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

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

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.

The major conclusion reached from the result of analysis is that the upper-extremity activity under study had no significant effect and hence, is not a limiting factor on maximum acceptable weight of lift. At this time there is no need to adjust MAWOL values for combined manual materials handling tasks involving upper-extremity.

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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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The major conclusion reached from the result of analysis is that the upper-extremity activity under study had no significant effect and hence, is not a limiting factor on maximum acceptable weight of lift. At this time there is no need to adjust MAWOL values for combined manual materials handling tasks involving upper-extremity.

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:

Predictive lift = 60 - (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-

Predicted lift = 1.40(max. isometric back st.) - 0.5(body weight).

For Table to head height-

Predicted lift = 0.5(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 = $11.93 - 1.12(\text{back st.}) + 0.16(\text{RPI})^2 + 0.005(\text{back st.})^2 - 8.81(\text{static end.})^2 - 0.1(\text{sex})(\text{Fl}) + 0.06(\text{ht})(\text{RPI}) + 0.03(\text{RPI})(\text{leg st.}) - 0.002(\text{back st.})(\text{leg st.}) - 0.03(\text{leg st.})(\text{stat. end.}) + 0.11(\text{static end.})(\text{FI})$ 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 * Ht. - 2.72867 * Stat.Ef. + 0.0209696 * RPI * Arm St. + 0.0534346 * RPI * Back St. - 2.51346 * RPI/Dynam.Ef.

Predicted Lift for female = -24.02682 + 0.19362 * RPI + 0.00607224 * Arm St. * Leg St.

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

Knuckle to Shoulder Height (Dryden, 1973):

Predicted Lift for male = 0.82766 * Chest Cir. + 0.55885 * Dyn.Ef.

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

Predicted Lift for both male and female = 24.12120 + 0.37912 * Sex * Dynam. Ef.

Shoulder to extended Reach Height (Knipfer, 1974):

Predicted Lift for male = 4.91337 + 0.19746 * Back St. - 0.01733 * Shoulder St. + 0.42917 * Age

Predicted Lift for female = 15.07131 + 0.34346 * Wt. + 0.83999 * Dynam. Ef. + 0.33545 * Forearm Circ.

Predicted Lift for both male and female = 5.225 * Sex + 0.00494 * Shoulder St. + 0.1944 * 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 68^0 to 72^0 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).

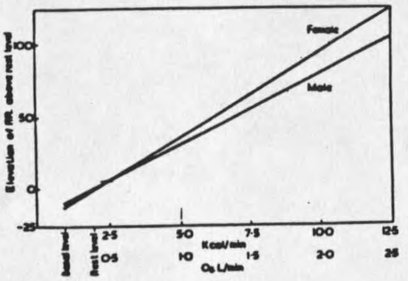

Figure 1. Relationship between Pulse Rate and Energy Expenditure.

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