine the maximum acceptable weight of lift:

1. Epidemiological
2. Biomechanical
3. Physiological
4. Psychophysical

(Mital, et al., 1993; NIOSH, 1981; Garg, et al., 1980).

Epidemiological Approach:

"Epidemiology is the study of disease occurrence in human populations". In general, it is concerned with discerning the injury patterns present, if any, and using these patterns to predict the occurrence of injury. The basic measurements in epidemiology are: counts (number of people in group suffering from back injuries, a particular back disorder, low back pain, etc.), prevalence rate (number of people in a group inflicted with some back disorder/total number of people in the group), and incidence rate (number of people developing a disorder/total number at risk/unit time) (Mital, et al., 1993). This methodology is not applicable for the determination of maximum acceptable weight of lift.

Biomechanical Approach:

The biomechanical approach to estimate the mechanical stresses on the body (primarily, forces acting on the lower

back) relies on two measures: the compression and shear forces generated at the L5/S1 disc of the spinal column and, pressures generated at the abdominal cavity (IAP) (Mital, et al., 1993).

The general concern in occupational biomechanics is to determine with given precision what a person can physically (mechanically) do. In an industrial setting, this means that the person's physical capabilities must be assessed along with the physical demands of a prospective job. In addition to the simple ability to perform, biomechanics is concerned with those physical attributes of the individual and job that have been found to produce potential harm to the musculoskeletal system (NIOSH, 1981). This approach is suitable for analyzing infrequent tasks only, since the models developed to date do not account for the fatigue that results when physical tasks are performed repeatedly (Mital, 1983).

The primary concern of this approach has been with the muscular strength and musculoskeletal loading; and, the experimental design has been such that the possibility of cardiovascular and muscular fatigue has been eliminated (Nicholson, 1989).

Studies, on forces developed by load lifting on musculoskeletal system, specifically on the low back, by various researchers, have shown that lifting of small loads (less than 20 kg) away from the body will produce large compressive and shearing forces on the low back.

Intervertebral discs may be destroyed by spinal forces as low as 1568 N (160 Kg) (Garg, et al., 1980).

Various biomechanical models have been developed to facilitate this approach. The models developed by Chaffin (1967, 1969), Fisher (1967), and Chaffin (1971) are static in nature. Chaffin's model (1967) can compute the static forces and torques at the major articulations of the body for a static midsagittal plane lifting task. Given the dimensions and the position of the body segments, the program computes the forces and torques at the wrist, elbow, shoulder, hip, knee, and ankle joints using the free body diagram (Ayoub, et al., 1980).

Physiological Approach:

Unlike the biomechanical approach, the physiological approach is applicable to repetitive lifting where the load is within the physical strength of the worker. While performing manual materials handling tasks, several physiological responses, such as, metabolic energy cost, heart rate, blood pressure, blood lactate are affected. Of all these responses, metabolic energy expenditure has been the widely accepted physiological response to repetitive handling as it is directly proportional to the workload at steady-state conditions (Mital, et al., 1993).

Since in industrial settings manual materials handling activities are made up of both dynamic and static efforts, the physiological responses to each ought to be properly

understood to obtain fairly accurate results (NIOSH, 1981).

The physiological approach has been used for the studies on simultaneous activities. Wiley and Lind (1975) and Kibom and Brundin (1976) examined the respiratory and circulatory responses to simultaneous static (hand-grip) and rhythmic (bicycle ergometer) exercises. Sanchez, et al., (1979) studied the effects of dynamic work (walking), static work (pushing, pulling or holding) and combined static and dynamic work on heart rate and oxygen consumption (Jiang, et al., 1986).

Psychophysical Approach:

Psychophysics is a very old branch of psychology that is concerned with the relationship between human sensations and their physical stimuli; very rarely is this a one-to-one relationship. Strength, in psychophysical context, is defined as the maximum voluntary force a person is willing to exert in a single attempt. Similarly, endurance (capacity) is the force a person is willing to repeatedly exert for an extended period of time without "feeling fatigued" (NIOSH, 1981).

Modern psychophysical theory, i.e., Stevens theory, states that the strength of a sensation (S) is directly related to the intensity of its physical stimulus (I) by means of a power function:

$$S = kI^n$$

where,

S = strength of a sensation

I = intensity of physical stimulus

k = a constant which is a function of the particular units of measurement that are used

n = the slope of the line that represents the power function when plotted in log-log coordinates. Experiments have determined the exponents for many types of stimuli, some of which are:

electric shock = 3.5, for taste (salt) = 1.3, for loudness (binaural) = 0.6, and for lifting weights = 1.45.

The psychophysical approach to manual materials handling job design requires individuals to adjust either the handling frequency, the weight of load or the force exerted on the object being handled according to their perception of physical strain. One variable is adjusted while all other variables are controlled. The individuals are told to adjust the workload to the maximum amount they can handle for a specified period of time, without undue strain or discomfort, and without becoming unusually tired, weakened or overheated, or out of breath. The final workload, thus selected, is the maximum acceptable frequency of handling or the maximum acceptable weight/force of handling (Mital, et al., 1993).

In the Psychophysical approach, a person adjusts the load such that repetitive lifting does not result in overexertion or excessive fatigue. The weight selected by the operator is

referred to as the maximum acceptable weight of lift (Ayoub, et al., 1980).

Psychophysical approach is simple to use and understand and it is effective in the sense that, it is only the individual worker who can integrate the various sensory inputs into one meaningful response (Garg, et al., 1980). The following indices can be used in the psychophysical approach:

- Rated perceived exertion (RPE)
- Body part discomfort frequency (BPDF)
- Body part discomfort severity (BPDS)

(Drury, et al., 1989).

Effectiveness of Various Approaches

Of the various approaches available for the ergonomic design of manual materials handling activities, epidemiological approach is never used whereas the other approaches are used frequently depending upon the type of workload, frequency, etc.

Biomechanical approach has been used by many researchers in the analysis of manual materials handling activities.

This approach is suitable for analyzing infrequent tasks only, since the models developed to date do not account for the fatigue that results when physical tasks are performed repeatedly (Mital, 1983).

For infrequent lifting, the acceptable weight of load determined by biomechanical approach was higher than that

determined by psychophysical approach (Nicholson, 1989).

Acceptable weight limits based on muscle strength testing and biomechanical modeling (Poulsen and Jorgensen, 1971; Poulsen, 1970; Martin and Chaffin, 1972; Chaffin, et al., 1977), in general, are higher than those based on psychophysical methodology (Snook, 1978; Ayoub, et al., 1978; ILO, 1965; Snook and Ervine, 1967).

Physiological approach is used in case of repetitive lifting also. The lifting capacity based on physiological approach overestimated the lifting capacity based on psychophysical approach at 2 lifts per minute by 25.36%. However, at 8 lifts per minute, the lifting capacity based on physiological approach underestimated the lifting capacity based on the psychophysical approach by 28.83% (Fernandez, et al., 1988).

At low frequencies the biomechanical approach is more appropriate, while at high frequencies the physiological approach is more appropriate. Utilizing the psychophysical approach to estimate lifting capacity is appropriate over the entire frequency range when compared to utilizing the physiological or the biomechanical approaches (Fernandez, et al., 1988).

The psychophysical approach seems to be a valid measure of lifting capacity across the lower and moderate lifting frequency range. Lifting capacity estimated by the psychophysical approach is relatively consistent (Fernandez,

et al., 1988).

Psychophysical techniques utilize a trained worker to adjust the load lifted until the maximum load which can be lifted repeatedly over a long work bout is reached (Ayoub, 1977).

According to Snook, the major advantages of psychophysical approach are the following:

1. It permits the realistic simulation of industrial work. For example, lifting can be a dynamic task through a given vertical distance, and not just isometric pull. Task frequency can be varied from very fast rates to very slow rates.

2. It can be used to study the very intermittent tasks that are commonly found in industry.

3. Its results are consistent with the industrial engineering concept of a "fair day's work for a fair day's pay".

4. Its results are very reproducible.

However, the following are the disadvantages of this approach:

1. It is a subjective method that relies upon self-report from the subjects.

2. Its results from very fast frequency tasks are higher than recommended metabolic criteria. Permissible loads for very fast tasks should probably be based upon metabolic criteria.

3. It does not appear sensitive to the bending and twisting motions that are often associated with the onset of low-back pain. For example, psychophysical results are higher for the floor to knuckle height lift than for the knuckle height to shoulder height lift (Marley, 1990).

Models Used for Different Approaches

Biomechanical:

Various biomechanical models have been developed in the

past many years. All the models are not concerned with lifting activities alone. All of these models estimate the reactive forces and torques on the various joints, with a few also estimating the compressive and shear forces in L4/L5 and L5/S1 discs (Ayoub, et al., 1980).

Chaffin's model (1967) can compute the static forces and torques at the major articulations of the body for a static mid-sagittal plane lifting tasks.

Fisher's model (1967), which was an expanded version of Chaffin's (1967) model, could compute the compressive, shear, and torque forces on the lumbar spine. This model corrects for the effect of abdominal pressure.

Chaffin's computer model (1969) estimates forces and torques at the fourth lumbar through the first sacral spinal vertebrae of a person performing a weight handling task. This is in addition to the estimation of forces and torques at six major articulations of the body (wrist, elbow, shoulder, hip, knee, and ankle). His 1971 model, which was an improvement on the 1969 model, considered even mass distribution of equipment gravity. All these models considered only the static forces, i.e., the forces generated due to movement acceleration was assumed to be negligible.

El-Bassoussi's model (1974) and Ayoub and El-Bassoussi's model (1976) took into consideration even the subject's movement and the forces generated by the movements. This model also considers the reactive forces and torques on

various body joints, as well as the compressive and shear forces at the L4/L5 and L5/S1 joints.

Physiological:

Frederick's model (1959) gives the interaction of all the independent variables (frequency, height of lift, load, etc.) but does not include any main effect. One of the serious drawbacks of this model is that, energy consumption is based on lifting as a single performance. Thus, this drawback makes this model not suitable to repetitive industrial tasks. Despite the fact that squat method of lifting requires higher rate of energy expenditure (Brown, 1971), this model does not take into account lifting postures, i.e., squat, stoop, etc.

The Aberg, et al., (1968) model requires the center of gravity to be determined. Its indifference to the gender for horizontal arm work and/or for pushing and pulling, difficulty in the determination of center of gravity, and non-consideration of the effect of posture and technique make this model to be used only in a limited sense.

Garg's model (1976), though the most flexible of all the metabolic rate prediction models, takes into account the activities in the sagittal plane alone. The assumption of this model, that an activity can be broken down into tasks and that the metabolic rate for the activity is the sum of the metabolic rates for all the tasks, has not been verified so far.

Psychophysical:

Various researchers have developed models to study the manual materials handling activities in a psychophysical approach. McConville and Hertzberg (1966) developed a model to examine the interaction of two variables: the weight and the width of one-handed, symmetrical boxes. The predictive lift equation developed with maximum weight of lift as dependent variable and for floor to knuckle height of lift is as follows:

$$\text{Predictive lift} = 60 - (\text{width of box in inches})$$

Poulsen (1970) developed prediction equations for investigating the maximum weight a person could lift for two different heights. Both males and females were used as subjects in his study. The predictive lift equation developed with maximum weight of lift as dependent variable, and for both male and female are as follows:

For Floor to table height-

$$\text{Predicted lift} = 1.40(\text{max. isometric back st.}) - 0.5(\text{body weight}).$$

For Table to head height-

$$\text{Predicted lift} = 0.5(\text{sum of right and left max. isometric arm push}).$$

McDaniel (1972), and Ayoub (1976) developed regression equations to estimate the predicted lift. The equations developed for male, female and both are as follows:

Floor to knuckle height of lift-

Predicted lift = $-176.36 + 0.02(\text{ht})^2 - 2.73(\text{static end.})^2$
 $+ 0.02(\text{RPI}) * (\text{arm st.}) + 0.05(\text{RPI}) * (\text{back st.}) -$
 $2.51(\text{FI/dynamic end.})$ for male.

Predicted lift = $-24.03 + 0.19(\text{RPI})^2 +$
 $0.006(\text{arm st.})(\text{leg st.})$ for female.

Predicted lift = $11.93 - 1.12(\text{back st.}) + 0.16(\text{RPI})^2$
 $+ 0.005(\text{back st.})^2 - 8.81(\text{static end.})^2 - 0.1(\text{sex})(\text{FI})$
 $+ 0.06(\text{ht})(\text{RPI}) + 0.03(\text{RPI})(\text{leg st.}) -$
 $0.002(\text{back st.})(\text{leg st.}) - 0.03(\text{leg st.})(\text{stat. end.}) +$
 $0.11(\text{static end.})(\text{FI})$ for both male and female.

The models developed by various researchers from three lifting ranges are as follows:

Floor to Knuckle Height (McDaniel, 1972):

Predicted Lift for male = $-172.3599 + 0.0220607 * \text{Ht.} -$
 $2.72867 * \text{Stat.Ef.} + 0.0209696 * \text{RPI} * \text{Arm St.} +$
 $0.0534346 * \text{RPI} * \text{Back St.} - 2.51346 * \text{RPI/Dynam.Ef.}$

Predicted Lift for female = $-24.02682 + 0.19362 * \text{RPI} +$
 $0.00607224 * \text{Arm St.} * \text{Leg St.}$

Predicted Lift for both male and female = $11.93388 -$
 $1.1024 * \text{Back St.} + 0.15811 * \text{RPI} + 0.00458322 * \text{Back}$
 $\text{St.} - 8.80718 * \text{Stat. Ef.} - 0.09552 * \text{Sex} * \text{FI} + 0.06007$
 $* \text{Ht.} * \text{RPI} + 0.0231265 * \text{RPI} * \text{Leg St.} - 0.00021627 *$
 $\text{Back St.} * \text{Leg St.} - 0.027092 * \text{Leg St.} * \text{Stat. Ef.} +$
 $0.11092 * \text{Stat. Ef.} * \text{FI}$

Knuckle to Shoulder Height (Dryden, 1973):

Predicted Lift for male = $0.82766 * \text{Chest Cir.} + 0.55885 * \text{Dyn.Ef.}$

Predicted Lift for female = $3.809 * \text{RPI} - 1.47347 * \text{Ht.} * \text{FI}/1000 - 0.31199 * \text{RPI} * \text{Stat.Ef.} + 1.22804 * \text{Percent Fat} * \text{FI}/1000$

Predicted Lift for both male and female = $24.12120 + 0.37912 * \text{Sex} * \text{Dynam. Ef.}$

Shoulder to extended Reach Height (Knipfer, 1974):

Predicted Lift for male = $4.91337 + 0.19746 * \text{Back St.} - 0.01733 * \text{Shoulder St.} + 0.42917 * \text{Age}$

Predicted Lift for female = $15.07131 + 0.34346 * \text{Wt.} + 0.83999 * \text{Dynam. Ef.} + 0.33545 * \text{Forearm Circ.}$

Predicted Lift for both male and female = $5.225 * \text{Sex} + 0.00494 * \text{Shoulder St.} + 0.1944 * \text{Horiz. Push St.}$

Where,

Dynam. = Dynamic

End. = Endurance

RPI = Reciprocal Pendoral Index

Stat. = Static

Ef. = Effort

Ht. = Height

St. = Strength

Wt. = Weight

Studies on MAWOL

As described above, various researchers have used different models to determine the Maximum Acceptable Weight of Lift.

Stevenson, et al., (1989) used an incremental lifting machine (ILM) to determine the maximum lifting performance by isoinertial tests and concluded that prediction of maximum lifting ability or endurance ability using ILM might be enhanced by closer approximation of specific task variables, or by inclusion of dynamic parameters to measure technique.

Dutta, et al., (1989) used efficiency of mechanical work as the response variable for optimization purposes in determining the optimum activity levels when carrying symmetrical loads in the sagittal plane. They concluded that to improve the efficiency of workers performing carrying task, loads should be very close to 18 kg and handling frequency should be near 3 times/min. The metabolic energy expenditure values indicated that carrying heavy loads for longer distances increases the mechanical work, metabolic costs, and heart rate. As a result, under this condition and with more frequent handling, intermittent carrying tasks closely approximate continuous carrying tasks. Therefore, carrying tasks involving handling light loads for shorter distances are more economical from the metabolic and mechanical work point of view.

Ciriello, et al., (1990) used psychophysical approach to investigate maximum acceptable weights and forces when performing manual handling tasks continuously for four hours at frequencies of 4.3 /min or slower. They concluded that the weights selected after 40 min were not significantly different from the weights selected after four hours. It was also concluded from this study that psychophysical methodology was appropriate for determining maximum acceptable weights for task frequencies of 4.3/min or slower.

Ciriello, et al., (1983) used psychophysical methodology to study the effect of size, distance, height, and frequency on manual handling tasks with 10 male and 12 female industrial workers as subjects. The results of this study indicated that acceptable weights for lower frequency tasks are lower compared to higher frequency tasks and that maximum acceptable weights and forces for female workers were significantly lower, but proportionately similar, to the maximum acceptable weights and forces for male workers.

Mital, (1983) conducted an experiment to verify the psychophysical methodology used for determining lifting capabilities of workers. The result indicated that male and female workers could lift only 65% and 84% respectively of the estimated value for 25 min, in 8-hour work duration. When the duration of the task increased from 8 hour to 12 hours, the amount of load lifted was only 70% and 77% respectively. The metabolic energy expenditure rate of the subjects decreased

significantly with time as the loads were reduced, and heart rate remained relatively constant at about 100 beats/min.

Kroemer, (1983) conducted experiments to determine the best technique for selecting persons suitable for materials handling. He concluded from the results of the experiment that isoinertial technique was better than static strength tests.

Ayoub, et al., (1983) used psychophysical approach to determine the maximum acceptable weight of lift which was used in the determination of Job Severity Index (JSI). JSI which is defined as the time-and-frequency-weighted average of the maximum weight required by each task divided by the selected lifting capacity given the lifting task conditions. The researchers proposed the use of JSI as a tool for job design and employee placement.

Gallagher, (1991) conducted experiments to study the psychophysically acceptable weights and physiological costs of performing combined lifting and lowering tasks in restricted postures. The results of the experiments indicated the following:

- psychophysically determined MAWOL averaged 11.3% lower when kneeling as compared to stooping, is slightly greater (3.5%) when handling loads asymmetrically, and is decreased (5.00%) with increasing lifting height when performing lifting and lowering tasks in restricted postures.

- energy expenditure was greater in the stooped posture, when lifting and lowering asymmetrically, and when lifting and lowering to a higher shelf height in restricted positions.

- the psychophysical approach of determining acceptable weights of lift was sensitive to differences in lifting capacity even for a relatively brief MMH periods.

Jiang, et al., (1986) studied psychophysically the effect of combined manual materials-handling activities on maximum acceptable weight of lift. The increase in the heart rate verified the subjects' comments that combined activity was more stressful than the individual component activities of the combination.

Ciriello, et al., (1993) conducted further studies of psychophysically determined maximum acceptable weights and forces. The results of their studies indicated that lifting boxes without handles produced consistent decreases (median, 16%) in maximum acceptable weights when compared with lifting boxes with handles. Lifting with extended horizontal reach (approximately 48 cm) produced consistent decreases (median, 48%) in maximum acceptable weights when compared with lifting close to the body (approximately 17 cm). No significant heart rate or oxygen consumption differences occurred in either of these variables. The maximum acceptable force of pulling was lower for longer (15.2 m) pulling tasks. The maximum acceptable weight for combination tasks was similar to that of the limiting components.

Snook, et al., (1991) reviewed some of the experiments already carried out to study lifting, lowering, pushing, pulling, and carrying tasks. Psychophysical approach was used in each case with the measurements of oxygen consumption, heart rate, and anthropometric characteristics. The results of the experiments showed lower means for the criterion tasks (i.e., low lift, center lift, low lower, center lower, initial push, sustained push, initial pull, sustained pull, and carry) were lower than the original values for female subjects, whereas opposite trend occurred for the male subjects.

Nicholson, (1989) did a comparative study of methods for establishing load handling capabilities and concluded from the results of the experiments that care must be exercised when using or recommending psychophysically determined weights with an origin of lift below knee level. The comparisons were limited to bimanual, sagittal plane lifting. The study supports the conclusions of Garg and Ayoub (1980) that the acceptable weights according to psychophysical studies are lower than those according to biomechanical criteria.

Mital, (1984) conducted an experiment on comprehensive maximum acceptable weight of lift database for regular 8-hour work shifts. The experimental data collected in this study, for 8 hours, were compared with previous studies of Snook, (1978) and Ayoub, et al., (1978) and was found that all three studies compared favorably.

Garg, (1980) did a literature survey on recommendations for the maximum weight of the load and work loads. The three different criteria (biomechanical, physiological, and psychophysical) were reviewed in the literature and the comparison showed that (1) the recommendations based on a given criterion are not in agreement, (2) the maximum permissible weights of the load based on psychophysical studies were lower than those based on biomechanical criteria, and (3) the psychophysical fatigue criteria, as compared to physiological fatigue criteria, resulted in greater work loads at higher frequencies of lifting.

Smith, et al., (1984) did a study on manual bag lifting. The results of the study indicated that for short work bout (approximately 30 minutes), average percent of PWC for the psychophysical approach was 55.3%

Gallagher, et al., (1990) conducted experiments to study psychophysical, physiological and biomechanical effects of lifting in stooped and kneeling postures. Results of this study indicated that lifting capacity was greater when the subjects could assume a stooped posture than when kneeling. The metabolic cost was greater in kneeling posture for heart rate, oxygen consumption, minute ventilation, and respiratory exchange ratio.

Karwowski, et al., (1986), in their investigation on the reliability of the psychophysical approach to manual lifting of liquids by females, observed that the use of the

psychophysical method in the present form, as applied to manual materials handling, should be limited to the low and moderate frequencies only, as originally intended by Snook and Irvine in 1986 (Karwowski, et al., 1986).

Snook, et al., (1970) conducted an ergonomic study to determine a man's physical capacities while performing manual materials handling tasks. Lifting, lowering, pushing, pulling, carrying, and walking tasks were studied in a controlled environment of 68° to 72° F and 40% to 55% relative humidity. The results of the study indicated that there were no significant differences between maximum acceptable weights of lift and maximum acceptable weights of lower. However, for different heights, maximum acceptable weights were significantly greater for lowering than for lifting. The initial force for pushing was significantly greater than initial force for pulling. There were no significant rate differences among three replications of the walking task.

Studies on Combined Manual Materials Handling

Very few research works have been carried out on combined manual materials handling activities. All the studies reported in this field relate to various activities only in the field of materials handling activities. No research work has been reported to determine the effect of upper or lower extremities activities which might come in the sequence of manual materials handling activities.

Taboun, et al., (1989) conducted research to determine the energy cost models for combined lifting and carrying tasks. In their experiment, oxygen uptake (VO_2 l/min.) and heart rate (beats/min) were the response variables, whilst a number of task related parameters: load handled, height of lift, frequency of handling, carrying distance and load width, were manipulated using rotatable central composite design.

From the results of their experiment, the researchers concluded that the values obtained for metabolic energy expenditure should be related to the aerobic work capacity of workers involved in the task. They also concluded that the energy cost equation developed from the experiment could be used with a high degree of accuracy to set job standards in industry.

The energy cost models developed were:

Model I: Applicable to individual carrying tasks and/or combined carrying and lifting from 75 cm (table height) to a height of 150 cm or less.

$$VO_2 = 0.1809 + [(BW+L) * (2.6112 * (BW+L) * 92.594 * D * H) + F * (318.16 * L + 7.9815 * BW * D + 49.1565 * L * D)] * 10^{-5} + 2.2956 * WID/L \quad (R^2 = 0.824)$$

Model II: Applicable to combined lifting and carrying tasks, where lifting starts from the floor to 150 cm height or less.

$$VO_2 = 0.0738 + [(BW+L) * (3.9918 * (BW+L) + 61.226 * D * H) + L * F * (424.131 + 81.926 * D)] * 10^{-5} + 3.851 * WID/L \quad (r^2 = 0.863)$$

Where,

VO_2 = oxygen consumption (l/min), BW = body weight (kg),
 L = load handled (kg), F = frequency (handling/min), D =
 carrying distance (m), H = height range of lift (m), and WID
 = box width (m) along the sagittal plane.

The above models give the best results when used within
 the following range limits;

1. Load: between 8 and 28 kg.
 2. Frequency: between 1 and 5 handling/min.
 3. Carrying distance: between 0 and 12 m.
 4. Height range of lift: from floor to 1.5 m.
 5. Box width: between 0.15 and 0.55 m.
- (Taboun, et al., 1989)

Gallagher, (1991) studied the acceptable weights and
 physiological costs of performing combined manual handling
 tasks in restricted headroom conditions. The independent
 variables included posture (stooping or kneeling on two
 knees), task symmetry (symmetric or asymmetric), and vertical
 lift distance (35cm or 60cm). He concluded from the results
 of the experiment that:

1. Effect of lifting height is similar whether one is
 lifting or performing a combined lifting and lowering task and
 that the MAWOL of the combined tasks was limited by the
 capacity to lift, rather than the capacity to lower.

2. Psychophysically determined MAWOL averages 11.3%
 lower when kneeling as compared to stooping, is slightly
 greater (3.5%) when handling loads asymmetrically, and is
 decreased (5.0%) with increasing lifting height when
 performing lifting and lowering tasks in restricted postures.

3. Energy expenditure was greater in the stooped
 posture, when lifting and lowering asymmetrically, and when
 lifting and lowering to a higher shelf height in these
 restricted positions.

4. The psychophysical approach of determining acceptable weights of lift was sensitive to differences in lifting capacity even for relatively brief MMH periods. Only 3% of tests had to be repeated due to violation of the 15% criterion.

5. IAP studies suggest lower limits in the stooped posture, while psychophysical studies indicate a more limited lifting capacity in the kneeling posture.
(Gallagher, 1991)

Jiang, et al., (1986) studied the effect of combined manual materials handling activities on the capacity of the workers. They conducted experiments with combined MMH activities: lifting from floor to knuckle height and carrying (LFK+C); lifting from floor to knuckle height, carrying and lifting from knuckle to shoulder height (LFK+C+LKS); and lifting from floor to knuckle height, carrying and lowering to the floor (LFK+C+LOW). They concluded from the experimental results that at higher frequencies (>6 lifts/min) the combined activities allowed for little resting time. Consequently, there was very little time for physiological recovery from muscle fatigue.

The lifting capacity of the combined MMH activities is determined by the limiting capacity of the individual component activity. The limiting capacity usually occurs at the most stressful individual activity or at the weakest limb of the human body used in handling the task, i.e., in the combined LFK, carrying 3.4m and LKS task at a pace of six handlings per minute, the LKS task becomes the limiting capacity because of the weakest strength for LKS height.

(Jiang, et al., 1986)

Ciriello, et al., (1993) carried out further studies of psychophysically determined maximum acceptable weights and forces and came to the conclusion that the maximum acceptable weight for combination tasks was similar to that of the limiting component. (Ciriello, et al., 1993)

Snook, et al., (1991) from their investigation of the combination task, consisting of a lift, carry, and lower concluded that the maximum acceptable weights for the combination task were significantly lower than that of individual carrying task performed separately. But, they were not significantly different from the values for individual lifting and lowering tasks performed separately. The heart rates for the combination task were significantly higher than those for the individual lifting, carrying, and lowering tasks (Snook, et al., 1991).

Taboun, et al., (1989) conducted experiments to determine the metabolic responses to combined manual materials handling tasks, viz., lifting and carrying and developed energy cost models for these tasks. The developed models were compared with responses for individual handling tasks and validated using the "Prediction Error Sum of Squares". They concluded from the results of the experiments that the most stressful task appeared to be the one in which a load (even as low as 13 kg) was lifted from the floor to the shoulder height and then carried over distances exceeding 3 m at relatively low frequencies. It was also established that the net metabolic

energy expenditure for the combined tasks cannot be estimated by summing the net steady-state metabolic costs for individual task components (Taboun, et al., 1989).

Heart Rate During Physical Activity

The heart rate during any physical activity can be thought of as comprised of Resting Pulse, Working Pulse, Work Pulse, Total Recovery Pulse (recovery cost), and Total Work Pulse (cardiac cost), defined as follows:

1. Resting Pulse: average heart rate before the work begins.
2. Working Pulse: average heart rate during the work.
3. Work Pulse: difference between the resting and working pulses.
4. Total Recovery Pulse (recovery cost): sum of heart beats from the cessation of work until the pulse returns to its resting level.
5. Total Work Pulse (cardiac cost): sum of heart beats from the start of the work until resting level is restored.

Karrasch, and Müller made use of their studies to determine an acceptable upper limit of work load as being that within which the working pulse did not continue to rise indefinitely, and when the work stopped, returned to the resting level after about 15 minutes. The maximum output under these conditions is the limit of continuous performance throughout an eight-hour working day.

According to E. A. Müller, the limit of continuous performance for men is reached when the average working pulse is 30 beats/min. above the resting pulse (i.e., work pulse = 30 b/min), both of these being measured in the same posture. Rohmert and Hettinger have made a systematic study

of the limits of work load, during which the heart rate remained steady, using a cycle-ergometer, and a hand crank for eight hours at a time. They came to the conclusion that this limit was still valid up to a work pulse of 40 b/min., provided that the resting pulse was measured when the operator was lying down. The authors show that for dynamic work involving a moderate number of muscles, 1 work calorie/min. = 10 work pulse.

Several studies undertaken in factories have shown that it is easier to measure the resting pulse when the subject is sitting than when lying down, so it is suggested that, for men, resting pulse should be taken when seated and 35 work pulses be fixed as the limit for continuous performance.

Christensen has suggested that within certain limits, ventilation of lungs, heart rate, and body temperature show a linear relationship with the rate of energy consumption, or the work performed. Table 1 shows reactions measured at various work loads (Grandjean, 1986).

Since the energy produced by muscle contraction is directly related to the oxygen used (the exact relationship depending on the proportion of carbohydrate, protein, and fat in the diet), energy expended may be measured by ascertaining the oxygen consumed and the carbon dioxide produced. Equipment for this purpose will therefore be required to measure the ventilation rate in m^3 , and to take a sample of the expired air for subsequent analysis. However, due to the

bulkiness of the equipment, and the requirement for the subject to wear mask over face during the experiment, it is not always feasible to follow this procedure.

Table 1. Relationship between Various Metabolic Measurements

Assessment of Work load	Oxygen Consum. Liters/min.	Lung Ventilation Liters/min.	Rectal Temp. Degree C	Heart Rate Beats/min
Very Low (Resting)	0.25 - 0.3	6 - 7	37.5	60-70
Low	0.50 - 1.0	11 - 20	37.5	75 - 100
Moderate	1.0 - 1.50	20 - 31	37.5 - 38.0	100 - 125
High	1.5 - 2.0	31 - 43	38.0 - 38.5	125 - 150
Very High	2.0 - 2.5	43 - 56	38.5 - 39.0	150 - 175
Extremely High (e.g. sport)	2.40 - 4.0	60 - 100	Over 39	over 175

The second and more practically viable method of measurement utilizes the relationship between pulse rate and energy expenditure (Figure 1) (Applied Ergonomics Handbook).

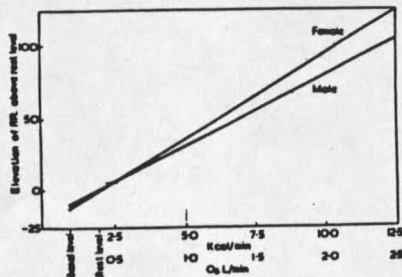


Figure 1. Relationship between Pulse Rate and Energy Expenditure.

Factors Affecting Maximum Acceptable Weight of Lift

Individual Factors:

The following are the individual factors which have been found to affect the maximum load handling capacity of an individual:

Age: it is a well known fact that people experience decreased capability with the increase in age. The studies conducted by Aberg (1961) indicated that the capacity decreases after 20 years of age. However, studies conducted by Mital, (1984) on comprehensive maximum acceptable weight of lift for regular 8-hour work shifts, did not show any significant age effects either on the maximum acceptable weight of lift, heart rate, or oxygen uptake for either males or females.

That ageing leads to reduction in physical work capacity, range of lumbar spinal motion, muscle strength, muscle contraction speed, shock absorbing characteristics of the lumbar disc, intra-abdominal pressure, load supporting capacity of the spine, and aerobic capacity has been well established. However, the effect of ageing on manual materials handling capabilities does not appear to be significant (Ayoub, et al., 1989; 1993).

Mital, et al., (1983) concluded from their experiments that age appeared to be important predictor of MAWOL.

Gender: Gender differences are also reflected in the manual materials handling capabilities of men and women. Primarily due to the difference in the muscle strengths, the MMH capability of women is substantially lower than that of men (Ayoub, et al., 1993). This has been verified from many experiments conducted by a number of researchers:

Physique/anthropometric strength: Several studies have shown that, compared to shorter individuals, tall people are relatively weaker in lifting strength and more susceptible to back pain as they have to lean and reach further to pick up or set down a load. "The review of scientific literature indicates that taller, muscularly weak, or obese individuals are disadvantaged when performing materials handling jobs, particularly repetitive MMH jobs. Muscularly built persons, on the other hand, have greater MMH capacity and are less prone to low-back pain (Ayoub, et al., 1993)".

Mital, et al., (1983) concluded from their experiment that body weight of the subject appeared to be an important predictor of MAWOL.

Training: It is a generally accepted fact that training the workers on the safety in materials handling plays a great part in reducing the hazardous effect of manual materials handling activities. Various European countries have been providing training to the workers on the concept of "human kinetics" with the aim of avoiding the unnecessary stress due

to materials handling (NIOSH, 1981).

"Since training has an educational value and enhances cardiovascular and muscular capabilities, MMH activities are perceived to become easier (reduced physical stress) and require less effort with training. Physical training, therefore, is highly desirable. The training program should include not only physical training but training in safe handling techniques and use of materials handling aids as well and should be extended not only to new employees but also to existing workers. Classroom instruction on the hazards of MMH activities should be an integral part of a training program" (Mital, et al., 1993).

Task Factors:

The following are the task factors that affect the maximum weight handling capacity of any individual:

Frequency: Garg, et al., (1979) concluded, from their experiment on effect of lifting frequency and technique on physical fatigue with special reference to psychophysical methodology and metabolic rate that maximum acceptable weight of lift increased with the increase in the frequency of lift.

Frequency of lifting is a task variable which affects the lifting capacity. Several investigations indicate that lifting capacity decreases when the frequency of lift increases (Ayoub, 1977).

Container size and type: The study conducted by Garg, et

al., (1980) showed that container size and type had significant effects on the maximum acceptable weight. From the same experiment they concluded that a person could lift heavier weight with a box type of container for container volumes approximately less than or equal to 0.11m^3 . For large container volumes ($>0.11\text{m}^3$), a bag type of container is more suitable.

The studies conducted by Tichauer, (1971); Aghazadeh, (1974), El Bassoussi, (1974) and Ayoub, et al., (1978) point out that as the size of the load increases in the sagittal plane, the mean weight lifted decreases (Ayoub, 1977).

The container size has a significant bearing on the maximum acceptable weight of lift. The maximum acceptable weight lifted was significantly higher when performing a bag lifting task either with handles or when the bag was 95% full. The maximum acceptable weight of lift for bag lifting tasks was higher (2.21 kg) than for box lifting tasks under the conditions of the experiment conducted by James L. Smith and Bernard C. Jiang (Smith, et al., 1984).

Height and range of lift: Mechanical work done in performing a repetitive lifting work can be expressed by the expression-

$$\text{Mechanical work} = \text{Load} * \text{Frequency} * \text{Height of Lift}$$

The expression shows that mechanical work required is directly proportional to the height of lift. Thus, metabolic energy expenditure should increase with an increase in the

vertical height of lift (NIOSH, 1981).

Similarly, the lifting capacity is different for different ranges of lift in the vertical direction, i.e., lifting capacity for the lifting range of floor to knuckle will be different from that of shoulder height to reach height. This is because of involvement of different muscle groups in the process of lifting (Fernandez, 1986).

Handles: Garg, et al., (1980), from their experiment on the study of container characteristics and maximum acceptable weight of lift, concluded that handles on the containers had a significant effect on the MAWOL. The maximum weight acceptable to a person was significantly lower when lifting a box without handles, as compared to lifting a box with handles.

Handle shape and size are relatively easy to define, but placement of handles on containers represents a more difficult problem. Laboratory and field studies of hand and handle placement were reviewed by Drury, et al., (1983) with the conclusion that handles should be placed so as to give both horizontal and vertical stability, except for heavy lifting, in which a symmetrical handle placement may be preferred, as it minimizes arm forces (Drury, et al., 1983).

Drury, et al., (1989) in a study of symmetric and asymmetric manual materials handling concluded that all handle positions were better than no handles, but the best handle

position changed from asymmetric for 9-kg boxes to symmetric for 13-kg boxes. The effect of handles was equivalent to a weight change of 1-2 kg for Heart Rate and Rated Perceived Exertion, but much higher (2-14 kg) for Body Part Discomfort measures.

Location of Center of Gravity: The location of center of gravity has a significant effect on the weight of lift (Mital, et al., 1983). Their results indicated that the maximum acceptable weight of lift decreased by 3.1% when the CG was offset by 12.7cm and by 7.6% when the CG was offset by 25.4cm. Asymmetrical lifting tasks are less stressful when the CG is located closer to the preferred hand. On the average 3% more weight was lifted when the CG was located closer to the preferred hand.

Density of Material: Mital, et al., (1983) concluded that the density of the material handled had a significant effect on the maximum acceptable weight of lift.

Subject: Mital, et al., (1983) concluded from their study that under identical conditions, there was a significant differences in the effect of frequency on the maximum acceptable weight of lift between the student and the industrial subject populations.

Environmental Factors:

The most common environmental variables which affect the

physiological behavior of workers are, ambient temperature, humidity, air movement, and atmospheric constituents (Fernandez, 1986).

Kamon and Belding (1971) reported that heart rate increased approximately 7 to 10 beats per minute for 10 degree centigrade rise in ambient temperature (Fernandez, J.E., 1986).

Snook and Irvine (1974) reported that the hot environment significantly increased heart rate and rectal temperature and significantly reduced the workload (Fernandez, 1986).

Hafez (1980) reported that the weight selected by subjects at 27-degrees Wet Bulb Globe Temperature (WBGT) were significantly different than the weight selected at 22-degrees WBGT. On the other hand, the weights selected at 32-degrees WBGT as well as the physiological responses (oxygen consumption, resting body temperature, resting heart rate, working body temperature, working heart rate) at 32-degrees WBGT were significantly different from those at 22-degrees WBGT (Fernandez, 1986).

The effects of all the above factors on the lifting capacity could be summarized by the following relation (Ayoub, et al., 1979):

$$\text{Lifting capacity} = W(h, p, s, f, b)$$

where,

h = Lifting height which has three levels: floor to knuckle height; knuckle height to shoulder height; shoulder height to reach height.

p = Percentile of the population assuming a normal distribution of lifting capacity. Five percentiles are considered using the mean and standard deviation of the lifting capacity at each lifting height; these percentiles are the 10th, 25th, 50th, 75th and 90th percentiles.

s = Sex of the worker. Two levels, males and females, are considered.

f = Frequency of lift. Six levels of frequency of lift were considered: 1, 2, 3, 4, 5 and 6 lifts per minute.

b = Box length, which is the box dimension in the sagittal plane of the body. Lengths of 10, 18, 24 inches were considered.

The value of W corresponding to given h , p , s , f , and b has to be read from a table.

CHAPTER 3

RATIONALE AND OBJECTIVES

The first study on combined manual materials handling activities was conducted in 1986. Though various researchers and organizations were involved in the study of manual materials handling activities, the studies were limited to individual activities alone. However, in industry, workers often perform various types of tasks consisting of a combination of materials handling activities. Though the mechanization of materials handling activities have helped in reducing the number of cases of occurrences of injuries in recent years, the compensation amount paid for these injuries indicates that it is still the leading injury class.

The situation in the developing economies around the world, where an ample labor force is available at a reasonably low cost, is completely different. The standards fixed for the maximum weight of lift, in most of the cases, are not updated according to the results of studies in this field. Thus, the workers are exposed to the risk of back injury which, mostly, are unnoticed for compensation purposes.

In addition to combined MMH activities involving only lifting, carrying, lowering, pushing, pulling etc., realistic industrial scenarios include specific upper-extremity activities to be performed by workers simultaneously or in sequence to the MMH activities. For instance, rice milling plants in the third-world countries require such activities as carrying the paddy in sacks to a platform for drying, lifting the sacks, carrying them to the parboiling tanks, dumping into the tanks, and opening the steam valves. This whole process involves upper extremities work in addition to material handling activities. This additional work may have a bearing on the amount of weight the worker could tolerate lifting safely. Similarly, steel furniture manufacturing industries require that cold rolled sheets be lifted, carried to the worksite, and lowered, and shearing, bending or forming operations be performed on these sheets. These tasks would add stress to various parts of the body of workers. Therefore, it is postulated that stress to upper-extremities may affect MAWOL.

The major objectives of this study are:

1. To establish using the psychophysical methodology, whether or not, combined manual materials handling task involving upper-extremity activity is a limiting factor on maximum acceptable weight of lift.
2. To determine values of maximum acceptable weight of lift for simulated lifting, carrying, combination of lifting

and carrying, and combined manual materials handling activities involving the upper extremity and compare to see if any relation existed between them.

3. To estimate the energy consumption during simulated lifting, carrying, and shearing activities and compare the results with that of combined manual materials handling task involving upper extremity.

CHAPTER 4

METHODS AND PROCEDURE

Subjects

Eight male students of Montana State University were randomly selected as subjects for this study. The sample size was determined on the basis of previous studies using similar criteria and protocol for the experiment. The subjects were so chosen that they were free from back pain and any type of musculoskeletal abnormalities. Each subject was thoroughly familiarized with the experimental procedure, before commencing on the data collection. Consent was duly obtained from each subject, through signing of the consent form.

EquipmentSensormedics Metabolic Cart

This equipment (Fig. 2), manufactured by Sensormedics Corporation, analyzes oxygen consumption by a Zirconium oxygen analyzer. The 2900c Sensormedics Metabolic Measurement Cart, available for experiment provides the following testing options:

Breath-By-Breath, Non-invasive Computer Assisted Anaerobic Threshold (AT) Detection, Automatic Maximum Oxygen Uptake (VO_2 Max) Analysis, Indirect Calorimetry, and Automated interpretation of test data. Testing mode technology can be selected from these as required by the experiment. The Metabolic Measurement Cart provides analysis of inhaled and exhaled respiratory gases. This analysis can be used to measure the energy expenditure of the body.

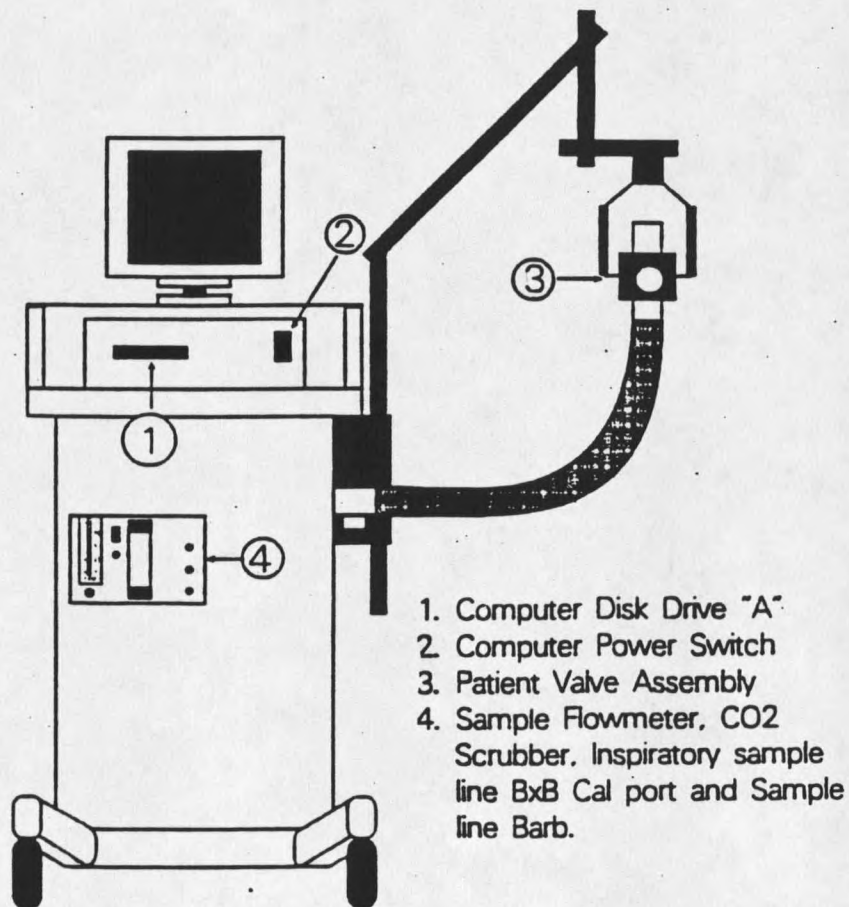


Figure 2. Metabolic Measurement Cart

Indirect calorimetry option of the Cart gives the measurement of respiratory gas exchange to assess the body's energy expenditure.

The subjects were hooked up to this equipment during lifting task only and energy expended by the body during the task was monitored.

LIDO Workset

This equipment (Fig. 3), manufactured by Loredan Biomedical, Inc., is designed to provide functional testing and rehabilitation in a single device. This equipment utilizes variety of attachments for simulating multiple exercise modes, high static and dynamic torque, and sensitive minimal torque. It can simulate diverse job tasks and daily activities.

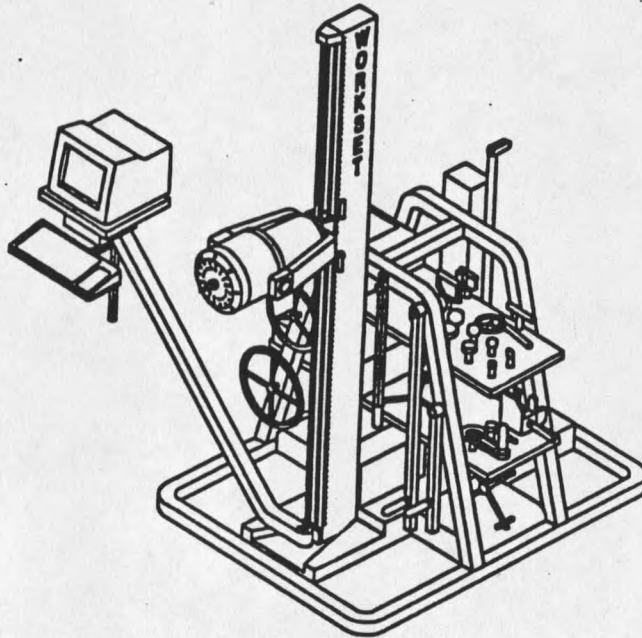


Figure 3. LIDO Workset System

This workset offers simulation, isokinetic, and isometric exercise types with concentric, eccentric, and continuous passive motion modes. These modes, plus the simulation functions of ramp up, ramp down, ramp up/down, and breakaway, provide various biomechanical models for real-world situations. There are high torque and low torque tool attachments.

Dynamic torque can be set as high as 120 ft-lb (162Nm) and static torque can be set to 150 ft-lb (202.5Nm) to allow practical testing of maximum strength of strong subjects. Similarly, weak subjects can also be tested and rehabilitated because the workset allows measurements as small as 4 in-oz with 2 in-oz resolution.

The workset has the capability of generating full documentation of subject performance including average and peak power or torque, average work, total work, and average range of motion. It also calculates the coefficient of variation and fatigue index that can help assess the subject's effort. Bilateral summary reports and progress reports provide side-to-side and test-to-test comparison information.

This equipment was used in this study to simulate the sheet metal shearing operations. The subjects, after performing lifting and carrying operations, performed simulated sheet metal shearing operations at a representative torque value of 4.16 Kg-m (30 ft-lb) for 4 or 2 cycles corresponding to the frequency of handling of 2 or 4 per

minute and went back to repeat the cycle. The energy consumed and power required to perform the operation are given by the output from the system computer.

Polar Vantage XL Heart Rate Monitor

The monitor (Fig. 4), manufactured by Polar USA, Inc., consists of a chest band, in combination with a sensor/transmitter, which, when strapped around the subject's chest, transmits the heart rate of the subject during workouts to the wrist monitor. The wrist monitor displays the heart rate at any particular moment and also has the capability of storing the heart rate data at predetermined intervals. The three intervals provided in the monitor are 5 seconds, 15 seconds and 60 seconds. If the heart rate is required at any desired time it can be instantly read from the monitor screen.

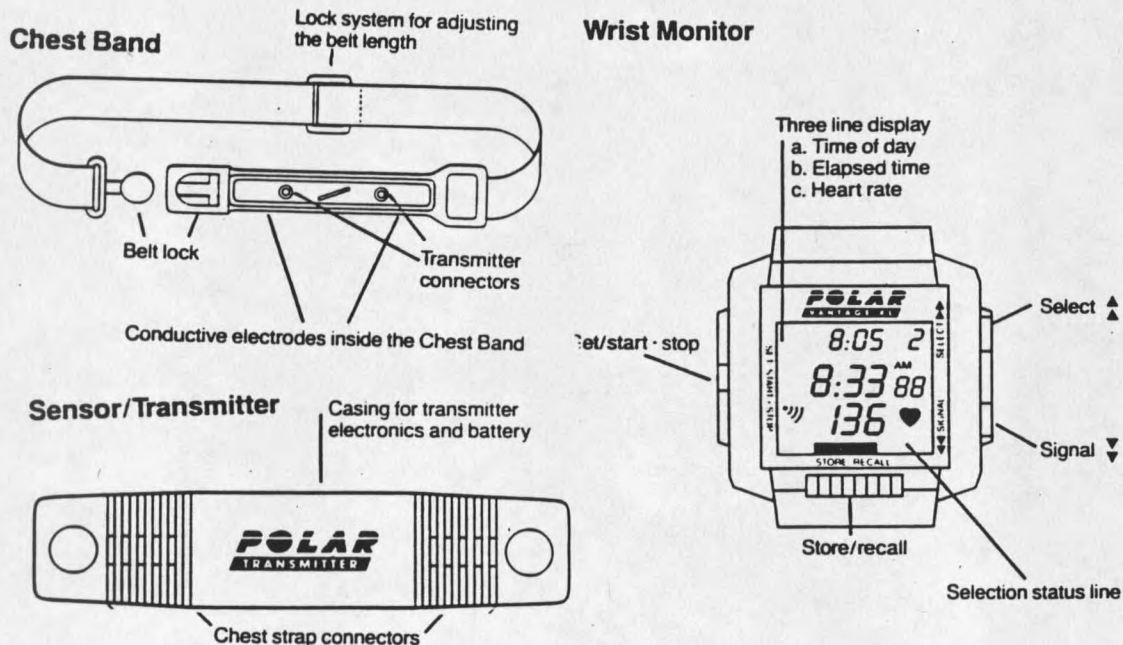


Figure 4. Polar Heart Rate Monitor Components

The heart rate monitor was used to measure the heart rate of the subjects during each of the experiments. The increase in heart rate during an experiment over resting heart rate value was used to estimate the energy expended (1 work kcal/minute \equiv 10 work pulse) during the experiment.

Anthropometric Measurement Kit

"TTM" Martin's Human Body Measuring Kit is a set of measurement instruments designed for making objective and quantitative measurements on the sizes and forms of various parts of the human body.

The kit essentially consists of instruments for measurement on distances in straight lines, on curves and circumferences, on thickness, on weight, angle, volume and center of gravity. The kit was used in the study for measuring the body height, knuckle height, and shoulder height of the subjects.

Frequency Counter

This is a device which, when set to a required frequency, will signal the subject, through an electronically produced auditory signal, to start the experiment. This eliminates the possible human error in reading the clock and signalling the subject to start the experiment. This device was used in the study to control the frequencies of handling of various tasks.

Familiarization Period

The subjects were familiarized with the experimental conditions and procedures. The objective of the familiarization period was to: (1) allow the subjects to become familiar with the use of equipment; (2) train the subjects in the method of psychophysical adjustment; (3) tone the forearm and shoulder muscle groups by performing the simulated sheet metal shearing tasks; and (4) increase cooperation and understanding between subject and the experimenter. The familiarization period lasted for one hour and included screening and introduction session and one training session.

Procedure

Required anthropometric measurements; stature, knuckle height and shoulder height and physiological data for each subject were collected. The MAWOL for each of the subjects was determined using psychophysical methodology. In order to make sure that each subject received the same instructions for the experiment, written as well as oral instructions were provided.

Psychophysical Measurement

The following experiments were conducted to collect various psychophysical data required for the determination of MAWOL:

Lifting: A vertical distance of lift of 76 cm from the floor (floor to knuckle) was used as height of lift for frequencies of 2 and 4 lifts per minute for the simulated lifting activity. Frequency for the experiment was controlled by a frequency counter device. For each frequency, one experiment, starting with heavy or light load depending upon a randomization procedure was conducted. The experiment consisted of two bouts. The first was an adjustment bout lasting 20 minutes and the next was a steady-state bout lasting 5 minutes. During the course of the adjustment bout, the subjects were told to lift a tote box (54 cm long, i.e., distance between two hands; 39 cm wide, i.e., distance along the sagittal plane) with handles, at predetermined frequency and adjust the load in the box (increase or decrease from the initial load depending on whether the initial load was light or heavy), until they felt confident of handling the load for a period of 8 hrs, with the provision of normal breaks during the shift work, without feeling unduly strained or overexerted or overexhausted. With the load adjusted in 20 minutes, the subjects were told to continue lifting for 5 more minutes. The oxygen consumption and heart rate measurements were taken during the experiment. The order of performing the operation was randomized. The final adjusted values of the load for each of the two experiments were then recorded as the maximum acceptable weight of handling for the experiment for the frequency at which the experiment was conducted.

Carrying: Two frequencies of carrying 2 and 4 per minute to a distance of 210 cm were utilized. The subjects picked up tote box (the same box used in the lifting experiment) containing lead shots from a height of 76 cm, carried it to a distance of 210 cm, and placed it on a table 76 cm in height. The next cycle consisted of carrying the tote box back to its original place. There was no lifting involved in this experiment. The order of operation was randomized. Heavy or light loads were used at random as in lifting experiment, and the subjects were told to adjust load (increase or decrease according to whether the initial load was light or heavy) for a period of 20 minutes, to the value which they felt confident of handling for a period of 8 hrs without feeling unduly tired or exhausted. The subjects continued carrying the adjusted load for 5 more minutes. Thus each experiment consisted of 25 minutes (20 minutes of adjustment bout and 5 minutes of steady-state bout) for each frequency. The final adjusted load at the end of each experiment was recorded as the maximum acceptable weight of handling for the frequency of handling.

Combined Lifting and Carrying: Combined lifting and carrying tasks were simulated by combining the individual lifting and carrying experiments as previously performed at two predetermined frequencies of 2 and 4 handlings per minute. The subjects lifted a tote box (same box used in the previous experiments) from floor to a height of 76 cm, carried it to a distance of 210 cm, and placed on a table 76 cm high. The

experiment was performed for 25 minutes; 20 minutes of adjustment bout and 5 minutes of steady-state bout. The final adjusted value of the load was recorded as MAWOL. Heart rate measurements were taken during the experiment.

Simulated combined activities: The simulated combined activity consisted of lifting through a vertical distance of 76 cm (floor to knuckle), carrying at knuckle height to a distance of 210 cm, and performing shearing operation. The sequence of operations (lifting, carrying, and shearing) was performed at frequencies of 2 and 4 per minute. The shearing operation was simulated on LIDO Workset for 20 sec and 10 sec for the two frequencies of handling of 2 and 4 per minute respectively with a force of 6.82 Kg (15 lb), velocity limit of 45 degree/sec, Range of motion of 75 degrees, moment arm of 61 cm (24 in), and the axis of rotation being 137 cm (54 in) from the floor. The subjects lifted a tote box (the same box used in the previous experiments) from floor to a height of 76 cm, carried the box at that height to a distance of 210 cm, placed it on a table of 76 cm height, and performed a simulated shearing task with the set parameters on LIDO Workset and returned to the original place without the load. This cycle was repeated at predetermined frequency for 20 minutes during which they adjusted the load to MAWOL and continued to perform for 5 more minutes as in the previous experiments. Heart rate measurements were taken during this experiment.

The combined manual materials handling task simulated in the experiment is the task of shearing sheet metal sheets to different sizes required to manufacture various types of steel furniture.

The protocol for the experiment has been given in Table 2.

Table 2. Protocol of Experiments.

Task	Height of lift cm	Distance cm.	Freq. 1/min
Lifting(L)	Floor-Knuckle	76	2
Lifting(L)	Floor-Knuckle	76	4
Carrying(C)	Knuckle Height	210	2
Carrying(C)	Knuckle Height	210	4
L + C	Lift to knuckle ht. and carry	76 210	2
L + C	Lift to knuckle ht. and carry	76 210	4
L + C + S	Lift, Carry and sheet metal shearing 4.16 Kg-m (30 ft-lb)	76 210	2
L + C + S	Lift, Carry and sheet metal shearing 4.16 Kg-m (30 ft-lb)	76 210	4

Note:

L: Lifting

C: Carrying

L+C: Lifting + Carrying

L+C+S: Lifting + Carrying + sheet metal Shearing

S: 20 & 10 sec for 2 & 4 lifts/min. at a Torque of 4.16 Kg-m.
(4 cycles corresponding to 2/min and 2 cycles corresponding to 4/min.)

Physiological measurements:

During the performance of the individual lifting task, oxygen consumption and the heart rate were monitored by using a Metabolic Measurement Cart and a Heart rate monitor. These values were used for the evaluation and comparison of the energy required to perform the individual tasks as well as the combined task.

Experimental Design

A randomized block design with factorial treatment combinations with subjects as blocks and experiments as treatments was used for analyzing the data.

Randomization of the sequence of experiments for the subjects was done on the basis of the randomization table developed for the purpose (Table 3).

Table 3. Randomization Table.

Random Sequence of Experiment for Subjects

Task	No.	SUBJECT #							
		I	II	III	IV	V	VI	VII	VIII
L2	1	4	6	8	7	2	3	5	5
L4	2	3	4	2	3	5	4	6	2
C2	3	8	8	4	1	6	7	3	7
C4	4	7	2	5	4	4	5	1	3
LC2	5	2	1	1	5	1	8	2	8
LC4	6	5	3	3	2	8	6	7	1
LCS2	7	1	5	7	8	7	2	4	6
LCS4	8	6	7	6	6	3	1	8	4

Note:

L2: Lifting task at 2 handlings/minute

L4: Lifting task at 4 handlings/minute

C2: Carrying task at 2 handlings/minute

- C4: Carrying task at 4 handlings/minute
 LC2: Lifting + Carrying task at 2 handlings/minute
 LC4: Lifting + Carrying task at 4 handlings/minute
 LCS2: Combination of Lifting, Carrying, and Shearing tasks at 2 handlings/minute
 LCS4: Combination of Lifting, Carrying, and Shearing tasks at 4 handlings/minute

Tasks were assigned numbers from 1 to 8, as in the second column of Table 3. Random numbers were generated in sequence for each subject and task corresponding to the random number assigned for the subject, thus generating the sequence of tasks for each subject.

Three independent and two dependent variables were considered for the experiment. Table 4 provides information on independent, dependent, and controlled variables used in the study.

Table 4. Independent, Dependent, and Controlled Variables.

Class	Variable
Independent	<ul style="list-style-type: none"> * Subject (block) * Type of task (4 levels)(factor) * Frequency of handling (factor) (2 and 4 handling/min)
Dependent	<ul style="list-style-type: none"> * MAWOL * Steady-state heart rate (SSHR) (B/min) * Estimated energy expenditure (Kcal/min)- calculated as a function of SSHR
Controlled	<ul style="list-style-type: none"> * Population (college students) * Sex (male) * Age (college going age) * Handles (with handles) * Box size (fixed) * Lifting technique (free style) * Carrying distance (210 cm) * Height of lift (76 cm) * Environment (Temp. 20-24°C and R.H. 45-55%)

Sharp and Legg (1988) and Legg and Myles (1985) showed that alternating starting load of lift between heavy and light had no significant effect on MAWOL values determined with

psychophysical method of adjustment. Hence, the starting load was not considered as a factor in this study.

A two-way analysis of variance (ANOVA) method was used for the analysis of the data collected from the experiments.

Table 5. Experimental Design Layout for MAWOL, MHR and Estimated Energy Expenditure.

Subject (S)	<u>Task (T)</u>							
	1		2		3		4	
	<u>Frequency (F)</u>		<u>Frequency (F)</u>		<u>Frequency (F)</u>		<u>Frequency (F)</u>	
	1	2	1	2	1	2	1	2
1								
2								
3								
4								
5								
6								
7								
8								

The models for the analysis of the experimental data were:

$$\text{MAWOL}_{ijk} = \mu + T_i + F_j + TF_{ij} + S_k + \epsilon_{k(ij)}$$

$\text{SSHR}_{ijk} = \mu + T_i + F_j + TF_{ij} + S_{k(1)} + W_1 + \epsilon_{k(ij)}$, here, weight is a random factor nested in subject. But subject, not being the main effect, $S_{k(1)}$ and W_1 will be combined into a composite blocking effect S_k reducing the model to,

$$\text{SSHR}_{ijk} = \mu + T_i + F_j + TF_{ij} + S_k + \epsilon_{k(ij)}$$

for $i = 4$ (no. of tasks), $j = 2$ (no. of frequency levels), and $k = 8$ (no. of subjects).

μ = grand mean,

T_i = effect of the i th task,

F_j = effect of the j th frequency,

S_k = effect of the kth block, and

$\epsilon_{k(ij)}$ = values of independent, normally distributed random variables having zero means and common variance σ^2 .

Energy expenditure values corresponding to each task were estimated on the basis of work-pulse (MHR - Resting heart rate), 1 Kcal/min being equivalent to 10 work-pulses. Therefore, no model was necessary for estimated energy expenditure.

Hypotheses Testing:

The following hypotheses were tested for determining whether task, frequency of handling, interaction between task and frequency and blocking effect had any effect on MAWOL and MHR:

Main Effects:

$H_0: T_i = 0$ for all i ,

$H_1: T_i \neq 0$ for at least some i ,

Critical region: reject H_0 at level $\alpha = 0.05$

if $F > F_\alpha(v_1, v_2)$ where, v_1 and v_2 are degrees of freedom.

$H_0: F_j = 0$ for all j ,

$H_1: F_j \neq 0$ for at least some j ,

Critical region: reject H_0 at level $\alpha = 0.05$

if $F > F_\alpha(v_1, v_2)$ where v_1 and v_2 are degrees of freedom.

Interaction Effect:

$H_0: TF_{ij} = 0$ for all i and j ,

$H_1: TF_{ij} \neq 0$ for at least some i, j

Critical region: reject H_0 at level $\alpha = 0.05$

if $F > F_\alpha(v_1, v_2)$ where v_1 and v_2 are degrees of freedom.

Blocking Effect:

$H_0: S_k = 0$ for all k ,

$H_1: S_k \neq 0$ for at least some k ,

Critical region: reject H_0 at level $\alpha = 0.05$

if $F > F_\alpha(v_1, v_2)$ where v_1 and v_2 are degrees of freedom.

CHAPTER 5

RESULTS AND DISCUSSION

Results of various experiments conducted during the study have been presented in this chapter. Data collected from the experiments were analyzed using a statistical software package, SYSTAT, on a PC at Montana State University. Table 5 provides descriptive statistics for the subject population used in the study. The following discussion is based on the objectives of the study as stated in chapter 3 of this report.

Population Sample

Table 6 gives the descriptive statistics of the subject sample involved in the experiments related to the study. Mean values of body height, body weight, knuckle height and shoulder height measurements of the subjects were calculated. Corresponding values of anthropometric estimates for U.S. adult males (Pheasant, S., 1986 and Woodson, et al., 1992) were obtained (Table 7). Hypotheses testing concerning one mean for sample size less than 30 was performed to determine if the population mean assumed for subject sample used for the study was identical to that of the U.S. male population at large.

The following statistic was used for hypothesis testing:

$$t = \frac{\bar{X} - \mu_0}{s/\sqrt{n}}$$

where,

\bar{X} = mean of the anthropometric measures of subject sample,

μ_0 = corresponding average value for U.S. adult males,

s = standard deviation of measures of subject sample,

and n = sample size.

$H_0: \mu = \mu_0$ and

$H_1: \mu \neq \mu_0$

Critical region: Reject H_0 for level $\alpha = 0.05$

if $t > t_{0.05, (7)}$

Table 6. Descriptive Statistics for Subject Sample.

	AGE	HEIGHT	WEIGHT	KNUHT	SHOUHT
No. of Cases	8	8	8	8	8
Minimum	19	172	65.91	72	146
Maximum	27	185.42	96.36	82.5	154
Range	8	13.42	30.45	10.5	8
Mean	22	179.92	78.95	76.19	150.63
Std. Dev.	2.73	4.12	10.5	3.40	3.07

Note:
 Height was measured in cm
 Weight was measured in Kg
 KNUHT : Knuckle Height measured in cm
 SHOUHT : Shoulder Height measured in cm

The results of the test of hypotheses indicate that the body height of the subject population was significantly greater (179.9 cm vs 175.5) than the average estimated value for U.S. adult male population. Similarly, shoulder height of

the subject population was significantly higher (150.6 cm vs 144 cm) than the corresponding average, estimated value for the U.S. adult male population. This was to be expected, since shoulder height is proportionately related to the body height.

However, body weight and knuckle height of the subject population was not significantly different (78.95 kg vs 76.36 kg and 76.19 cm vs 76.5 cm) from those of U.S. adult males. Knuckle height and body weight are the two main variables in determining the lifting capacity of a person. All the tasks were performed at knuckle height, and mean knuckle height was not significantly different from that of the U.S. population. Therefore, the subject population can be assumed to be a representative of the population at large.

Table 7. Statistical Values of Anthropometric Measures.

Measure	Sample	SD(S)	Pop(μ)	t	Df	Prob
Mean Body Height (cm)	179.9	4.12	175.5	3.055	7	.018
Mean Body Weight (Kg)	78.95	10.5	76.36	.764	7	.470
Mean Knuckle Ht. (cm)	76.19	3.40	76.50	-.26	7	.802
Mean Shoulder Ht. (cm)	150.6	3.07	144.0	6.108	7	0.00

Table 8. Values of MAWOL for Subject Sample, Average U.S. Industrial Workers and t-statistic.

Measure	Sub.	Pop.	STD	t	Df	Prob.
MAWOL (Kg) for Lifting at 4/min.	17.6	22	5.9	-2.11	7	.0386
MAWOL (Kg) for Carrying at 4/min.	20	27	20	-2.54	7	.0209

Table 8 shows the values of MAWOL for the subject population and average U.S. industrial worker population (Mital, et al., 1993) and the result of t-statistic calculated to test whether there was a significant difference between the subject population and the U.S. industrial worker population at large. The average values for lifting at knuckle height and carrying at a frequency of 4/minute for U.S. industrial workers were taken for the purpose of analysis. The result of the test and quantitative values of MAWOL for the two groups show that the values for industrial workers were significantly higher than those for the subject (student) population (22 and 27 vs 17.6 and 20 for lifting and carrying respectively). The purpose of testing significance for the subject population with the population means was to check for potential bias in ergonomic results which are correlated with anthropometry. Moreover, the major objective of the research was to determine if an upper-extremity activity had any effect on MAWOL in combined manual materials handling task and not to prepare guideline or design workload. Based on all the anthropometric measures and MAWOL values for the subject population there was no reason to suspect any real bias.

Diagnostics and Residual Analysis

Before proceeding on with analysis of the collected data, residual analysis was done to see if there was any outlier in the collected data which could possibly affect the results of

analysis. Table 9 provides the summary of diagnostics test:

Table 9. Results of Diagnostics Test

Variable	Outlier(Case No.)	Measured Value	Studentized Residual
MAWOL (Kg)	12	37	2.922
	31	35	2.987
Steady-state HR (B/min.)	4	136.2	2.730
	36	87.6	-3.182
	43	136.2	4.600
Est. Energy Expenditure(Kcal/m)	43	6.12	3.329
	55	7.36	2.935

The plot of studentized residuals against estimates (Appendix D: Fig.7-9) showed that steady-state heart rate values for case 36 and 43 were outside the horizontal band within 3 units around zero. The cause of the values outside the control limits might have been recording error from the heart rate monitor or consumption, by the subject, of certain cold drinks which would elevate heart rate within certain time duration. The estimated energy value for task being dependent upon the heart rate, case 43 value for estimated energy expenditure was expected. The final analysis of the collected data was performed with the outlier values for the mean heart rate (values for case no. 36 and 43) and estimated energy expenditure (value for case no. 43) removed. Removal of outliers will not require modification to the model or additional analysis due to the lack of an interaction effect and recommendations of Milliken and Johnson (1984).

Table 10 provides the descriptive statistics of MAWOL values for the subjects as determined from the four different types of tasks performed at the two different frequencies.

Table 10. Descriptive Statistics of MAWOL (Kg) for Different Tasks

	Tasks							
	L2	L4	C2	C4	LC2	LC4	LCS2	LCS4
No. of Cases	8	8	8	8	8	8	8	8
Minimum	12	11	14.5	13	9	9.5	10	8.5
Maximum	30	28.5	38.5	37	26	24	35	24
Range	18	17.5	24	24	17	14.5	25	15.5
Mean	20.4	17.6	23.2	20	18.5	15.9	18.9	14.4
Std. Dev.	6.4	5.9	8.6	7.8	5.8	5.1	8.9	5.1

Cursory glance at the table indicates that the mean values of MAWOL is higher for lower frequencies and lower for higher frequencies.

The mean MAWOL values for combined lifting and carrying (LC_i) and combined lifting, carrying and shearing (LCS_i) tasks appear to be nearer to the value for individual lifting task (L_i).

Table 11. Descriptive Statistics for Steady-state Heart Rate (Beats/min.)

	Tasks							
	L2	L4	C2	C4	LC2	LC4	LCS2	LCS4
No. of Cases	8	8	8	8	8	8	8	8
Min.	87.8	94	78.6	87.6	77.6	77.6	79.6	91.4
Max.	125.6	136.2	136.2	136.2	116.8	144.8	137.8	144.4
Range	37.8	42.2	57.6	48.6	39.2	67.2	58.2	53
Mean	98.9	113.9	92.7	96.2	91.4	108.8	107.5	112.1
STD.	11.8	16.4	13.9	5.9	11.5	20.9	18.1	16.7

Table 12. Descriptive Statistics of Estimated Metabolic Energy Expenditure (Kcal/min.)

	Tasks							
	L2	L4	C2	C4	LC2	LC4	LCS2	LCS4
No. of Cases	8	8	8	8	8	8	8	8
Minimum	0.96	1.88	0.66	1.26	0.36	0.96	0.94	1.14
Maximum	4.22	7.42	6.12	5.42	4.88	6.88	7.36	7.34
Range	3.26	5.54	5.46	4.16	4.52	5.92	6.42	6.2
Mean	2.85	4.33	2.27	2.67	1.55	3.25	3.57	3.48
Std. Dev.	1.09	1.5	2.1	1.44	1.46	1.92	2.41	1.87

The bold figures in the shaded cells are based on the energy values obtained from metabolic cart and the rest were estimated using work-pulse values.

Note (for Tables 9,10 and 11):

L2 : Lifting at 2/min.

L4 : Lifting at 4/min.

C2 : Carrying at 2/min.

C4 : Carrying at 4/min.

LC2 : Combined Lifting and Carrying at 2/min.

LC4 : Combined Lifting and Carrying at 4/min.

LCS2: Combined Lifting, Carrying and Shearing at 2/min.

LCS4: Combined Lifting, Carrying and Shearing at 4/min.

Tables 11 and 12 provide descriptive statistics of steady-state heart rate (b/min.) and the estimated energy expenditure (Kcal/min.) during the performance of the tasks at two different frequencies of 2 and 4/min.

Figures 5 and 6 represent graphically the values of MAWOL (Kg) and work-pulse (elevation of heart rate above resting level) for different tasks at two different frequencies.

FIGURE 5

MAWOL for Different Tasks At Frequencies of 2 and 4/min.

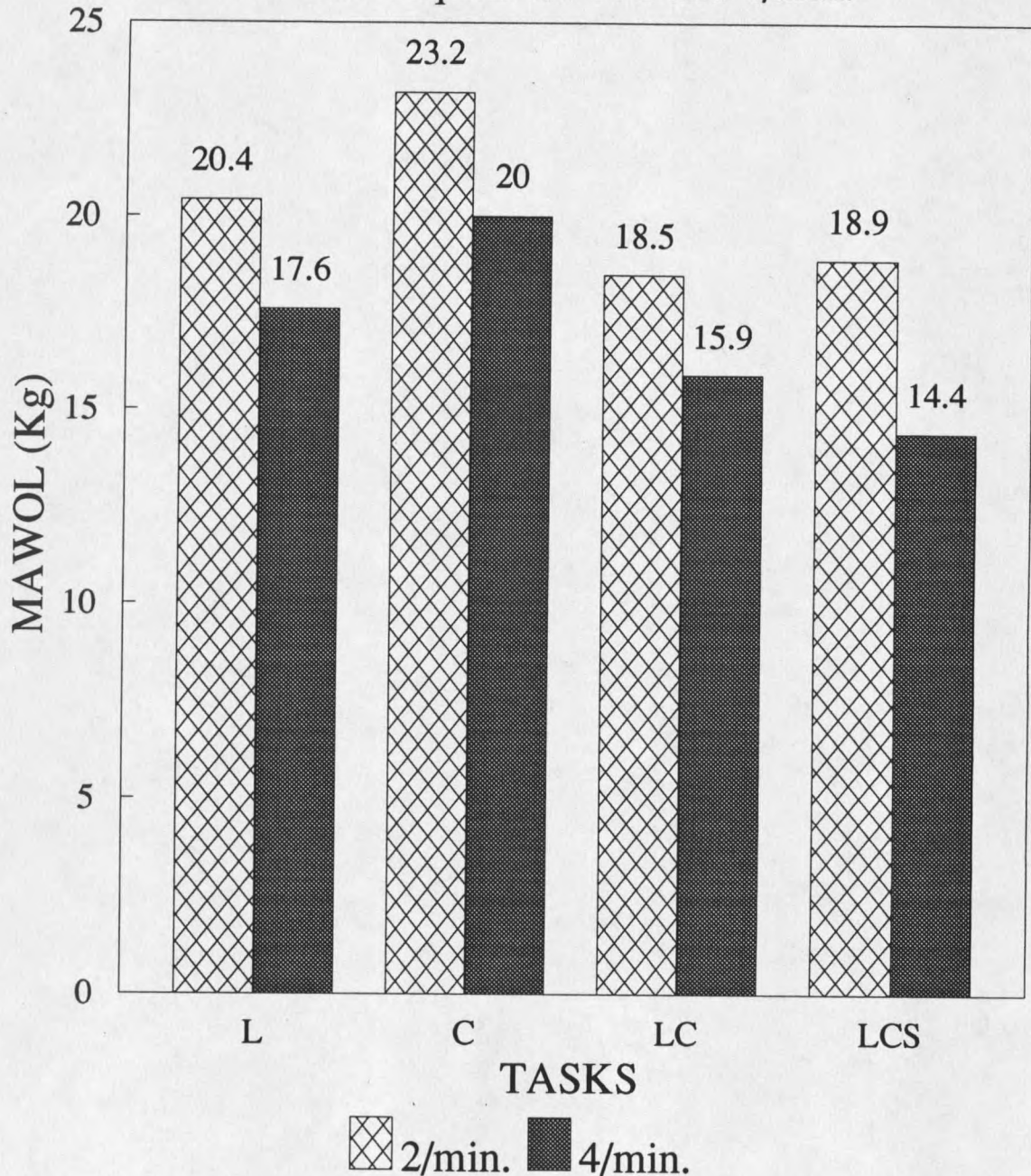
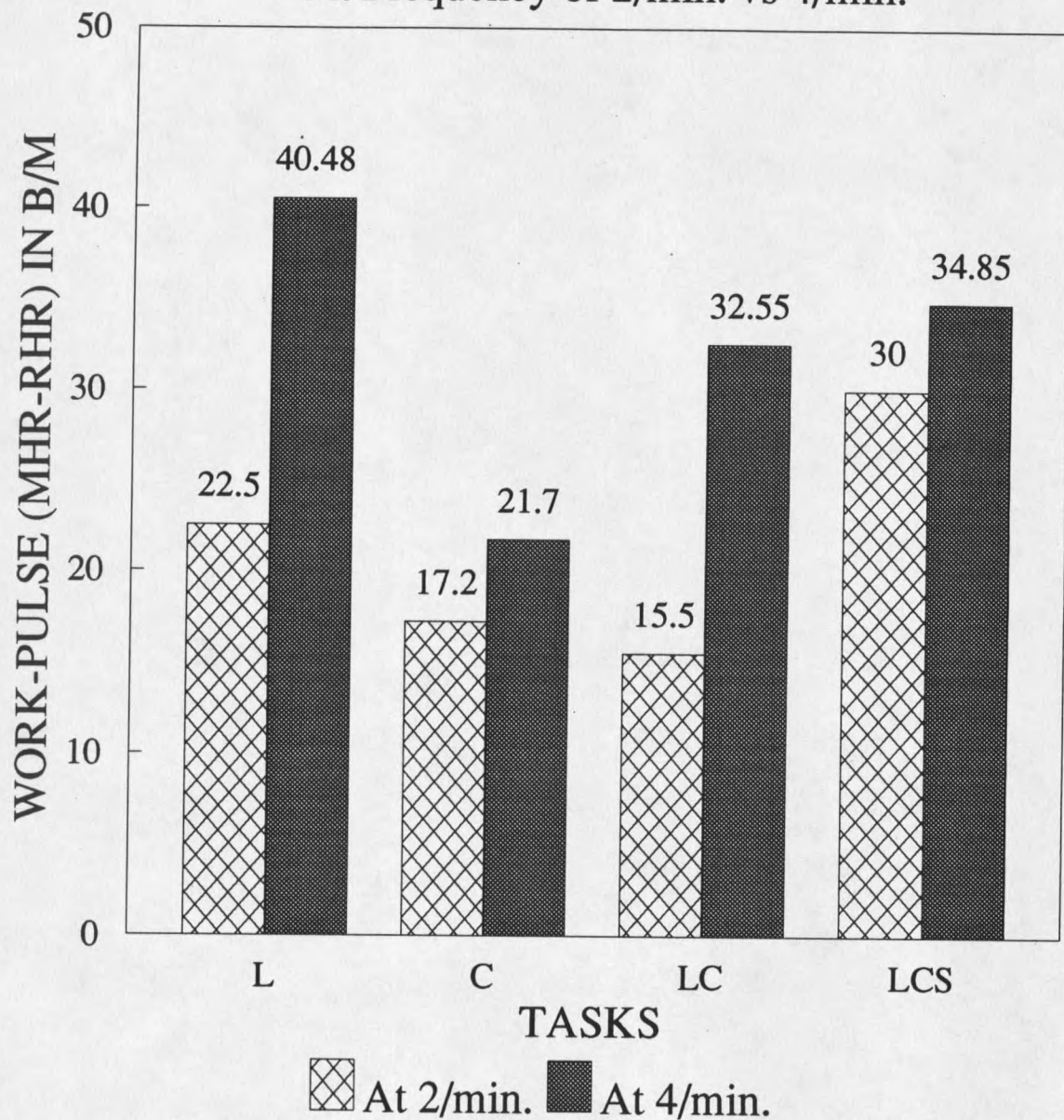
**Note:****L : Lifting Task****C : Carrying Task****LC : Combined Lifting and Carrying Task****LCS : Combined Lifting, Carrying and Shearing Task**

FIGURE 6

Work-pulse for Different Tasks At Frequency of 2/min. vs 4/min.



Note :

RHR : Resting Heart Rate in Beats/min.

MHR : Mean Heart Rate in Beats/min.

L : Lifting

C : Carrying

LC : Combined Lifting and Carrying

LCS : Combined Lifting, Carrying and Shearing

Analysis of Variance (ANOVA)

Table 13 provides ANOVA summary for MAWOL. According to the summary, BLOCK, Task and frequency of handling have significant effect on the value of MAWOL. Since random variability among the subjects is expected, a completely randomized block design with subjects as blocks was used to analyze the main effects.

Table 13. ANOVA Summary for MAWOL

Model Variables

S = Subject

T = Task

F = Frequency

MAWOL = Maximum Acceptable Weight of Lift

Categorical Variables S T F

Model MAWOL = CONSTANT + T_i + F_j + TF_{ij} + S_k + $\epsilon_{k(ij)}$

Levels Encountered

S = 8

T = 4

F = 2

Analysis of Variance

Source	SS	DF	MS	F-Ratio	P
BLOCK	2047.75	7	292.536	25.12	0.00*
Task	234.969	3	78.323	6.726	0.001*
Frequency	169	1	169	14.512	0.00*
Task*Frequency	9.156	3	3.052	0.262	0.852
Error	570.625	49	11.645		

* Statistically significant at $\alpha = 0.05$.

Task had significant effect on the value of MAWOL.

Frequency, also had significant effect on the value of MAWOL for different Task. This verifies the cursory glance inference on Table 8 and also corresponds to the results of previous researchers that MAWOL values are inversely proportional to the frequency of handling (Ayoub, 1977; Garg, et al., 1979). The interaction between task and frequency did

not have a significant effect on MAWOL.

Table 14 provides the summary of ANOVA for Steady State Heart Rate. The probability figures in the summary report indicate that Block, Task and Frequency had significant effect on Mean Heart Rate whereas Task and interaction between Task and Frequency did not have significant effect on Mean Heart Rate.

Table 14. ANOVA Summary for Steady State HR (B/min.)

Model Variables

S = Subject
T = Task
F = Frequency
SSHR = Steady State Heart Rate

Categorical Variables S T F

Model $SSHR = \text{CONSTANT} + T_i + F_j + TF_{ij} + S_k + \epsilon_{k(ij)}$

Levels Encountered

S = 8
T = 4
F = 2

Analysis of Variance

Source	SS	DF	MS	F-Ratio	P
BLOCK	8224.018	7	1174.860	10.171	0.000*
Task	1276.093	3	425.364	3.682	0.018*
Frequency	2747.760	1	2747.760	23.788	0.000*
Task * Frequency	416.722	3	138.907	1.203	0.319
Error	5429.076	47	115.512		

* Statistically significant at $\alpha = 0.05$.

Table 15. ANOVA Summary for Estimated Energy Expenditure (Kcal/min.)

Source	SS	DF	MS	F-Ratio	P
BLOCK	53.381	7	7.626	3.426	0.005*
Task	26.880	3	8.960	4.026	0.012*
Frequency	17.381	1	17.381	7.809	0.007*
Task * Frequency	7.652	3	2.551	1.146	0.340
Error	106.833	48	2.226		

* Statistically significant at $\alpha = 0.05$.

Table 15 provides the summary of ANOVA for estimated Energy consumption in Kcal/minute during the performance of various Tasks. Probability figures in the summary report show that Block, Task and Frequency had significant effect on estimated energy consumption, while Task and interaction between Task and Frequency did not have significant effect. The result corresponded with the results of the effect of independent variables upon steady-state heart rate due to the fact that energy expenditure was estimated on the basis of steady-state heart rate.

Post Hoc Tests (Tukey's Test)

Post Hoc Test of Tasks on MAWOL

Since ANOVA summary on MAWOL (Table 13) showed that task and frequency had significant effect on MAWOL, steady state heart rate and estimated energy expenditure it was necessary to determine the nature of these relationships. Tukey's test, which gives the matrix of pairwise comparison probabilities, was used to determine these relationships. Table 16 gives the result of post hoc test of task on MAWOL. Matrix of pairwise comparison probabilities and Table 9 show that values of MAWOL for combined lifting and carrying and combined lifting, carrying and shearing tasks were significantly lower than those from carrying task alone (Mean values of 18.5, 15.9 and 18.9, 14.4 vs 23.2, 20 for Frequencies of 2 and 4/min., respectively). All other Tasks were not significantly

different from each other. Since all Tasks excluding carrying involved lifting as one of the components and each of them being significantly lower than the carrying task, it is fair to conclude that lifting was not only a common factor but was also a limiting factor. This result agrees with the conclusion reached by the previous studies that for a combination of manual materials handling tasks the value of MAWOL is limited perceptually by the most stressful component in the combination (Jiang et al., 1986; Ciriello, et al., 1993 and Snook, et al., 1991).

Table 16. POST HOC Test of Task (Tukey's Test) on MAWOL

Matrix of Pairwise Comparison Probabilities

	L	C	LC	LCS
L	1.00			
C	0.152	1.00		
LC	0.459	0.004*	1.00	
LCS	0.235	0.001*	0.971	1.00

* Statistically significant at level $\alpha = 0.05$.

Note :

L = Lifting

C = Carrying

LC = Combined Lifting and Carrying

LCS = Combined Lifting, Carrying and Shearing

Since combined lifting and carrying and combined lifting, carrying and shearing were not found to be significantly different from each other (mean values of 18.5 and 15.9 vs 18.9 and 14.4 for frequencies of 2 and 4/min., respectively), the addition of upper-extremity activity in the form of shearing task did not seem to have any significant effect on MAWOL.

Similarly probability figures for the test of Frequency on MAWOL show that the values of MAWOL for the two frequencies were significantly different from each other. Table 8 quantitatively justifies this inference and also shows that the values of MAWOL were higher at lower frequencies and lower at higher frequencies (mean values of 20.4 vs 17.6 for lifting; 23.2 vs 20 for carrying; 18.5 vs 15.9 for combined lifting and carrying; and 18.9 vs 14.4 for combined lifting, carrying and shearing for frequencies of 2 and 4/min., respectively). These results agree with the conclusion of the researchers (Ayoub, 1977 and Garg, et al., 1979).

Table 17. Tukey's Test of Task on Steady-state Heart Rate
Matrix of Pairwise Comparison Probabilities

	L	C	LC	LCS
L	1.000			
C	0.215	1.000		
LC	0.343	0.986	1.000	
LCS	0.813	0.034*	0.062	1.000

* Statistically significant at level $\alpha = 0.05$.

Post Hoc Test of Task on Steady-state Heart Rate

ANOVA summary (Table 14) showed that task had significant effect on the steady-state Heart Rate. Tukey's test of Task on steady-state Heart Rate (Table 17) and Frequency show that combined lifting, carrying and shearing task was significantly higher (107.5 and 112.1 vs 92.7 and 96.2 at frequencies of 2 and 4 per minute, respectively) than the individual carrying task. Tukey's test of Frequency on steady-state Heart Rate

show that the values of heart rates at higher frequency were higher than those at lower frequencies (98.95, 92.743, 91.350, 107.525 vs 113.975, 96.2, 108.775, 112.125 for lifting, carrying, combined lifting and carrying and combined lifting, carrying and shearing tasks at frequencies of 2 and 4/min., respectively).

Post Hoc Test of Task on Estimated Energy expenditure

Table 18 shows that the carrying task had significantly lower energy expenditure than lifting task (2.27 and 2.67 vs 2.85 and 4.33 for lifting and carrying at frequencies of 2 and 4 per minute, respectively). Similarly, the values of energy expenditure were significantly lower for lower frequency than for higher frequency (2.85, 2.27, 1.55, and 3.57 vs 4.33, 2.67, 3.25, and 3.48 for the tasks at frequencies of 2 and 4 per minute, respectively).

Estimated energy expenditure values for tasks were higher for higher frequency than those at lower frequency. However, the mean energy expenditure value for combined lifting, carrying and shearing task was lower for higher frequency than that for lower frequency. The reason for this was because of the involvement of more number of cycles of shearing task at lower frequency for the combined task. Four cycles of shearing operation was simulated for a frequency of 2/min. for the combined task while only two cycles of shearing operation was simulated corresponding to a frequency of 4/min. for the combined task. This is justified by the value of power output

data (Table 18) obtained from the LIDO Workset.

Table 18. Power Output Values (Kg-m/sec.) from LIDO

Subject	LCS2	LCS4
1	5.54	4.85
2	11.36	10.67
3	5.82	4.16
4	8.17	8.45
5	14.69	5.82
6	6.10	9.97
7	10.25	9.42
8	9.00	7.48
Mean	8.87	7.6

Pearson Correlation (Pairwise)

Correlation between Frequency and MAWOL and between steady-state Heart Rate and MAWOL was found to be negative (-0.236 and -0.152, respectively) while the correlation between Frequency and Steady-state Heart Rate was found to be positive (0.291).

Comparison of Results

Due to variations in the protocol used by different researchers, it is not possible to compare the results of this study in particular to any one result from previous studies. However, the frequencies of lift and height range of lift being the same, the results of MAWOL values from the study conducted by Fernandez, et al., (1988) have been taken to compare with the results of lifting task at a frequency of 2

per minute of this study. Table 19 gives the values of MAWOL from the previous study and this study.

Table 19. MAWOL Values from Previous Study and Present Study (Kg).

	Frequency lift/min	MAWOL (Kg)	Sample Size(n)	Std. Dev. (S)
Fernandez (1988)	2	24.21 kg (53.75 lbs)	12	5.97 kg (13.14 lbs)
Present Study	2	20.4 kg	8	6.4 kg

Testing of two means

$$H_0: \mu_1 = \mu_2$$

$$H_1: \mu_1 \neq \mu_2$$

Level of significance: $\alpha = 0.05$

Criterion: reject H_0 if $t > t_{.025,18}$ or $t < -t_{.025,18}$

where,

$$t = \frac{(\bar{X}_1 - \bar{X}_2) - \delta}{\sqrt{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}} \times \sqrt{\frac{n_1 \times n_2 (n_1 + n_2 - 2)}{(n_1 + n_2)}}$$

Calculation: Substituting the corresponding values in the above equation, $t = 3.454$ which is greater than 2.101 the value corresponding to $t_{.025,18}$

Decision: Since $t = 3.454$ exceeds the value 2.101, H_0 must be rejected at level $\alpha = 0.05$. Thus MAWOL values for the two samples are not the same.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The following are the conclusions derived in terms of objectives of this study:

1. The shearing activity involving the upper-extremity is not a limiting factor on maximum acceptable weight of lift in combined manual materials handling task. At this time, there is no reason to suspect that MAWOL values would need to be adjusted for upper-extremity activities.

2. The values of maximum acceptable weight of lift for different tasks showed that frequency was an important factor in determining the MAWOL with the psychophysical approach. MAWOL values are inversely proportional to frequency of handling. This result agreed with the conclusion arrived at from previous studies (Ayoub, 1977 and Garg, et al., 1979).

3. Among the Tasks involving lifting, lifting is a limiting factor on the value of MAWOL. The value of MAWOL for all combinations examined is nearer to the value of MAWOL for individual lifting alone under the same experimental conditions. This agrees with the result of study on the

effect of combined manual materials handling activities on the capacity of workers by Jiang, et al., 1986.

4. Estimated energy expenditure varied with the change in frequency of handling. The mean value of estimated energy expenditure for individual task is more for higher frequency than for lower frequency. The exception to this, according to the result of analysis, is the values of energy consumption for combination of lifting, carrying and shearing, in which case it was lower at lower frequency. The reason for this is the involvement of four cycles of shearing activity in the combination with frequency of 2/min and 2 cycles of shearing in the combination with frequency of 4/min. Thus the combination with lower frequency had lower value for the estimated energy consumption.

5. The energy consumption for the combination of activities is not equal to the sum total of the energy required by the individual components in the combination.

Recommendations for Future Research

1. This study, being the first of its kind, used one specific type of upper-extremity task for the analysis. The results of this study may not be applicable to all types of upper-extremity activity. Hence, research should be continued to study other upper-extremity tasks and compare the results to determine if any type of locally stressful upper-extremity activity is insignificant to the value of MAWOL.

2. This study utilized the change in the heart rate above the resting heart rate level of an individual to assess the physiological stress during the performance of a task. Though the results obtained have been consistent, future studies could utilize other methods of assessing energy consumption (i.e., measurement of VO_2) and compare the results.

3. Duration of an individual task on the combination of tasks might have some effect on the value of MAWOL. Future research could study such combinations. Since this study involved an upper-extremity task with average power requirement of 8.87 Kg-m/sec, research could be done with tasks requiring more than this value.

REFERENCES

REFERENCES

- Applied Ergonomics Handbook. Published by INCREASE Science and Technology Press Ltd., INCREASE House, 32 High Street, Guildford, Surrey, England GUI 3EW.
- Ayoub, M. M. (1977). Lifting Capacity of Workers. Journal of Human Ergology, 6: , pp. 187-192.
- Ayoub, M. M., Dryden, R., McDaniel, J., Knipfer, R., and Dixon, D. (1979). Predicting Lifting Capacity. American Industrial Hygiene Association Journal, 40:12, pp. 1075-1084.
- Ayoub, M.M., Mital, A., Asfour, S.S., and Bethea, N.J. (1980). Review, Evaluation, and Comparison of Models for Predicting Lifting Capacity. Human Factors, 22:3, pp. 257-269.
- Ayoub, M.M., Mital, A., Bakken, G.M., Asfour, S.S., and Bethea, N.J. (1980). Development of Strength and Capacity Norms for Manual Materials Handling Activities: The State of Art. Human Factors, 22:3, pp. 271-283.
- Ayoub, M.M., and Selan, J.L. (1983). An Ergonomic Approach for the Design of Manual Materials-Handling Tasks. Human Factors, 25:5, pp. 507-515.
- Ayoub, M.M. (1987). The Problem of Manual Materials Handling. Trends in Ergonomics/Human Factors IV, S.S. Asfour (Editor), Elsevier Science Publishers B.V. (North - Holland), pp. 901-907.
- Chaffin, D.B., Andres, R.O., and Garg, A. (1983). Volitional Postures During Maximal Push/Pull Exertions in the Sagittal Plane. Human Factors, 25:5, pp. 541-550.
- Ciriello, V.M., Snook, S.H. (1983). A Study of Size, Distance, Height, and Frequency Effects on Manual Handling Tasks. Human Factors, 25:5, pp. 473-483.
- Ciriello, V.M., Snook, S.H. (1983). A Study of Size, Distance, Height, and Frequency Effects on Manual Handling Tasks. Human Factors, 25:5, pp. 473-483.

- Ciriello, V.M., Snook, S.H., Blick, A.C. and Wilkinson, P.L. (1990). The Effect of Task Duration on Psychophysically-determined Maximum Acceptable Weights and Forces. Ergonomics, 33:2, pp. 187-200.
- Ciriello, V.M., Snook, S.H., and Hughes, G.J. (1993). Further Studies of Psychophysically Determined Maximum Acceptable Weights and Forces. Human Factors, 35:1, pp. 175-186.
- Clark, T. S., and Corlett, E. N. (1984). The Ergonomics of Workplaces and Machines: A Design Manual. Taylor & Francis, London and Philadelphia.
- Drury, C.G., and Pizatella, T. (1983). Hand Placement in Manual Materials Handling. Human Factors, 25:5, pp. 551-562.
- Drury, C.G., Deeb, J.M., Hartman, B., Wolley, S., Drury, C.E., and Gallagher, S. (1989). Symmetric and Asymmetric Manual Materials Handling- Part 1: Physiology and Psychophysics. Ergonomics, 32:5, pp. 467-489.
- Dutta, S.P., and Taboun, S. (1989). Developing Norms for Manual carrying Tasks using Mechanical Efficiency as the Optimization criterion. Ergonomics, 32:8, pp. 919-943.
- Eastman Kodak Company (1986). Ergonomic Design for People at Work. Eastman Kodak Company, Ergonomics Group, Health and Environment Laboratories. Van Nostrand Reinhold Company, New York.
- Fernandez, J. E. (1986). Psychophysical Lifting Capacity over Extended Periods. Unpublished Ph.D. Dissertation, Texas Tech University, Lubbock, TX.
- Fernandez, J. E. (1988). The Psychophysical Approach: The valid Measure of Lifting Capacity. Trends in Ergonomics/Human Factors V. pp. 837-845.
- Gallagher, S., and Unger, R. L. (1990). Lifting in Four Restricted Lifting Conditions: Psychophysical, Physiological and Biomechanical Effects of Lifting in Stooped and Kneeling Postures. Applied Ergonomics, 21:3, pp. 237-245.
- Gallagher, S. (1991). Acceptable Weights and Physiological Costs of Performing Combined Manual Materials Handling Tasks in Restricted Postures. Ergonomics, 34:7, pp. 939-952.

- Garg, A., and Saxena, U. (1979). Effects of Lifting Frequency and Technique on Physical Fatigue with Special Reference to Psychophysical Methodology and Metabolic Rate. American Industrial Hygiene Association Journal, 40:4, pp. 894-903.
- Garg, A., and Saxena, U. (1980). Container Characteristics and Maximum Acceptable Weight of Lift. Human Factors, 22:4, pp. 487-495.
- Garg, A., and Ayoub, M.M. (1980). What Criteria Exist for Determining How Much Load Can be Lifted Safely. Human Factors, 22:4, pp. 475-486.
- Grandjean, E. (1986). Fitting the Task to Man: An Ergonomic Approach. Taylor & Francis, London and Philadelphia.
- Hicks, C. R. (1982). Fundamental Concepts in the Design of Experiments: Third Edition. Holt, Rinehart and Winston, New York, Chicago, San Francisco.
- Jiang, B.C. (1986). Psychophysical Modelling for Combined Manual Materials-Handling Activities. Ergonomics, 29:10, pp. 1173-1190.
- Karwowski, W., and Yates, J.W. (1986). Reliability of the Psychophysical Approach to Manual Lifting of Liquids by Females. Ergonomics, 29:2, pp. 237-248.
- Kroemer, K. H. E. (1983). An Isoinertial Technique to Assess Individual Lifting Capability. Human Factors, 25:5, pp. 493-506.
- Legg, S.J. and Myles, W.S. (1985). Metabolic and Cardiovascular Cost, and Perceived Effort over an 8-hour Day When Lifting Loads Selected by the Psychophysical Method. Ergonomics, 28:1, pp. 337-343.
- Loredan: LIDO Workset II System - User's Guide.
- Marley, R.J. (1990). The Effect of Frequency upon Physical Work Capacity for Lifting Tasks. Ph.D. Dissertation, Wichita State University.
- Miller, I., Freund, J. E., and Johnson, R. A. (1990). Probability and Statistics for Engineers, Fourth Edition. Prentice Hall/ Englewood Cliffs, New Jersey.
- Milliken, G.A. and Johnson, D.E. (1984). Analysis of Messy Data. Van Nostrand Reinhold Company, New York.

- Mital, A., and Ayoub, M.M. (1980). Modeling of Isometric Strength and Lifting Capacity. Human Factors, 22:3, pp. 285-290.
- Mital, A., and Manivasagan, I. (1983). Maximum Acceptable Weight of Lift as a Function of Material Density, Center of Gravity Location, Hand Preference, and Frequency. Human Factors, 25:1, pp. 33-42.
- Mital, A. (1983). The Psychophysical Approach in Manual Lifting- A Verification Study. Human Factors, 25:5, pp. 485-491.
- Mital, A. (1984). Comprehensive Maximum Acceptable Weight of Lift Database for Regular 8-Hour Work shifts. Ergonomics, 27:11, pp. 1127-1138.
- Mital, A., Nicholson, A.S., and Ayoub, M.M. (1993). A Guide to Manual Materials Handling. Taylor and Francis, London, Washington D.C.
- Morrissey, S.J., and Liou, Y.H. (1988). Maximum Acceptable Weights in Load Carriage. Ergonomics, 31:2, pp. 217-226.
- Nicholson, A.S. (1989). A Comparative Study of Methods for Establishing Load Handling Capabilities. Ergonomics, 32:9, pp. 1125-1144.
- NIOSH (1976). Report on International Symposium on Safety in Manual Materials Handling. State University of New York at Buffalo, July 18-20, 1976. US Department of Health, Education and Welfare, Public Health Service, Center for Disease Control, NIOSH.
- NIOSH Technical Report (1981). Work Practices Guide to Manual Lifting. U.S. Dept. of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health.
- Pheasant, S. (1986). Bodyspace: Anthropometry, Ergonomics and Design. Taylor & Francis, Philadelphia.
- Polar Vantage XL: Heart Rate Monitor - User's Instruction Manual.
- Sensormedics: 2900 Metabolic Measurement Cart - Operator's Manual.
- Sharp, M.A. and Legg S.J. (1988). Effects of Psychophysical Lifting Training on Maximal Repetitive Lifting Capacity. American Industrial Hygiene Association Journal, 49:12,

pp. 639-644.

Singleton, W. T. (1972). Introduction to Ergonomics. World Health Organization, Geneva.

Smith, J. L., and Jiang, B. C. (1984). A Manual Materials Handling Study of Bag Lifting. American Industrial Hygiene Association Journal, 45:8, pp. 505-508.

Snook, S. H., Irvine, C. H., and Bass, S. F. (1970). Maximum Weights and Work Loads Acceptable to Male Industrial Workers: A Study of Lifting, Lowering, Pushing, Pulling, Carrying, and Walking Tasks. American Industrial Hygiene Association Journal, 31, pp. 579-586.

Snook, S.H. (1978). The Design of Manual Handling Tasks. Ergonomics, 21:12, pp. 963-985.

Snook, S.H. (1985). Psychophysical Considerations in Permissible Loads. Ergonomics, 28:1, pp. 327-330.

Snook, S.H., Ciriello, V.M. (1991). The Design of Manual Handling Tasks: Revised Tables of Maximum Acceptable Weights and Forces. Human Factors, 34:9, pp. 1197-1213.

Stevenson, J.M., Andrew, G.M., Bryant, Greenhorn, D.R., and Thomson, J.M. (1989). Isoinertial Tests to Predict Lifting Performance. Ergonomics, 32:2, pp. 157-166.

Taboun, S. M., and Dutta, S. P. (1989). Energy Cost Models for Combined Lifting and Carrying Tasks. International Journal of Industrial Ergonomics, Elsevier Science Publishers B.V., Amsterdam, pp. 1-17.

Woodson, W. E., Tillman, B., and Tillman, P. (1992). Human Factors Design Handbook. McGraw-Hill, Inc.

APPENDICES

APPENDIX A
PRELIMINARY FORMS

**SUBJECT CONSENT FORM
FOR
PARTICIPATION IN HUMAN RESEARCH**

You are invited to participate in a study titled "Evaluation of the Effect of Upper Extremity Activities on the Maximum Acceptable Weight of Lift of a Combined Manual Materials Handling Task." This study will examine the use of a subjective method (the psychophysical approach) to determine the acceptable limits of weight handling for a combination of manual materials handling (MMH) tasks as often observed in the industries. The results of the study are expected to aid industrial engineers in determining the maximum limits of load handling for any MMH task which, ultimately, will lead to reduced risk of back injury due to unsafe and excessive load handling.

If you decide to participate, you will be required to perform simulated lifting, carrying, and combination of lifting, carrying and bending tasks. Beginning with an unknown weight of load, you will keep adjusting the load (increasing or decreasing) till you feel confident of handling the load for an extended period of 8 hours without feeling unduly stressed, overheated or overexhausted. Two frequencies of handling will be used and each of the session will last for 25 minutes. Including orientation and familiarization sessions, you will be expected to participate for a total of about 5 hours of observations spread over a maximum of 8 days.

Depending upon the stage of experimentation, further information will be collected. These variables include anthropometric measures such as body height, body weight, knuckle height etc. During performance of the simulated tasks, measures of heart rate and oxygen consumption may be monitored.

Because these tasks are simulated using a non-functional tool, and the dependent physiological measures taken are non-invasive, you should not experience any unusual discomfort nor risk of injury resulting from the equipment or procedures. Because the tasks involve the musculature of the upper extremities, however, you may experience some minor soreness in these muscles and/or stiffness in the involved joints. The I&ME Department of Montana State University cannot provide compensation for such conditions or any other health problems that might arise as a result of this experiment.

You have voluntarily accepted to participate in the experiment and hence, will not be monetarily compensated for your effort. Since your participation is completely voluntary, you may choose to withdraw from participation at any time and for whatever reason. Such a withdrawal will not affect your relationship, if any, with the I&ME Dept. or with Montana State University. All information obtained during this study by which you could be identified will be held in strict confidence.

If at any time you have questions regarding this research, you may contact either the student assistant or Dr. Robert Marley, Industrial & Management Engineering Dept, 315 Robert Hall, Montana State University, Bozeman, MT 59717, (406) 994-3971.

By placing your signature below, you are indicating that you have read all of the above information and are willing to participate. You may keep a copy of this form.

Signature of Participant

Date

Dr. Robert J. Marley
(or authorized assistant)

Date

Form II

Instruction of Psychophysical Approach for Subjects:

The objective of this study is to determine the weight-handling ability of individuals in a representative work situation. This is an experiment to find reasonable quantities that normal healthy persons can handle under different manual materials handling activities at two and four handling per minute. These activities are: lift from floor to knuckle height (L); carry for 2.1 m (C); L and C; L and C and bending activity for 20 seconds at 2 handling per minute and for 10 seconds at 4 handling per minute.

THIS IS NOT A TEST TO DETERMINE YOUR MAXIMUM WEIGHT-LIFTING CAPACITY. I repeat, THIS IS NOT A TEST TO DETERMINE YOUR MAXIMUM WEIGHT-LIFTING CAPACITY. Rather, it is a study to find reasonable quantities - I repeat, reasonable quantities - that individuals can handle repetitively under the specified conditions.

We want you to imagine that you are working in a steel furniture factory during a normal working day, getting paid for the amount of work that you do. In other words, the more work you do the more money you make. You are expected to work continuously at least 30 minutes, as hard as you can, without straining yourself or without becoming unusually tired, weakened, overheated or out of breath.

ONLY YOU WILL ADJUST THE WORKLOAD. If you feel that you can work harder without getting overloaded, add more weight to the box. If you feel you are working too hard and could not keep up the rate for half hour, you should remove some weight from the box. Remember, only you will adjust this workload.

DO NOT BE AFRAID TO MAKE ADJUSTMENTS. You have to make enough adjustments so that you get a good feeling for what is too heavy and what is too light. You can never make too many adjustments, but you can make too few.

REMEMBER....THIS IS NOT A CONTEST. NOT EVERYONE IS EXPECTED TO DO THE SAME AMOUNT OF WORK. WE WANT YOUR JUDGEMENT ON HOW HARD YOU CAN WORK WITHOUT BECOMING UNUSUALLY TIRED. TAKE IT EASY.

Remember to adjust the weight, when necessary, so that the box represents the maximum weight that you would be willing to handle at this pace, height and distance.

APPENDIX B
DATA COLLECTION FORMS

Form I : Physiological data of the subjects.

Date:		Time:	
Name of the Subject :		Subject # :	
Age (Years) :			
Body Weight (Kg) :			
Height (cm) :			
Shoulder Height (cm):			
Knuckle Height (cm):			
Knee Height (cm) :			

Form II : MAWOL for Lifting Task

Subject #	MAWOL (kg)	Oxygen Consumption (l/min)	HR max	Date	Time
1					
2					
3					
4					
5					
6					
7					
8					

Form III : MAWOL for Carrying Task

Carrying Height from the floor (cm) :
 Range of Carry (cm) :
 Frequency of Handling :

Subject #	MAWOL (kg)	HR max	Date	Time
1				
2				
3				
4				
5				
6				
7				
8				

Form IV : MAWOL for Combined Lifting and Carrying Task

Height of Lift (cm) :
 Distance of Carry (cm) :
 Frequency of Handling (/min) :

Subject #	MAWOL (kg)	HR max	Date	Time
1				
2				
3				
4				
5				
6				
7				
8				

Form V : MAWOL for Combined Lifting, Carrying and Shearing Tasks

Height of Lift (cm) :
 Distance of Carry (cm) :
 Shearing Torque Applied (Kg-m) :
 Frequency of Handling (/min) :

Subject #	MAWOL (kg)	HR max	Date	Time
1				
2				
3				
4				
5				
6				
7				
8				

Form VII : Estimated Energy Expenditure for the Tasks

Subject #	Lifting (L)	Carrying (C)	L + C	L+C+S
1				
2				
3				
4				
5				
6				
7				
8				

Primary Data Collection Form

Subject #:
Age:
Body Height:
Body Weight:
Shoulder Height:
Knuckle Height:

Experiment #: 1

Date:
Resting Heart Rate(RHR):
Mean Heart Rate(last 5 min.):
Oxygen Consumption(L/min.):
Energy Consumption(Kcal/min.):
MAWOL(Kg):

Time:
HR Max:

Experiment #: 2

Date:
Resting Heart Rate(RHR):
Mean Heart Rate(last 5 min.):
Oxygen Consumption(L/min.):
Energy Consumption(Kcal/min.):
MAWOL(Kg):

Time:
HR Max:

Experiment #: 3

Date:
Resting Heart Rate(RHR):
Mean Heart Rate(last 5 min.):
Energy Consumption(Kcal/min.):
MAWOL(Kg):

Time:
HR Max:

Experiment #: 4

Date:
Resting Heart Rate(RHR):
Mean Heart Rate(last 5 min.):
Energy Consumption(Kcal/min.):
MAWOL(Kg)

Time:
HR Max:

Experiment #: 5

Date:
Resting Heart Rate(RHR):
Mean Heart Rate(last 5 min.):
Energy Consumption(Kcal/min.):
MAWOL(Kg):

Time:
HR Max:

Experiment #: 6

Date:

Resting Heart Rate(RHR):

Mean Heart Rate(last 5 min.):

Energy Consumption(Kcal/min.):

MAWOL(Kg):

Time:

HR Max:

Experiment #: 7

Date:

Resting Heart Rate(RHR):

Mean Heart Rate(last 5 min.):

Energy Consumption(Kcal/min.):

MAWOL(Kg):

Time:

HR Max:

Experiment #: 8

Date:

Resting Heart Rate(RHR):

Mean Heart Rate(last 5 min.):

Energy Consumption(Kcal/min.):

MAWOL(Kg):

Time:

HR Max:

APPENDIX C

RAW DATA

Table 20. Raw Data

SUBJECT	TASK	FREQUENC	MAWOL	SSHR	ENERGY
1	1	1	12	90	3
1	1	2	11	94	3.982
1	2	1	17	89.4	0.84
1	2	2	16	136.2	5.42
1	3	1	9	91	1.3
1	3	2	9.5	96.2	2.22
1	4	1	11.5	105	2.6
1	4	2	8.5	118.6	3.96
2	1	1	30	94.4	3.194
2	1	2	28.5	125	4.186
2	2	1	38.5	90	1.2
2	2	2	37	100	4.2
2	3	1	22.5	95	2.1
2	3	2	22	144.8	6.88
2	4	1	25	127.6	4.56
2	4	2	16	115	3.9
3	1	1	22.5	95.4	3.35
3	1	2	20	110.6	5.408
3	2	1	25	87.8	0.68
3	2	2	22.5	99.2	1.72
3	3	1	26	86.8	1.48
3	3	2	17	120.2	3.52
3	4	1	25.5	94.4	0.94
3	4	2	15	91.4	1.14
4	1	1	27.5	97.2	4.216
4	1	2	22.5	97.2	3.64
4	2	1	33.5	78.6	0.66
4	2	2	23.5	89	1.6
4	3	1	25.5	85.8	0.78
4	3	2	24	100.6	2.26
4	4	1	35	106.6	2.26
4	4	2	24	110.6	2.66
5	1	1	17.5	125.6	1.542
5	1	2	18	136.2	7.42
5	2	1	17.5	123	4.9
5	2	2	15.5	87.6	1.26

Table 20. (Contd.)

5	3	1	17	116.8	4.88
5	3	2	16	124.4	4.94
5	4	1	12	137.8	6.68
5	4	2	10.5	144.4	7.34
6	1	1	19	98	2.816
6	1	2	15.5	102.6	4.322
6	2	1	20	136.2	6.12
6	2	2	18	98.8	2.38
6	3	1	16.5	77.6	0.36
6	3	2	14	77.6	0.96
6	4	1	10	79.6	1.16
6	4	2	11	94	1.9
7	1	1	13	103.2	0.956
7	1	2	12	135	1.876
7	2	1	14.5	90.2	1.42
7	2	2	13	103.4	2.84
7	3	1	16	91.6	1.06
7	3	2	10.5	110.8	3.48
7	4	1	13	103.4	7.36
7	4	2	12	118.6	4
8	1	1	21.5	87.8	3.692
8	1	2	13.5	111.2	3.788
8	2	1	19.5	90.2	2.32
8	2	2	14.5	95.4	1.94
8	3	1	15.5	86.2	0.42
8	3	2	14.5	95.6	1.76
8	4	1	19.5	105.8	2.98
8	4	2	18.5	104.4	2.94

Table 21. Resting Heart Rate Values (Beats/minute) for Different Tasks at Two Frequencies.

Sub.	L2	L4	C2	C4	LC2	LC4	LCS2	LCS4
1.	73	74	81	82	78	74	79	79
2.	73	75	78	58	74	76	82	76
3.	86	82	81	82	72	85	85	80
4.	78	72	72	73	78	78	84	84
5.	74	62	74	75	68	75	71	71
6.	76	75	75	75	74	68	68	75
7.	76	72	76	75	81	76	75	78
8.	75	76	67	76	82	78	76	75

Table 22. RANDOM NUMBER TABLE FOR LOAD

Task	<u>SUBJECT #</u>							
	1	2	3	4	5	6	7	8
L2	0.12	0.37	0.34	0.46	0.67	0.71	0.79	0.75
L4	0.02	0.78	0.13	0.76	0.75	0.69	0.79	0.12
C2	0.41	0.47	0.53	0.78	0.51	0.31	0.26	0.97
C4	0.42	0.07	0.34	0.52	0.34	0.11	0.31	0.67
LC2	0.95	0.75	0.35	0.57	0.29	0.23	0.67	0.18
LC4	0.25	0.68	0.41	0.78	0.43	0.09	0.74	0.02
LCS2	0.08	0.35	0.66	0.87	0.26	0.62	0.57	0.76
LCS4	0.47	0.55	0.59	0.55	0.08	0.64	0.84	0.12

Even numbers signify HEAVY LOAD

Odd numbers signify LIGHT LOAD

Task	1	2	3	4	5	6	7	8
L2	H	L	H	H	L	L	L	L
L4	H	H	L	H	L	L	L	H
C2	L	L	L	H	L	L	H	L
C4	H	L	H	H	H	L	L	L
LC2	L	L	L	L	L	L	L	H
LC4	L	H	L	H	L	L	H	H
LCS2	H	L	H	L	H	H	L	H
LCS4	L	L	L	L	H	H	H	H

APPENDIX D

GRAPHS

FIGURE 7

Studentized Residual vs Estimate For MAWOL

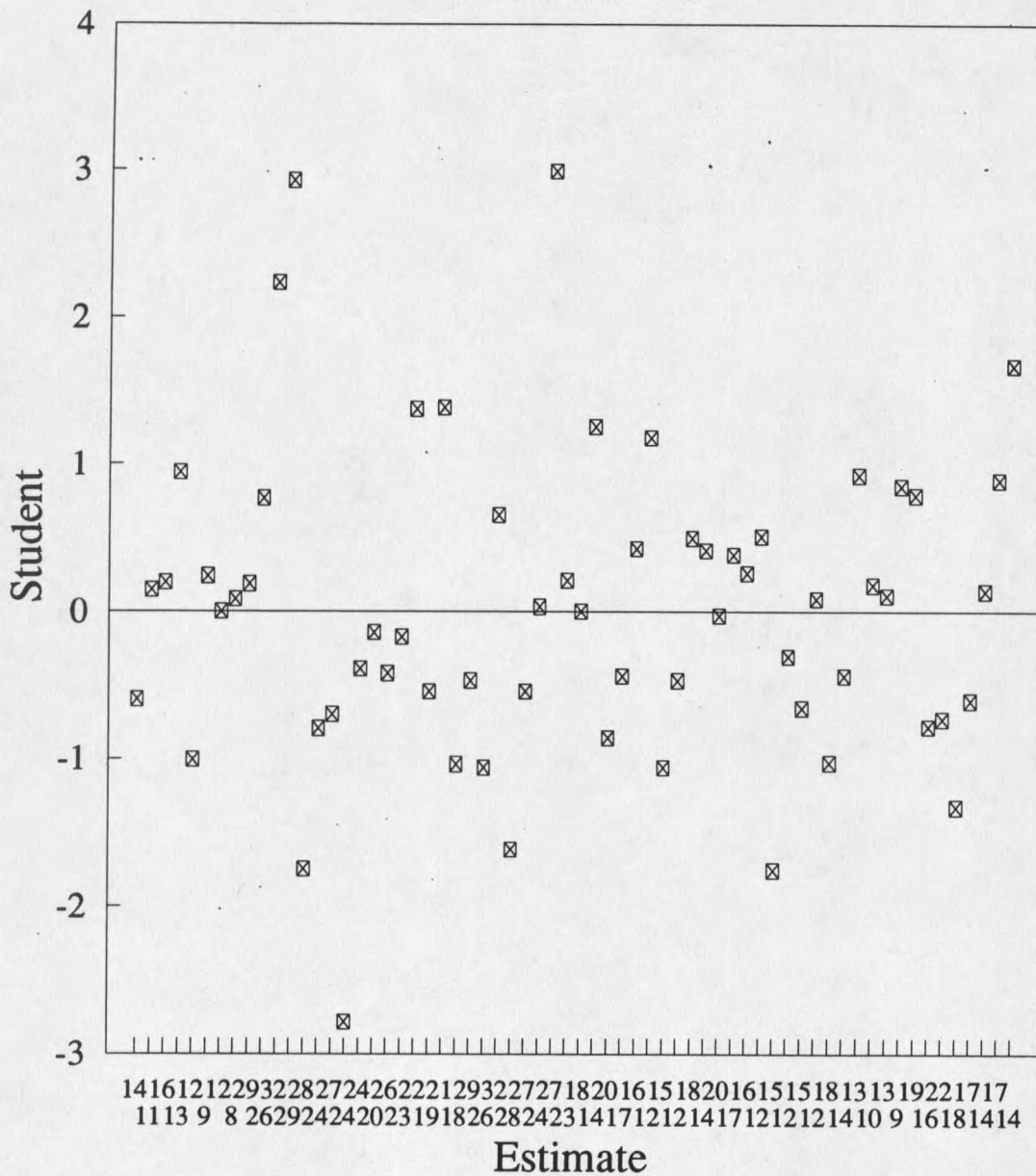
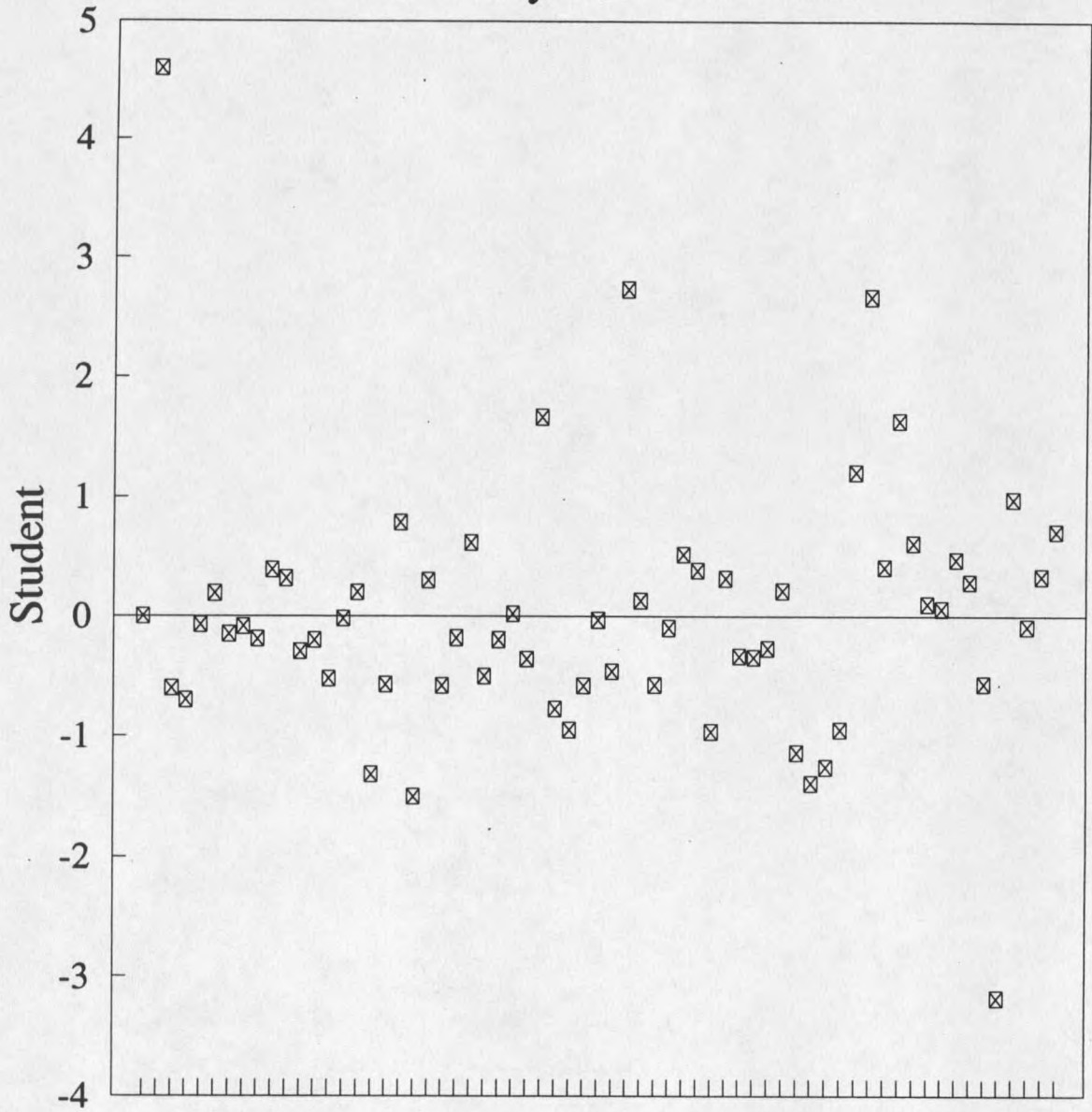


FIGURE 8

Studentized Residual vs Estimate For Steady-state Heart Rate

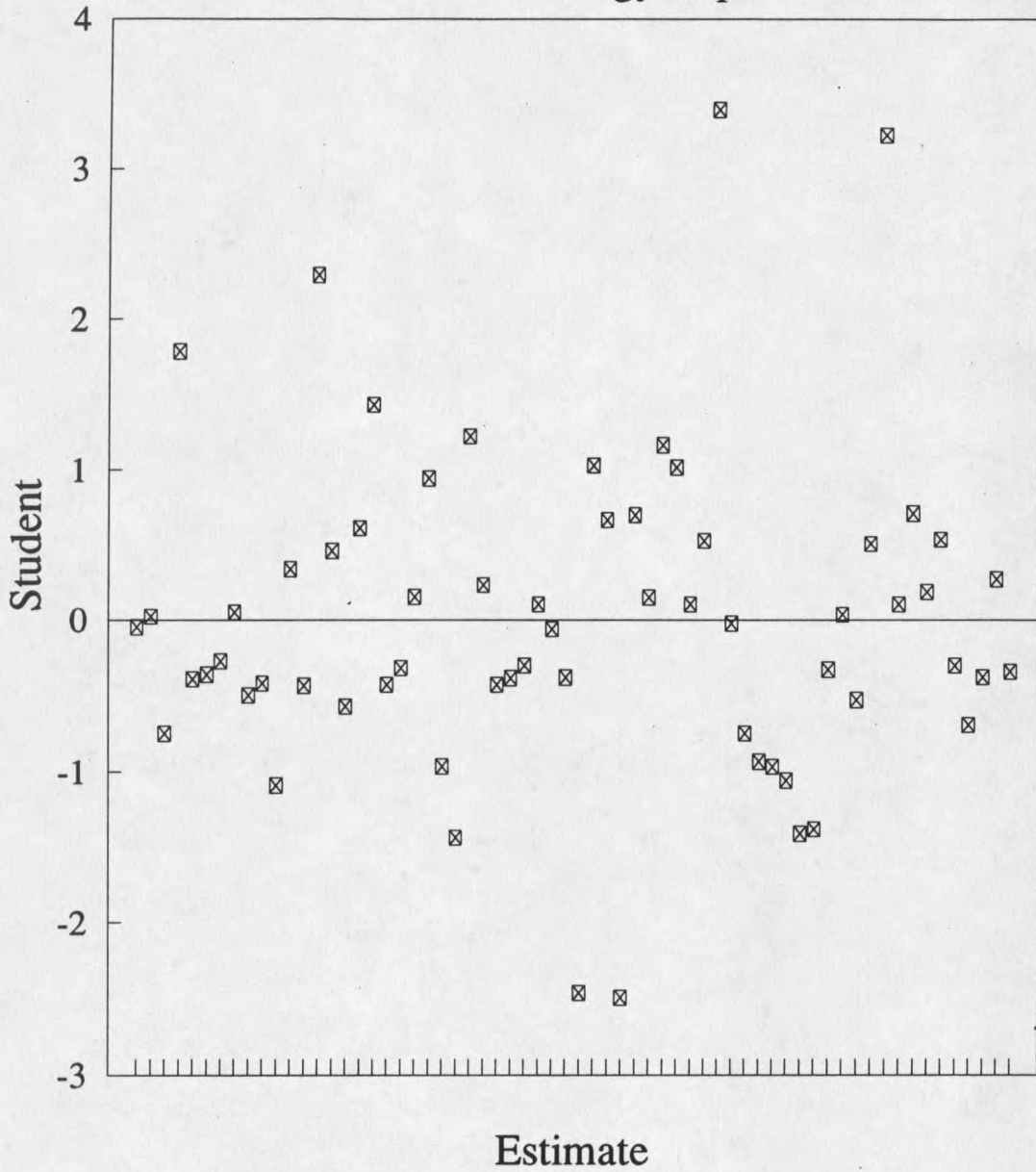


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Estimate

FIGURE 9

Studentized Residual vs Estimate For Estimated Energy Expenditure



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