PSYCHOPHYSICAL LIFTING CAPACITY OVER EXTENDED PERIODS

by

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ABSTRACT

The primary objectives of the study were:

1. Study the effects of the psychophysically determined Maximum Acceptable Weight Of Lift (MAWOL) of individuals over extended periods.

2. Study the effects of the physiological responses (oxygen consumption and heart rate) over extended periods, with the weight lifted was constant.

3. Development of prediction equations for MAWOL.

4. Comparison of lifting capacity of individuals using the psychophysical and physiological approaches.

To accomplish this a laboratory study was conducted using 12 male subjects. Following a familiarization period, the subjects performed two psychophysical lifting tasks consisting of a floor to 30 inch lift at 2 and 8 lifts/minute. The subjects lifted the MAWOL at the two frequencies for an eight hour period when: (1) MAWOL was adjusted over the eight hours, (2) MAWOL being constant. Oxygen consumption and heart rate were measured every hour for eight hours.

Results indicated that the MAWOL decreased on the average to 85.97% of MAWOL, with the decrement to 88.32% of

MAWOL at 2 lifts/ minute and 83.62% of MAWOL at 8 lifts/minute. Heart rate and oxygen consumption showed a significant increase after lunch. Heart rate significantly increased with a significant decrease in oxygen consumption between the second and first hour of work; heart rate and oxygen consumption measured in the latter hour of the 2-hour sessions of the eight hour period were lower than the previous hour. Exponential, logarithmic, power and linear models to predict MAWOL over the eight hours were developed.

Results also indicated that lifting capacities using the psychophysical approach underestimated the lifting capacities using the physiological approach at 2 lifts/minute; however, at 8 lifts/minute the lifting capacities using the psychophysical approach overestimated the lifting capacities using the physiological approach.

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CHAPTER I

INTRODUCTION

In industries where today the trend is towards automation, manual material handling (MMH) is still prevalent. This situation exists due to economic limitations, or technical and practical constraints. This study is directed towards lifting, a MMH task considered to be stressful.

Manual material handling has been recognized as the major hazard to industrial workers (NIOSH, 1981). Statistics compiled by the National Safety Council in 1973 indicated that MMH tasks constituted 23 percent of all compensatable work injuries. This amounted to 590,000 injuries and cost approximately 10.4 billion dollars. In 1980, the injuries increased to 670,000 despite improved medical care, increased automation in industry, and more extensive use of some preemployement examinations (NIOSH, 1981). From 1938 to 1965, the number of compensatable back injuries increased by 11.4 percent while the average cost increased approximately 400 percent (Snook and Ciriello, 1974). National Safety Council statistics from 1958 through 1980 depict an alarming exponential relationship between back injuries and their cost over the years.

The prevention of low back injuries in industry has traditionally been attempted by (1) careful selection of workers, (2) good training procedures in safe lifting, and (3) designing the job to fit the worker (Snook, 1978).

Various approaches have been utilized by researchers to determine operator MMH capacity. These approaches are (1) epidemiological, (2) biomechanical, (3) physiological, and (4) psychophysical.

CHAPTER II

REVIEW OF LITERATURE

A review of literature revealed that a comparison of the various approaches to assess the operator's capacity relied on data interpolation, extrapolation and adjustment, and not on experimental data collected in one single study (Garg, 1980 and Asfour, 1980).

Tasks in manual material handling can be helped by improved job design and employee placement procedures in order that job demands can be controlled to stay within individual capacities. The four primary approaches to determine lifting capacity are (1) the epidemiological approach, (2) the biomechanical approach, (3) the physiological approach, and (4) the psychophysical approach. There are three classes of variables affecting lifting capacity. These are (1) worker variables, (2) task variables, and (3) environmental variables.

This chapter reports the review of literature on the four approaches and the variables affecting lifting capacity.

Epidemiological Approach

Epidemiology is a science concerned with the identification of incidence, distribution, and potential controls for illness and injuries in a population. The factors which modify risk of injury are divided into job and personal risk factors. The characteristics of the job which contribute to risk are weight handled, size of load, and frequency of lifting. Personal risk factors include gender, age, anthropometry, lift technique, attitude, training and strength. The epidemiological approach has received infrequent use in the literature because the relationship between health problems and MMH activities is not clear, and epidemiological studies are time consuming and expensive.

Biomechanical Approach

Biomechanical models attempt to establish the physical stresses imposed on the musculoskeletal system during a lifting action. These physical stresses include reaction forces and torques on various joints of the body and compression and shear forces on the lower back (Ayoub, 1983). The ultimate goal of the biomechanical approach is to set limits on the physical stresses imposed during the lifting and then determine the load-lifting capacity based on these limits. For low frequency tasks, biomechanical models are more appropriate than physiological models. Biomechanical analyses can be divided into two classes, static and dynamic models.

Static biomechanical models analyze a static situation or assume that the movement is so slow that it can be considered as a series of static positions. Examples of static biomechanical models are found in the works of Chaffin (1969), Chaffin and Baker (1970), Martin and Chaffin (1972), Garg and Chaffin (1975), and Fish (1978).

A dynamic model estimates the forces and torques at various articulations of the body during a lifting task, with the analysis being made knowing the displacement of the body segments with respect to time. Examples of dynamic models are El-Bassoussi (1974), Park and Chaffin (1974), Tichauer (1975), Muth, et al. (1978), Smith (1980), and Smith, et al. (1982). Recently, a model was developed at Texas Tech University by Ayoub, et al. (1986) which calculates the linear and angular velocities, accelerations, forces, and torques at the center of hand, wrist, elbow, shoulder, hip, knee and ankle; along with shear and compressive forces at the L5/S1 joint.

Physiological Approach

The physiological approach may use several criteria, such as oxygen consumption, heart rate, pulmonary ventillation, blood pressure, lactic acid accumulation or percent of physical work capacity as indices of heaviness of work performed. Generally, the criterion is the energy expenditure while lifting loads. Oxygen consumption is usually measured to estimate the energy expenditure (Ayoub, et al., 1983).

Unlike the biomechanical approach, the physiological approach is applicable to highly repetitive types of lifting. Another point of difference is the effect of lifting technique. Brown (1971), and Garg and Saxena (1979) concluded that the back bent (stoop) while lifting was less physiologically fatiguing than the back straight (squat) while lifting. However, the back bent has a larger biomechanical stress than the back straight while lifting (NIOSH, 1981).

Das (1951) studied the effects of weight, frequency, height and the method of lifting on energy expenditure. He concluded that the knee bent-back straight method of lifting (leg-lift) causes more energy expenditure than the back bent-knees straight method (back lift) for lighter loads, but was conversely true for heavy loads. This was later confirmed by Asfour (1980).

Muller (1953) proposed 5 kcal/minute as the limit of energy expenditure for an 8-hour work day.

Frederik (1959) developed a predictive model to estimate the energy expenditure. The formula is:

$$E = f * a * w * c / 1000,$$

where

E = total energy expenditure/hour (kcal),

f = frequency of lift (lifts/hour),

a = vertical lifting ranges (feet),

w = weight of lift (pounds),

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

He also recommended that the energy expenditure should not be more than 3.33 kcal/minute for an average man to work all day. This model is restricted to certain ranges of lift while the consumption of energy is based on lifting as a single performance.

Michael, Hutton, and Horvath (1961) conducted experiments on the cycle ergometer and the treadmill at various loads and speeds for a continuous 8-hour period. They concluded that 35 percent of the maximum aerobic capacity (PWC) was the limit of work that could be performed without undue fatigue.

Bink (1962) stated that the physical work capacity depends on (1) the capacity of oxygen intake, and (2) the capacity of food intake. Obtaining the mean food intake of a 35 year old man during 24 hours from the 'Food tables in the Netherlands' to be 4100 kcal, Bink developed a formula expressing physical work capacity as a linear function of the logarithm of working time, which was:

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

where

A = physical working capacity (kcal/minute),

t = working time (minute),

a = aerobic capacity (kcal/minute).

From this expression, for an 8-hour work day (480 minutes), the allowable energy expenditure for an average 35 year old man is 5.2 kcal/minute.

Brouha (1967), and Suggs and Splinters (1961) recommended that the mean heart rate should not exceed 115 beats/ minute, considering heart rate as the criterion of energy expenditure for an 8-hour day.

Astrand (1967) reported that 50 percent of VO2max determined by bicycling was the upper limit of work tolerance for an 8-hour work day. All her subjects chose between 25 and 55 percent of VO2max with a mean of 39 percent.

Aquilano (1968) studied a carton-handling job consisting of the lifting of two weights at two heights from a time-study and physiology viewpoint. Four Kcal was used as the physiological level corresponding to 128 percent performance. He concluded that the time standards, determined by a stop-watch, were unacceptable from a work physiology point of view.

Hamilton and Chase (1969) studied the effects of frequency of lift and the load on oxygen consumption and heart rate. Their results showed that increases in the load and frequency of lift causes linear increases in oxygen consumption and heart rate.

Snook and Irvine (1969) recommended a mean heart rate of 112 beats per minute for leg tasks and 99 beats per minute for arm tasks as the upper limits of energy expenditure for an 8-hour work day.

Aberg, et al. (1969) developed a model under actual work conditions in the Swedish industry. The model was based on the fact that mechanical work was connected with a change of the positional energy of a mass, a change of the velocity of a mass, a change of the compressional energy of a spring, and frictional losses. The model appeared as:

$$VO2 = BWn * k1 + BWcl * k2 + BWcl * (GCBh * k3 + GCBv * k4) + (WWP + WT) * (Lha * k5 + u * Lhc * k6 + Lvu * k8 + Lvd * k8)$$

where

VO2 = computed oxygen uptake (l/min),

BWn = body weight, naked (kg),

BWcl = body weight, with clothing (kg),

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

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

WWP = weight of work piece (kg),

WT = weight of tool (kg),

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

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

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

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

u = coefficient of friction in horizontal movement,

k1-k8 = constants.

Garg, Chaffin, and Herrin (1978) developed regression equations to predict energy expenditure for manual material handling operations. They assumed that a complex task could be divided into several sub-tasks; if the energy consumption of each sub-task was known, the summation of the energy expenditure of the respective sub-tasks would be equal to the energy expenditure of the task. Regression equations for the three different postures (i.e. stand, stoop, squat) are as follows:

Arm lift (standing position assumed)

$$E = 0.024 * BW + (0.062 * BW * (H2 - 0.81) + (3.19 * L - 0.52 * S * L) * (H2 - H1)) * F/100$$

$$\text{for } 0.81 < H1 < H2$$

Stoop lift (standing position assumed)

$$E = 0.024 * BW + (0.325 * BW * (0.81 - H1) + (1.41 * L + 0.76 * S * L) * (H2 - H1)) * F/100$$

$$\text{for } H1 < H2 < 0.81$$

Squat lift (standing position assumed)

$$E = 0.024 * BW + (0.514 * BW * (0.81 - H1) + (2.19 * L + 0.62 * S * L) * (H2 - H1)) * F/100$$

$$\text{for } H1 < H2 < 0.81$$

where

E = energy expenditure (kcal/min),

BW = body weight (kg),

H1 = the starting point of lift (m),

H2 = the ending point of lift (m),

S = gender; male is 1, female is 0,

F = frequency of lift (lifts/min),

L = weight of lift (kg).

Mital (1980) reported that oxygen consumption and heart rate increase with increases in the load of lift, frequency of lift, vertical height of lift, box width and box length. With handles on the boxes, oxygen consumption decreased slightly during lifting.

Asfour (1980) reported that oxygen consumption increases with an increase in load of lift, frequency of lift, box length and box width. He also stated that for a given fixed work output it was physiologically preferred to lift heavier loads at slower paces than lighter loads at faster paces. Asfour used stepwise linear regression techniques to develop energy cost prediction models for lifting and lowering tasks. The two models are:

For floor to 30"

VO2 = 545.7538 - 106.4477 * TA
+ F * L * L * (35002.65 - 350.58 * L) /1000000
+ 17.47 * F * L * H * WB * LB * ANG /1000000
+ 16435.22 * BW * F * F /1000000

For 30" to 50" from floor

VO2 = 371.5055 - 51.9573 * TA
+ BB * F * F * (31856.54 - 2332.8 * F) /1000000
+ 12684.91 * F * L * L /1000000
+ 12.31 * F * H * L * WB * LB * ANG /1000000

where

VO2 = oxygen consumption (ml/min),

TA = task type; TA = 1 for lifting,

TA = 2 for lowering,

BW = body weight (lbs),

F = frequency of lift (lifts/min),

L = weight of lift (inches),

H = height of lift (inches),

WB = box width (inches),

LB = box length (inches),

ANG = angle of twist; ANG = 1 for 0 degrees,

ANG = 2 for 90 degrees.

Bakken (1983) indicated that the lifting range, frequency of lift, and the interaction (range with frequency) had a significantly high effect on the subject's heart rate response during a lifting activity.

Intaranont (1983) conducted an experiment to predict anaerobic threshold (AT) for lifting tasks. No significant difference was found for AT values predicted for the two ranges of lift or lifting frequencies studied. Four regression models were presented to predict anaerobic threshold and lifting capacity.

Lifting from floor to knuckle height

AT = (471892.555 + 1.439 * WT * F * F - 3461.837 *

PB - 11.744 * WT * WT - 3771.16 * WT ** R

+ 24.964 * LBW * LBW) * 10 ** (-5)

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

Lifting from knuckle to shoulder height

AT = (157396.895 - 21.615 * WT * F - 1611.729 * PA + 2.113 * WT * WT) * 10 ** (-5)

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

where

AT = anaerobic threshold (l/min),

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

WT = body weight of a subject (lbs),

F = frequency of lift (lifts/min),

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

R = LBW / WT,

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

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

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

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

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

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

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

Mital and Shell (1984) reported that previous physiological fatigue criterion (33% PWC) leads to metabolic overloading and must be downgraded if overexertion is to be avoided. They proposed limits of 29 percent of physical work capacity (0.8 l/min) for males and 28 percent of physical work capacity (0.6 l/min) for females.

Psychophysical Approach

Psychophysics is a very old branch of psychology that is concerned with the relationship between sensations and their physical stimuli (Snook, 1978). Modern psychophysical theory (Stevens, 1960) states the strength of a sensation (S) is directly related to the intensity of its physical stimulus (I) by means of a power function:

S = k * I ** 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, e.g. for electric shock=3.5, for taste(salt)=1.3, for loudness (binaural)=0.6, and for lifting weights =1.45

Psychophysics has been applied to many practial problems in many areas (Snook, 1978). These include the scales of effective temperature, loudness, and brightness in the developing of the ratings of perceived exertion (RPE), by the USAF in lifting and by the US Army in studies of threadmill walking.

In the study of MMH tasks, the use of the psychophysical approach requires the subject to control (adjust) one of the task variables (usually the weight of the load but sometimes the frequency of lift). The subject then monitors his own feeling of exertion or fatigue and adjusts the load accordingly. Subjects are instructed to adjust their work load to the maximum amount that they can perform without strain or discomfort, without being tired, weakened, overheated, or out of breath (Asfour, 1980).

Earlier studies were undertaken by Snook and Irvine (1966, 1967, 1968, 1969), Snook, et al. (1970), McDaniel (1972), Dryden (1973), Knifer (1974), Snook and Ciriello (1974), Aghazadeh (1974), Ayoub, et al. (1976), Ayoub (1978), Asfour (1980), Bakken (1983), Mital (1983), Jiang (1984), and Mital (1985).

Previous efforts to compare the psychophysical and physiological criteria for determining safe acceptable weights have concluded that the recommendations based on the psychophysical approach are lower than the weight recommendations of the physiological approach at low frequencies, and this was conversely true at high frequencies (Garg and Ayoub, 1980). At frequencies of 4 to 6 lifts per minute, the two approaches had similiar weight recommendations; this is depicted in figure 1. This comparison relied on several different studies and on interpolation , extrapolation and adjustments.

In contrast, Mital (1985) in his study of 37 industrial male workers and 37 industrial female workers performing 36 different lifting tasks, concluded that the weight estimates based on the physiological fatigue criterion were consistently higher than psychophysical weight estimates as shown in figure 2. For males, the difference in weight estimates based on the two criteria ranged from 0.3 kg at 12 lifts per minute to 4.3 kg at 1 lift per minute; for females, the difference was 0.4 kg and 5.5 kg at these frequencies.

Mital (1983) conducted an experiment to verify the psychophysical methodology used in determining lifting capacity of workers. After a 25-minute bout where the worker estimated the weight he could lift, the worker lifted for an actual

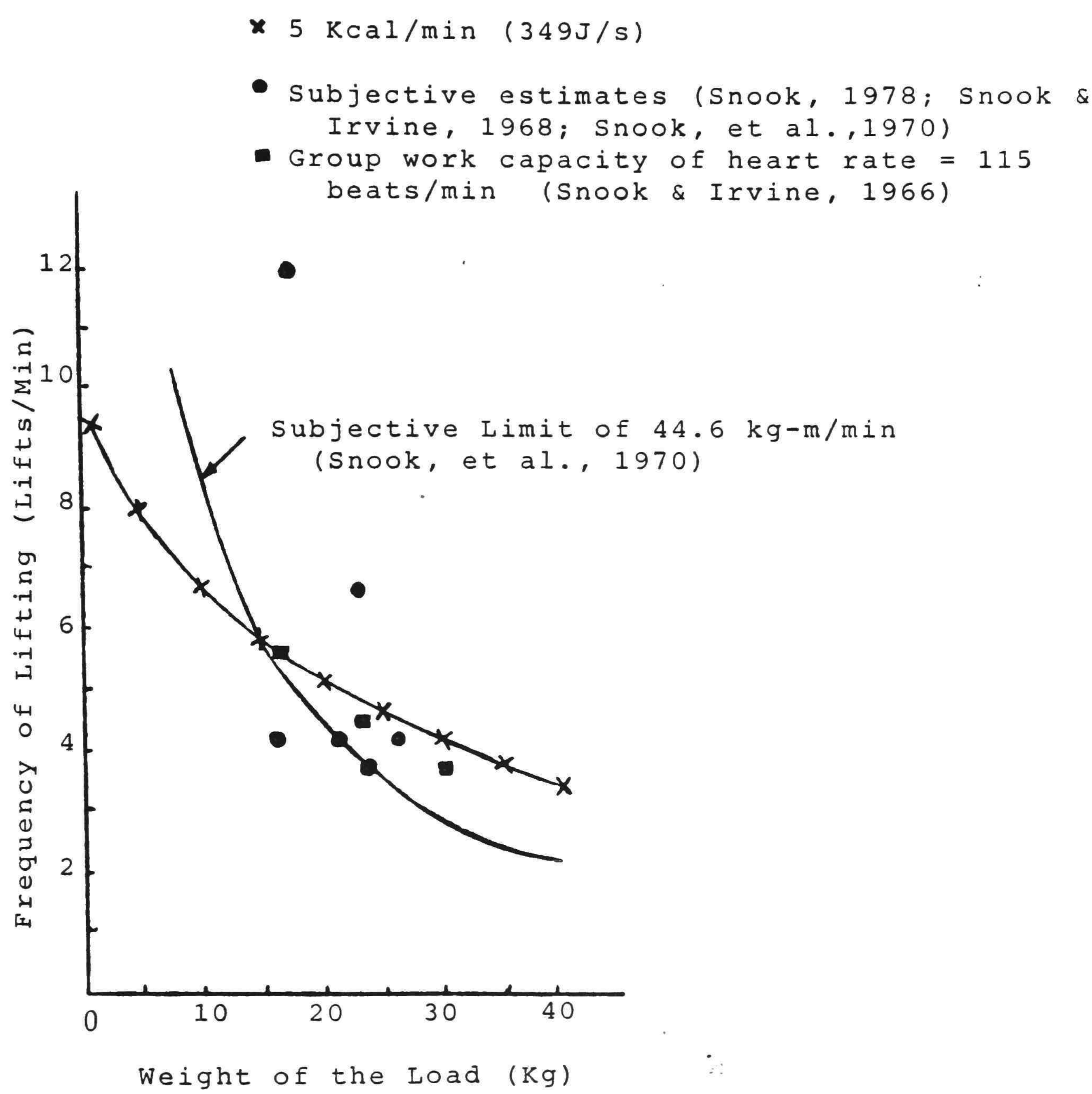

Figure 1: Comparison of psychophysical and physiological fatigue criteria for lifting from floor to 0.51m height (Garg, 1980)

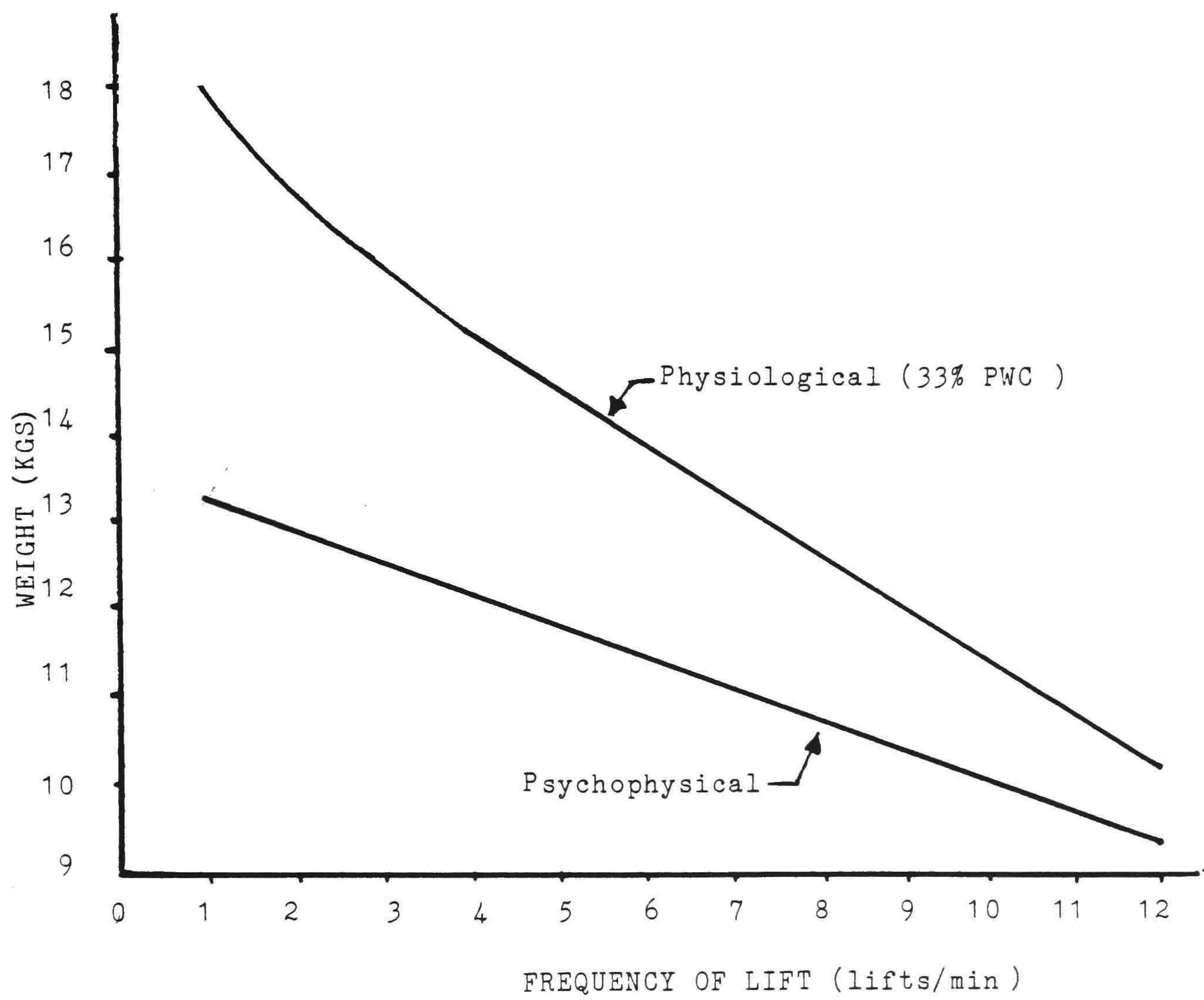

Figure 2: Relationship between oxygen uptake, weight and frequency for males (Mital, 1985.)

8-hour and 12-hour period. Males lifted 65% of the estimated value, while females lifted 84% for an 8-hour period. When the period was increased to 12 hours the males lifted only 70% and females 77% of the estimated weights as shown in figure 3 . Figure 4 shows the changes in oxygen consumption with time for the males. Figure 5 shows the changes in heart rate with time for males.

Worker Variables

Worker variables include age, sex, body weight, PWC, strength, and training. These factors are reviewed in the following paragraphs.

Age

It is a known fact that maximum oxygen uptake decreases with advancing age. Astrand and Rodahl (1977) reported that at age 65, the mean value of PWC is about 70% of a 25 year old individual. However, Shepard (1974), Muller (1962) and Adams (1967) reported that for a given submaximal load, the oxygen consumption was not affected by age.

Maximal strength varies with age, as reported by Astrand and Rodahl (1970). These researchers concluded that the maximal strength is reached between 20 and 30 years of age, and decreases gradually; at the age of 65 the strength is approximately 80% of that attained between ages 20 and 30.

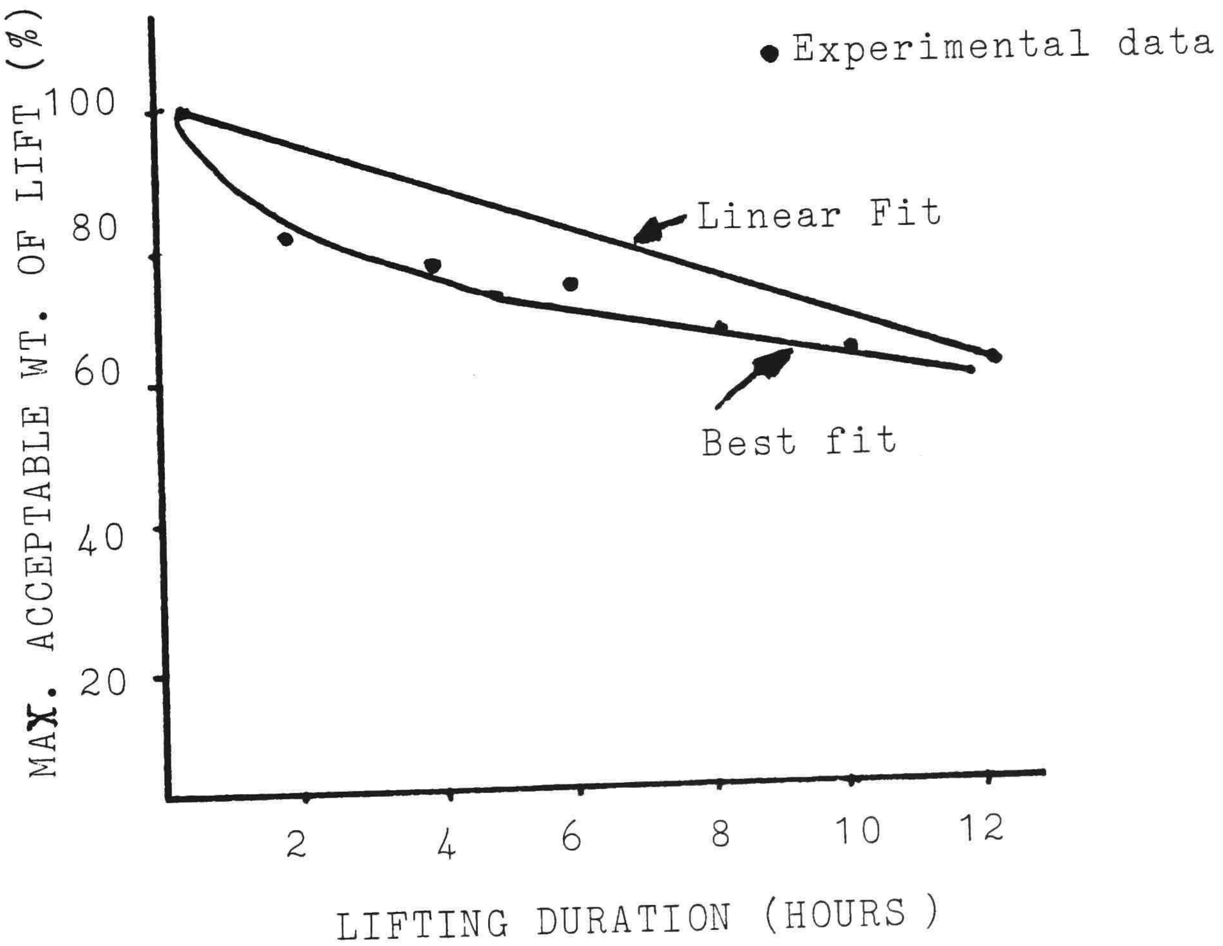

Figure 3: Change in maximum acceptable weight of lift with time for males (Mital, 1983)

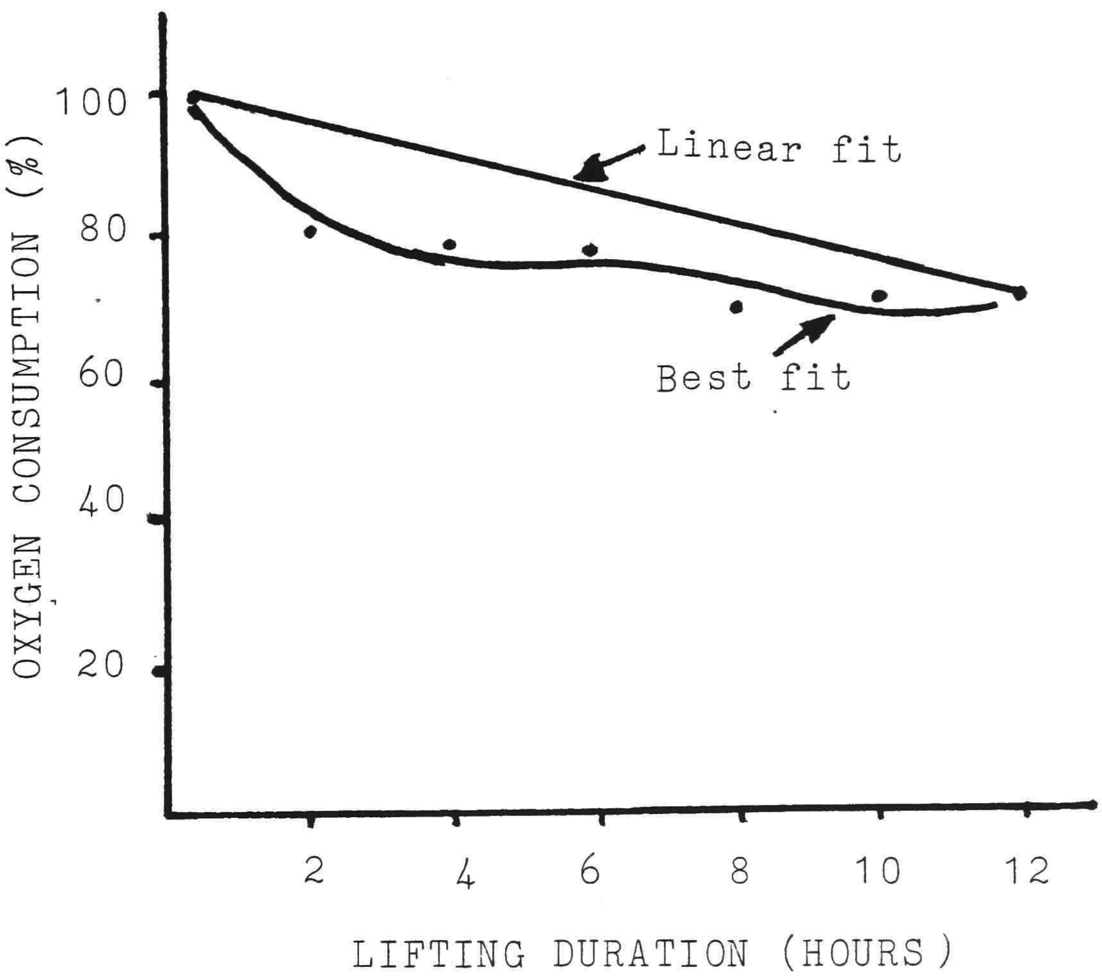

Figure 4: Variation in oxygen consumption with time for males (Mital, 1983)

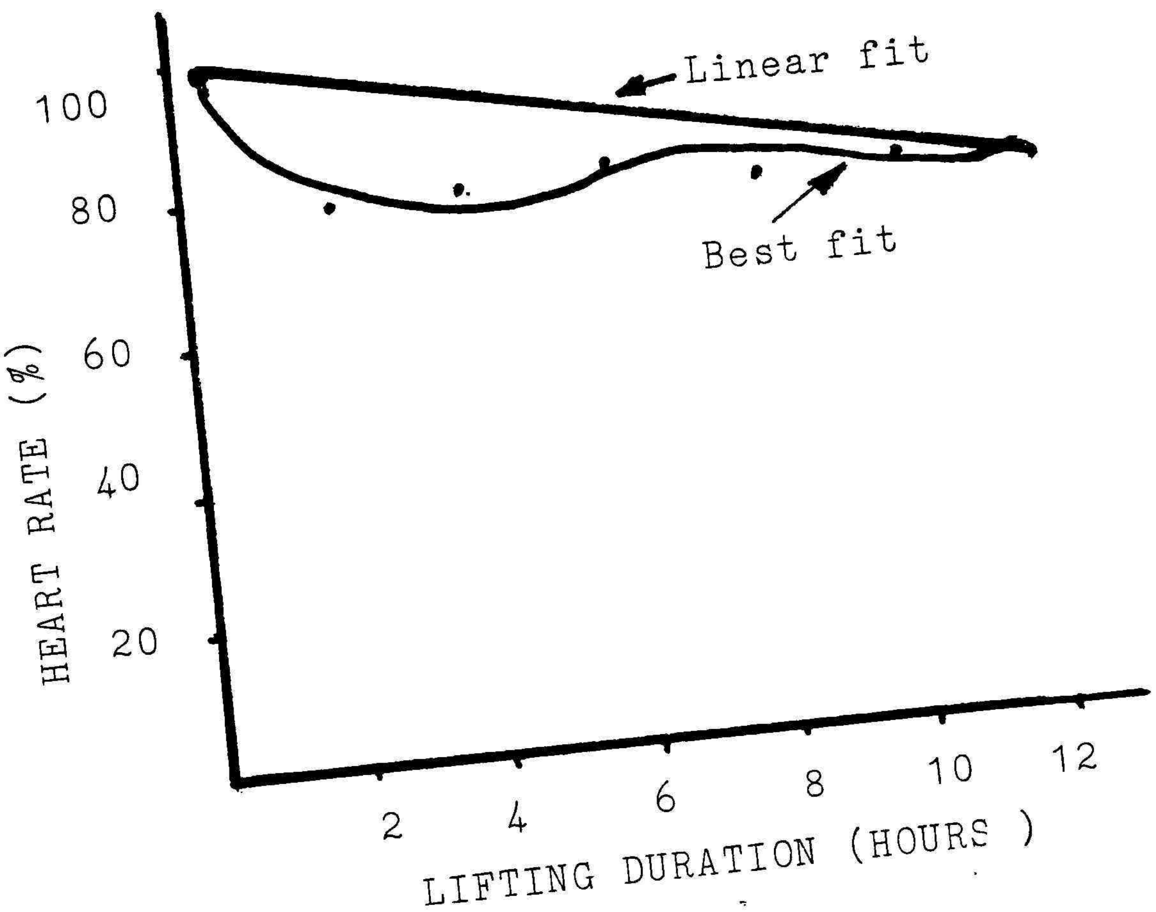

Figure 5: Variation in heart rate with time for males (Mital, 1983)

Ayoub, et al.(1978) reported that age has no affect on ones determination of maximum acceptable weight of lift.

Sex

Astrand and Rodahl (1977) reported that at any given age the VO2 max for women averages about 70-75% of that for men.

Asmussen and Heeboll-Neilson (1962), Petrofsky and Lind (1978), Chaffin (1974), and Snook and Ciriello (1974) report that female lifting strength was 60% of that of males on the average.

There is also a distinct difference in anthropometrics, heart rates, and injury risks as reported by Astrand and Rodahl (1977), Herrin, et al. (1974), Garg (1976), and Grasley, et al. (1978).

Body Weight

An increase in body weight is associated with an increase in metabolic energy expenditure; therefore a heavier person tends to expend more energy than a lighter one (Asfour, 1980).

The VO2 max of men who are not fat is linearly related to the body weight. The same is true for women but the relationship has a lower slope, particularly noticeable after puberty (NIOSH, 1981).

Physical Work Capacity (PWC)

The term physical work capacity is synonymous with maximal oxygen uptake (VO2 max.), aerobic capacity and maximal aerobic power. It is defined as the highest oxygen uptake the individual can attain while performing a physical activity (Astrand and Rodahl, 1977).

PWC varies from individual to individual, the dependent factors being age, sex, body mass, training, task, environment, testing protocol and equipment, and genetic factors (Astrand and Rodahl, 1977).

Methods and procedures to determine the aerobic capacity for an individual have been discussed extensively by Kamon and Ayoub (1976).

Aerobic capacity for an individual is task dependent. Petrofsky and Lind (1978) recommended the use of aerobic lifting capacity as a measure of physical fitness for lifting. The two ways to increase work loads to estimate the aerobic lifting capacity are (1) increasing frequency of lift and (2) increasing weight of lift.

Intaranont (1983) used a submaximal procedure and increased the weight of lift approach to determine an individual's aerobic lifting capacity. He concluded that aerobic lifting capacity was less than aerobic capacity determined by bicycling, which was in agreement with Petrofsky and Lind (1978).

Strength

Kroemer (1976) defined strength as 'the capacity to produce torque or work by maximal voluntary contraction'. Fox and Mathews (1981) stated that female lifting strength was 60% of that of males on the average.

Astrand and Rodahl (1977) indicated that the day-to-day variation of the maximal strength capacity ranges from + 10% to 20% for individuals between the ages of 20 and 30 years, after which it gradually declines.

Training

The maximal oxygen uptake of individuals increases through training (Asfour, 1980). These results agree with similiar conclusions by Astrand (1952), Ekblom, et al. (1968), Fox, et al. (1973), Fox, et al. (1975), Saltin, et al. (1969), Astrand and Rodahl (1977), and Tzankoff, et al. (1972). However, these sources showed that the average improvement varied from 5 to 20% due to training.

Training having an influence on oxygen consumption at submaximal loads is still a controversial situation. Tzankoff, et al, (1972), Fox, et al. (1975), and Clausen, et al. (1970) reported no increase in oxygen consumption at submaximal loads.

No change was reported in maximal heart rate through training by Ekbolm, et al. (1968), and Maksud, et al. (1973); however Saltin, et al. (1968), Fox, et al. (1973), and Fox, et al. (1975) reported a decrease in maximal heart rate. Training had no affect on heart rate during submaximal exercise as reported by Fox, et al. (1973), Fox, et al. (1975), and Frick, et al. (1967).

Task Variables

Weight of Load

Increases in weight of load lifted leads to an increase in the energy cost expended by the worker. Various research endeavors by Frederik (1959), Aquilano (1968), Hamilton and Chase (1969), Garg (1976), Mital (1980), and Asfour (1980) concluded that increases in load lead to increase in metabolic energy rate.

Frequency of lift

There is a definite decrease in one's lifting capacity as the frequency of lifting is increased, Snook and Irvine (1968), Aghazadeh (1974), Ayoub, et al. (1978), Snook, et al. (1978), Asfour (1980), and Bakken (1983).

With an increase in frequency of lift, the individual's physiological responses also increased, Van Wely (1961), Bastina et al. (1961), Aquilano (1968), Hamilton and Chase (1969), and Mital (1980).

Height of lift, and Range of lift

In repetitive lifting mechanical work can be written as

Mechanical Work = Load * Frequency * Height of lift.

Since mechanical work is proportional to height of lift, metabolic energy expenditure should increase with an increase in vertical distance of lift (NIOSH, 1981).

Aquilano (1968) and Garg (1976) stated that lifting capacity depends on the height range of lift, i.e. lifting from floor upd 500/le height is different from lifting from shoulder height to reach height, as different muscle groups are involved.

Snook (1978), and Ayoub, et al. (1978) indicated the maximum acceptable weight using the psychophysical approach was highest in the case of lifting from floor to knuckle height.

Handles

Mital (1980) concluded in his study that appropriate handles on the box facilitated its handling and reduced risk of injury. Garg and Saxena (1980) confirmed these results by concluding in their study that the maximum acceptable weight of lift for boxes with handles was greater than those without handles.

Container Size

Ayoub, et al. (1978) pointed out in their study, using the psychophysical approach, that the amount of weight lifted was inversely proportional to the box size in the sagittal plane. These results were consistent with the conclusions by Martin and Chaffin (1972), Aghazadeh (1974), and Asfour (1980).

Ciriello and Snook (1978), investigating the effects of width of the box in the frontal plane on lifting capacity, concluded that there was no significant difference in amount of weight lifted using two box widths (35" and 22.5"in the frontal plane).

Environmental Variables

Brouha (1967) suggested that the environmental factors, particularly temperature, humidity, air movement, and atmospheric constituents, were the most common variables which affected the physiological behavior of workers.

Kamon and Belding (1971) reported that heart rate increases approximately 7 to 10 beats per minute for 10 degree centigrade rise in ambient temperature. Snook and

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

Hafez (1980) reported that the weight selected by subjects at 27 degrees Wet Bulb Globe Temperature (WBGT) were significantly different than the weights 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.

CHAPTER III

SCOPE AND OBJECTIVES

This study differs from Mital's studies in the 8-hour lifting phases. Mital (1983) allowed the weight to be adjusted over the 8-hour period. In this study (experiment 3) the weight was not adjusted; rather, it was held constant over the 8-hour period. The scope of this phase was to compare the physiological responses of an individual over every hour of the 8-hour working period. Experiments 1 and 2 were repetitions of Mital's studies. Mital's conclusions (1985) differ from results of Ayoub (1978) and Snook (1978) on the comparison of the physiological and the psychophysical approaches; experiment 1 will addressed this problem. Mital's (1983) data was clustered; Mital did not report any individual data but only the means of the various combinations. Experiment 2 was repeated for this reason.

The significance of this study included the updating of existing capacity data to reflect the effect of time on task. This was obtained from the results of the 8-hour adjustment allowed phase. The results of the 8-hour no-adjustment allowed phase showed the drawbacks or shortcoming of using existing capacity norms if the physiological responses are significantly different over the eight hour period.

The objectives of this study were:

1. Comparison of the lifting capacities of individuals using the psychophysical and physiological approaches.

2. Verification of the psychophysical methodology; comparing the estimated weights (using the psychophysical approach) with the weight lifted in an 8-hour lifting session, while the subject is allowed to adjust weights over the 8-hour period along with the comparison of the physiological responses (oxygen consumption and heart rate) over the 8-hour period.

3. Comparison of the physiological responses (oxygen consumption and heart rate) over an 8-hour lifting session, the weight lifted being the maximum acceptable weight (the subject was NOT allowed to make any weight adjustments).

4. Development of prediction equations for MAWOL.

5. Comparison of the one time maximum lift with maximum acceptable weight of lift at the two frequencies.

6. Relationship between the 6-foot incremental lift with MAWOL and the loads lifted over the 8-hour sessions.

CHAPTER IV

METHODS AND PROCEDURES

This chapter includes a description of the subjects, apparatus, procedures for data collection, and experimental design.

Subjects

Twelve male subjects from the student body at Texas Tech University participated in this study. The subjects were paid $5.00 per hour. Only male subjects were used in this experiment as the results could be extended to the female population. The selection of subjects was according to the height and weight criteria as depicted in Table 1. The stratified plan was developed by Ayoub and Halcomb (1976). The numbers in the cells correspond to the number of subjects for that particular height/weight combination, when the total number of subjects equal 100. The number in the parentheses are the number of subjects selected in this study. The reason for using students as subjects was the availability in terms of schedule flexibility and experimental duration. The weights estimated by subjects were not significantly different from weights estimated by industrial subjects (Mital, 1986).

TABLE 1

Height-Weight Stratified Plan

WEIGHT in lbs					
	0	2	2	6	10 (4)
192.5					
	2	4	4	4	6
175.8					
	2	4	8	4	2 (4)
161.5					
	6	4	4 (1)	4 (2)	2 (1)
144.8					
	10	6	2	2	0
102.5					
	62.7	66.7	68.2	69.6	75.2

HEIGHT in inches

The power of the test was calculated from statistical data obtained from Snook (1978). The sum of the square of the treatment effects was assumed to be 8 lbs. For a confidence interval equal to 95% and the number of subjects equal to 12, the power of the randomized complete block experiment was between 0.65 and 0.77 (Walpole and Myers, 1985). This is adequate for one of the experimental designs, and serves as a rough approximate for the experiment as a whole.

Apparatus

A Beckman Metabolic Measurement Cart (MMC) with a two-way valve was used to measure the oxygen consumption, as shown in figures 6 and 7.

Heart rate was measured by a small heart rate monitoring device called a 'Exersentry' (Respironics, Inc.), described by Jiang (1984) and shown in figures 8 and 9.

An anthropometric kit, as shown in figure 10, was used to measure the height of the subjects.

The lifting apparatus as described by Asfour (1980) was used for the lifting exercise in this study as shown in figure 11. This machine lowered the box pneumatically to a pre-determined level when the subject lifted the box to a certain level.

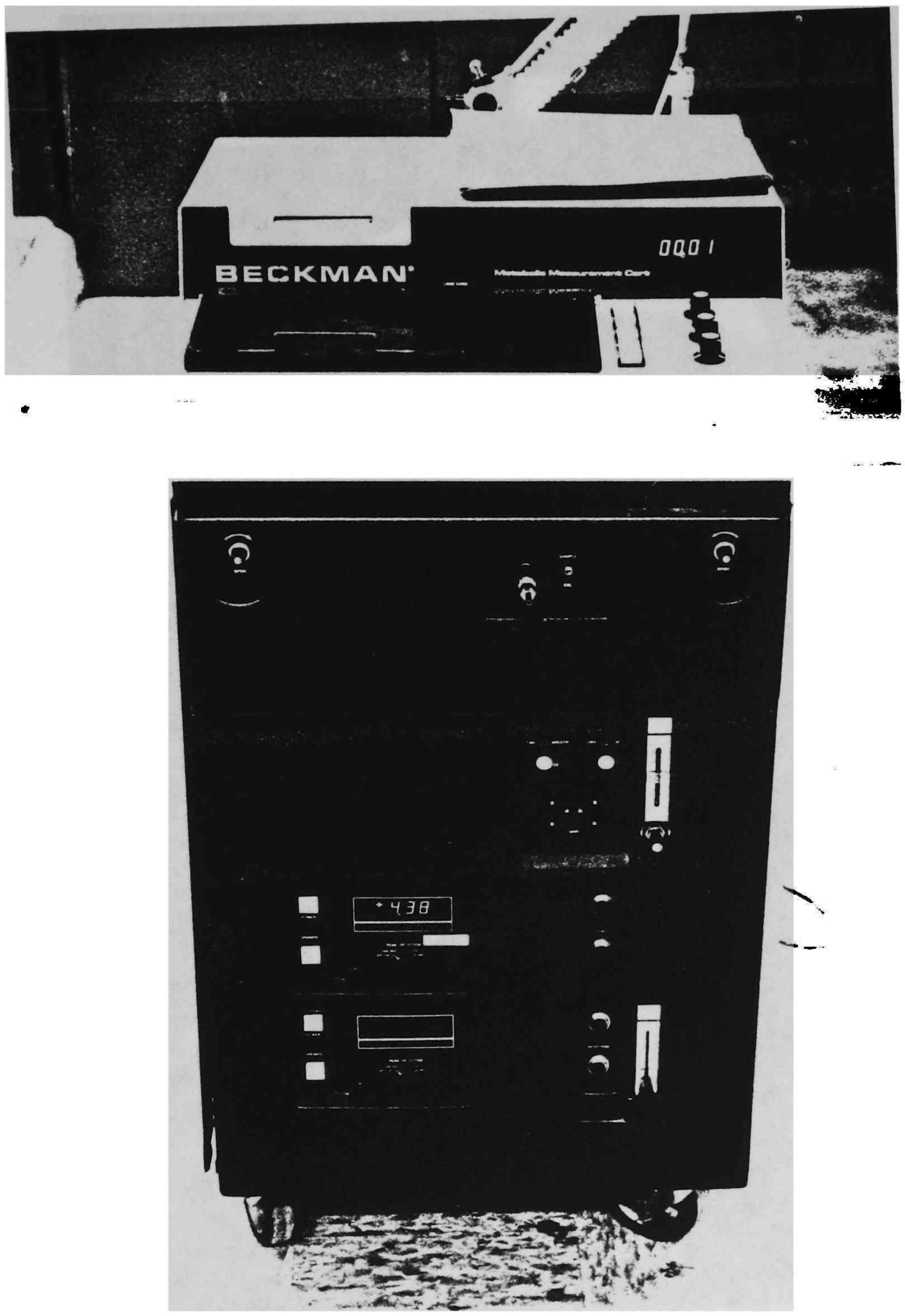

Figure 6: Beckman Metabolic Cart

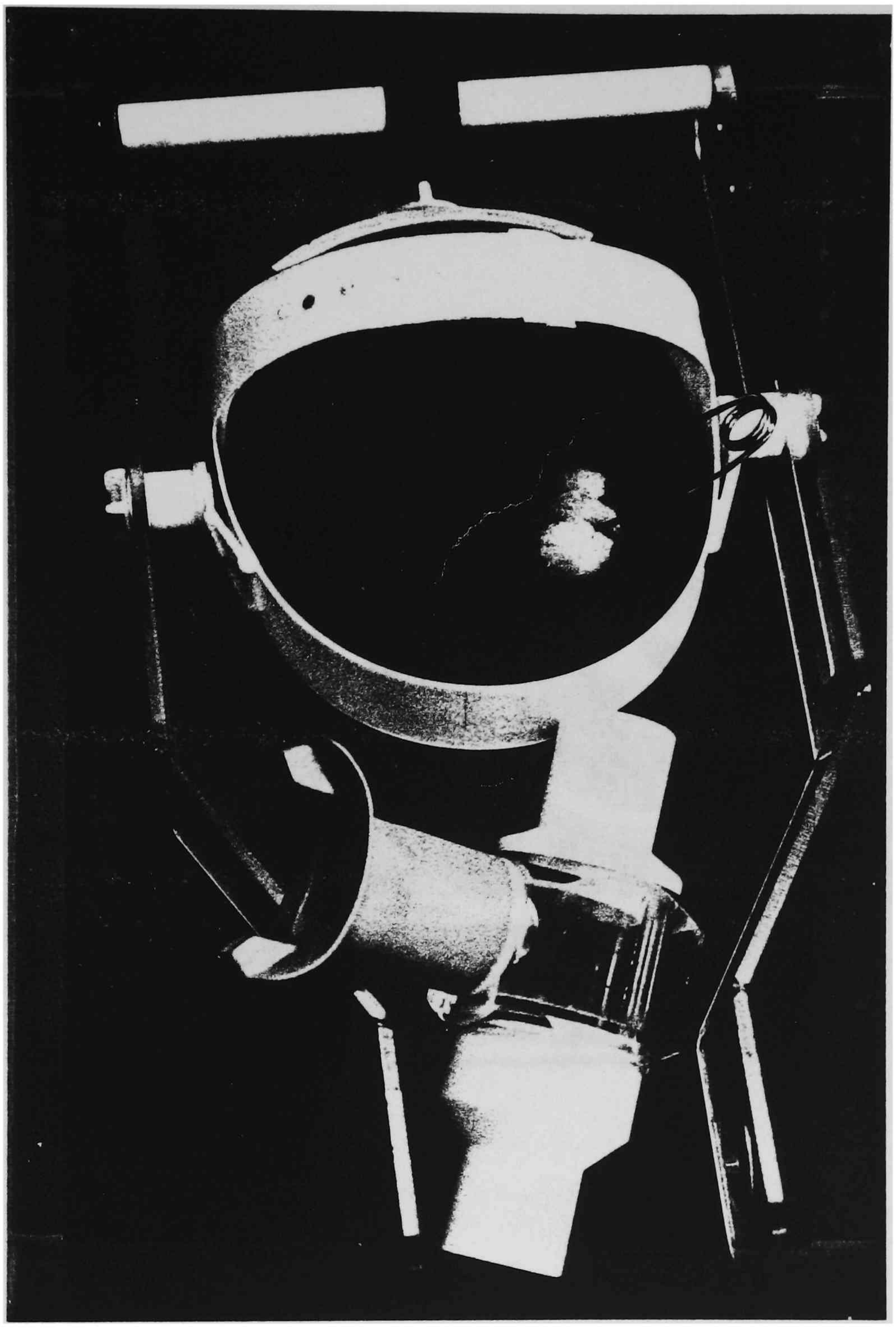

Figure 7: Mouthpiece, nose-clip and head-set

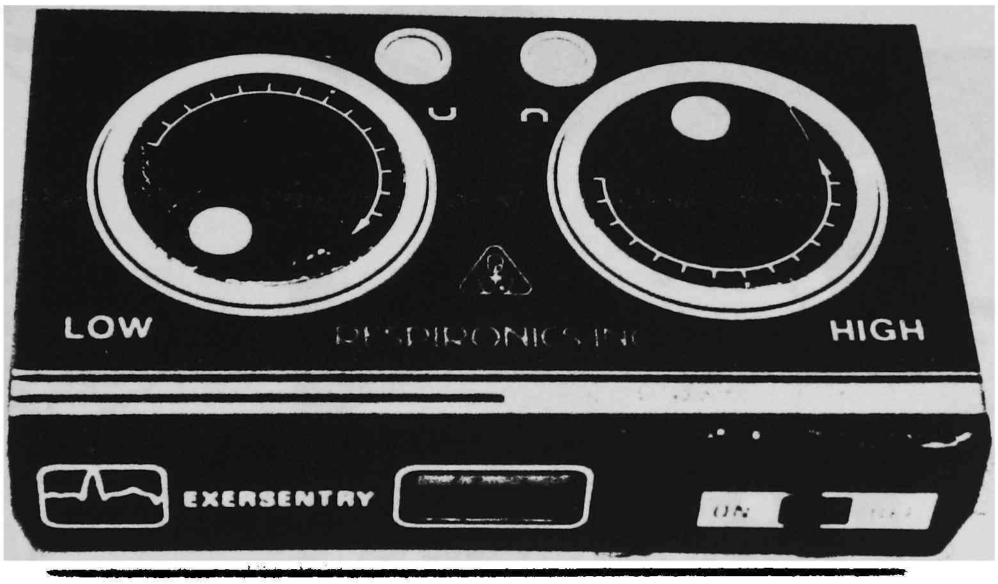

Figure 8: Exersentry Heart Rate Monitor

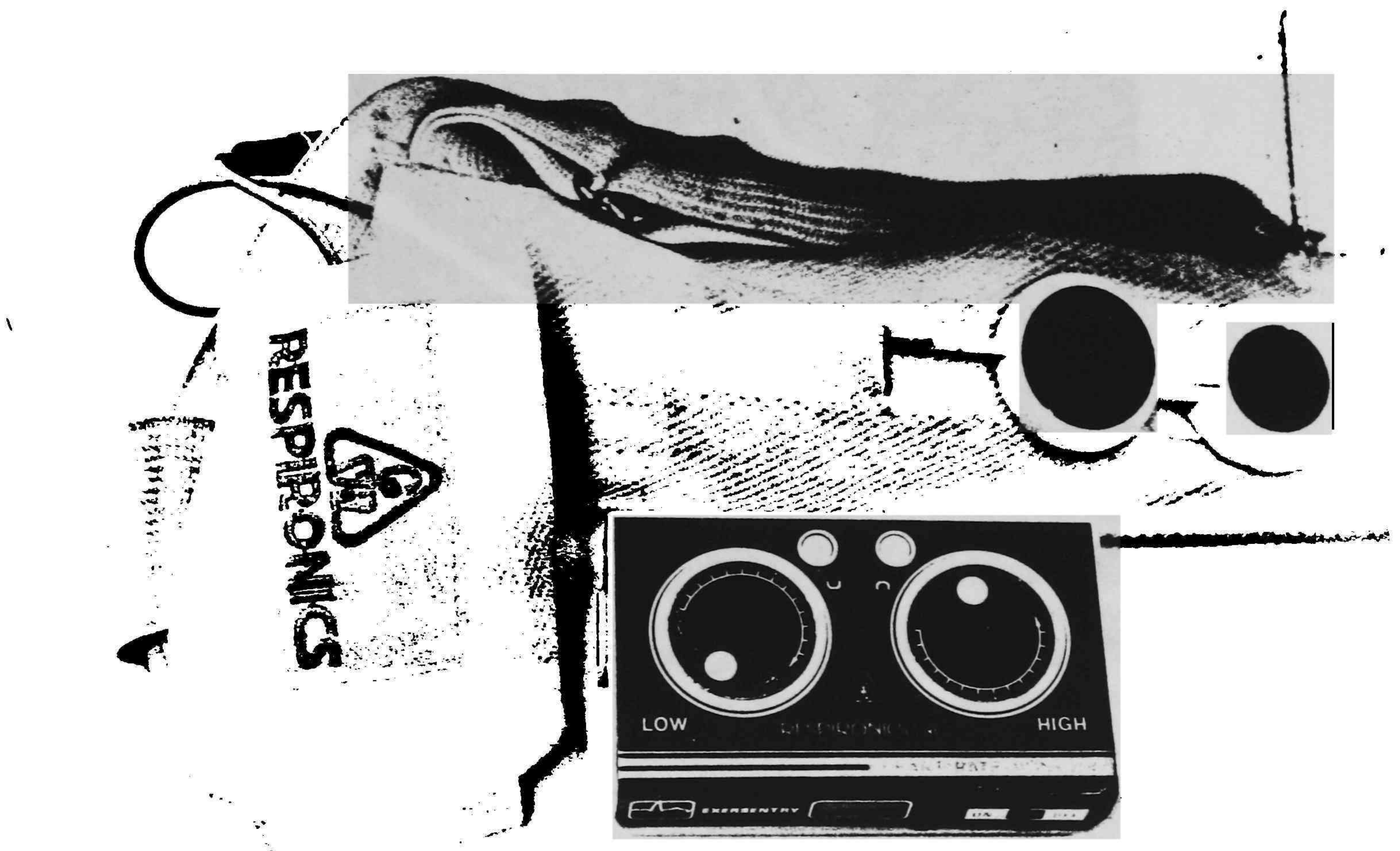

Figure 9: Exersentry and shoulder straps with electrodes

Figure 10: Anthropometric Kit

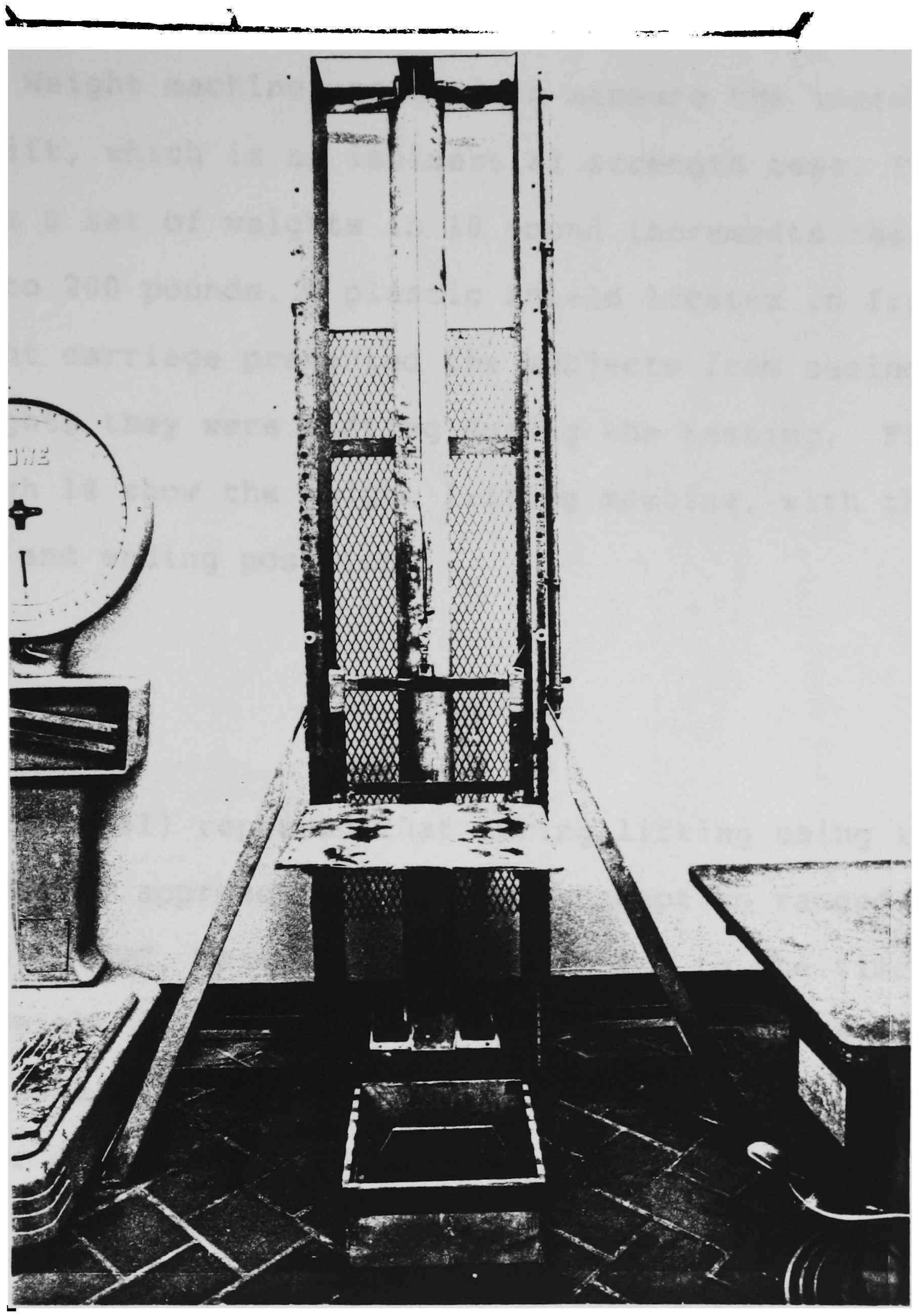

Figure 11: Lifting Apparatus

The weight lifting machine, also known as the Air-Force Factor-X Weight machine was used to measure the incremental 6-foot lift, which is an isoinertial strength test. The machine has a set of weights in 10 pound increments that range from 40 to 200 pounds. A plastic shield located in front of the weight carriage prevented the subjects from seeing how many weights they were lifting during the testing. Figures 12 through 14 show the weight lifting machine, with the starting and ending positions.

Procedures

Preselection

Jiang (1981) reported that during lifting using the psychophysical approach the oxygen consumption ranged from 0.38 to 0.86 PWC. This could have been due to the time duration of weight adjustment which was 6 to 10 minutes, less than the usual 20 to 25 minutes limit, prescribed in other studies or due to the MAWOL being estimated for a one hour session. This result, though not very typical, does occur and there had to be some manner of avoiding such high energy expenditures in a lifting task using the psychophysical approach. High energy expenditures were critical in this study as too high percentage PWC would cause the subject to be easily fatigued, leading to the termination of the 8-hour experiment or decrement of the load lifted.

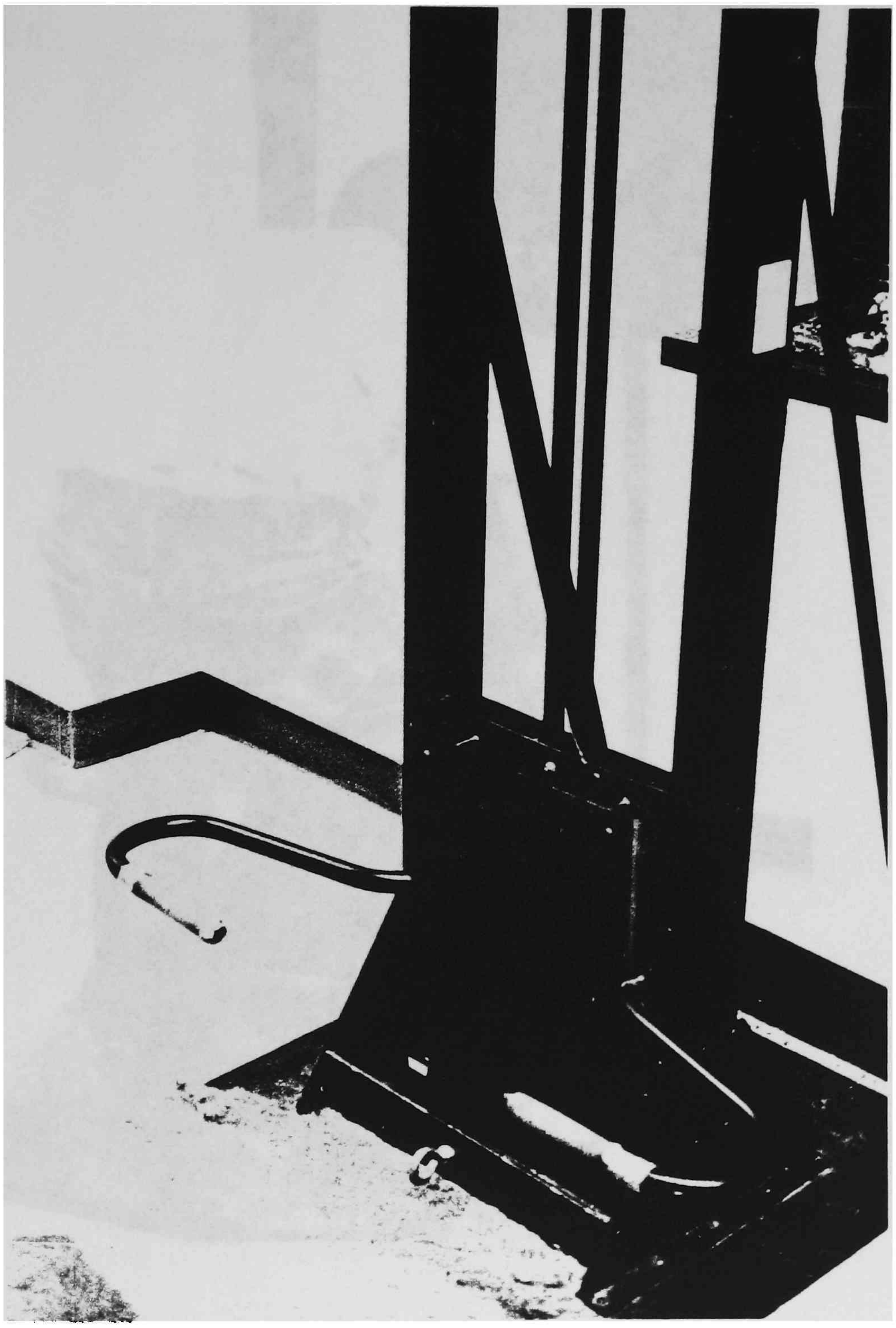

Figure 12: Weight Lifting Machine

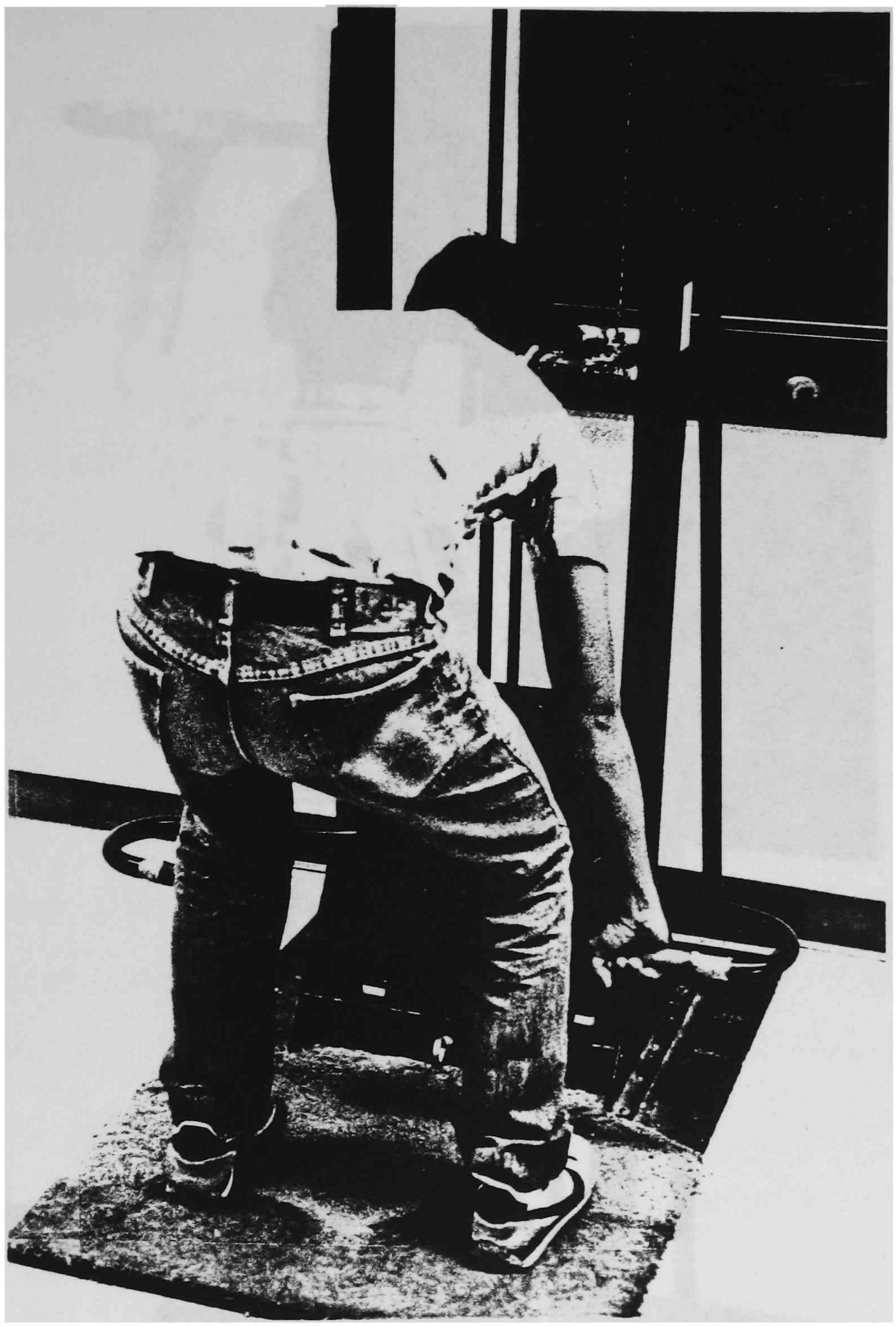

Figure 13: Starting position at weight lifting machine

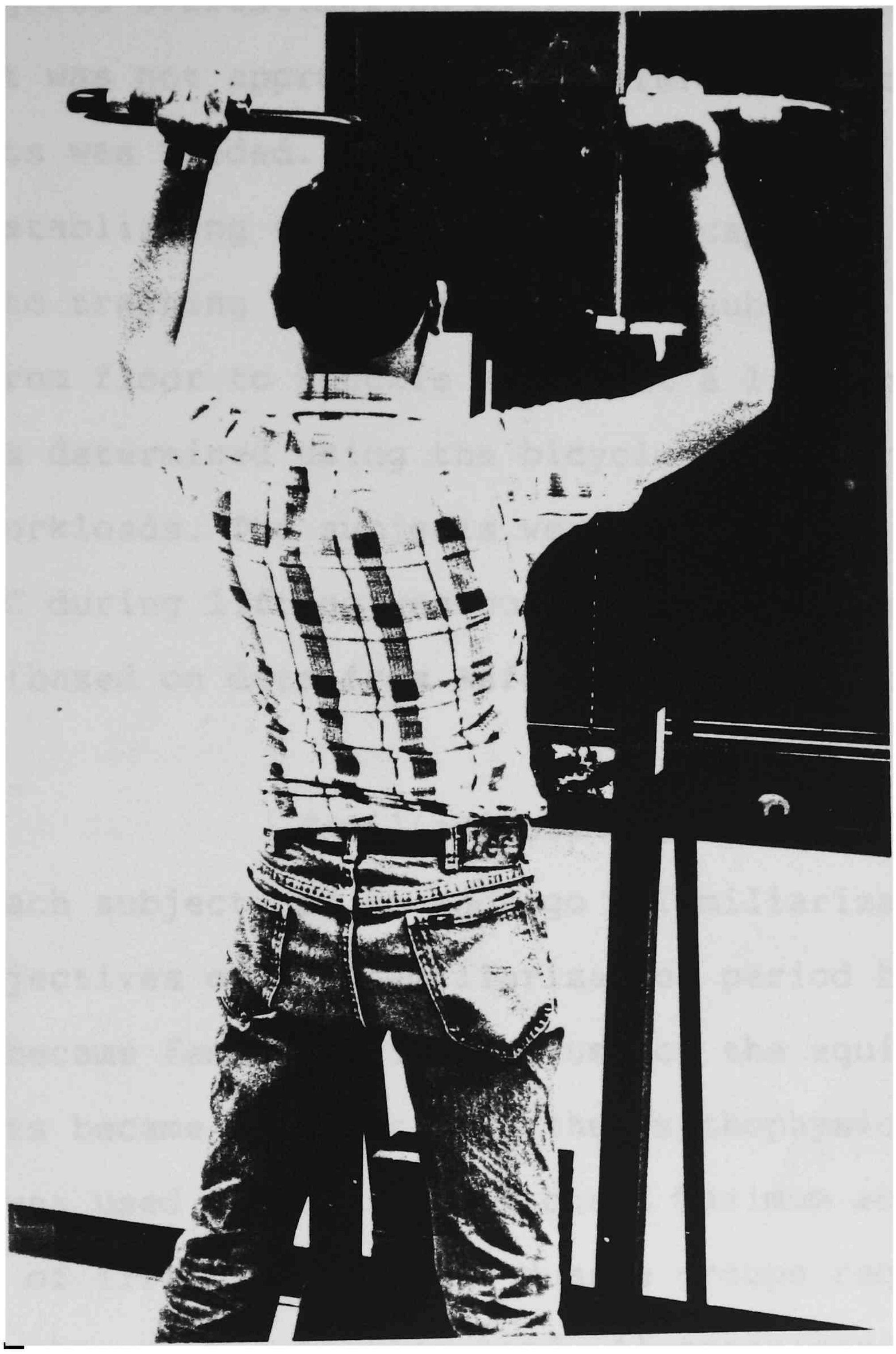

Figure 14: Final position at weight lifting machine

This study warranted the effect of time on task; however, gross overestimation of the maximum acceptable weight of lift was not appropriate, therefore a preselection of subjects was needed.

Establishing the psychophysical capacity of subjects prior to training was necessary. The subjects were asked to lift from floor to knuckle height at 6 lifts per minute. The PWC was determined using the bicycle ergometer at 3 sub-maximal workloads. The subjects were screened if their percentage PWC during lifting was outside the 0.25 and 0.50 PWC range (based on data from Asfour, 1980 and Mital, 1980).

Familiarization period

Each subject had to undergo a familiarization period. The objectives of the familiarization period being: (1) subjects became familiar with the use of the equipment, (2) subjects became familiar with the psychophysical methodology which was used in determining one's maximum acceptable weight of lift, (3) tone the muscle groups required to lift during the experimentation, and (4) experimenter became familiar with subjects to enhance cooperation.

The familiarization period consisted of a 5 day, one hour per day program. The first four days the subject was required to lift from floor to knuckle height using the psychophysical methodology. The duration of the lifting task was 40 minutes. The first 30 minutes the subject adjusted his load until he felt that the load represented his maximum weight of lift (MAWOL). The subject was then required to lift this load for another 10 minutes; during this period (10 min.) the apparatus used to measure the physiological responses (two-way valve and nose clip for oxygen consumption measurement and exersentry for heart rate monitoring) were attached. The frequency of lift for the four day familiarization sessions was randomly selected from either 4 or 6 lifts/minute. On the fifth day, the subject's PWC, isoinertial strength (6-foot incremental lift), and one-time maximum lift was determined.

Percentage Body Fat Determination

The subjects percentage body fat was determined by underwater weighing based on formulae developed by Sloan (1967), Wilmore (1969), and Brozek, et al. (1963). Methods and procedures to determine percentage body fat have been discussed extensively by Sinning (1975).

Physical Work Capacity (PWC) Determination

A submaximal test as described by Kamon and Ayoub (1976) was used to reduce risks to the subjects. The subjects were asked to refrain from eating, smoking or consuming carbonated drinks during the lifting sessions. A mouthpiece was inserted in the subject's mouth and a nose-clip on his nose so that respiration would occur only through his mouth. The resting heart rate was measured with the subject resting in a sitting position. This was known as the Resting Heart Rate (RHR); the Maximum Heart Rate (MHR) was calculated by the formula 220-Age (Astrand and Rodahl, 1977). The Heart Rate Range (HRR) was then determined from MHR-RHR (Intaranont, 1983).

The PWC was calculated by extrapolating the regression line of oxygen consumption and heart rate at three steady states to predict the maximum oxygen consumption at maximum heart rate (220-Age) as described by Kamon and Ayoub (1976).

Oxygen consumption is assumed to be proportional to percentage HRR (de Vries, 1980). The protocol called for the second and third workload to be 50% and 65% of VO2 maximum respectively, therefore 50% HRR and 65% HRR was considered.

PWC was measured by two different tasks consisting of lifting and bicycling. (1) Aerobic lifting capacity: The lifting range considered was floor to knuckle height; the lifting frequency was kept constant at 2, 6 and 8 lifts per minute. The loads were adjusted so that workload 2 and workload 3 were 50% and 65% respectively of HRR. The oxygen consumption (liters per minute) and heart rate (beats per minute) were recorded throughout the test. Steady state had to be achieved before the next workload was applied; this was usually obtained in 4-5 minutes. (2) Aerobic capacity by bicycling: The test protocol required the subject to pedal the bicycle ergometer at three different workloads for 4 to 5 minutes at each load at a speed of 60 rpm. The first workload was 50 watts; the second and third workload were adjusted so that they were 50% and 65% of HRR respectively. Oxygen consumption and heart rate were recorded throughout the test (Intaranont, 1983). At the 3 steady states, the oxygen consumption and heart rate were considered as the pertinent data for the extrapolation of PWC. Figure 15 shows the subject on the bicycle ergometer.

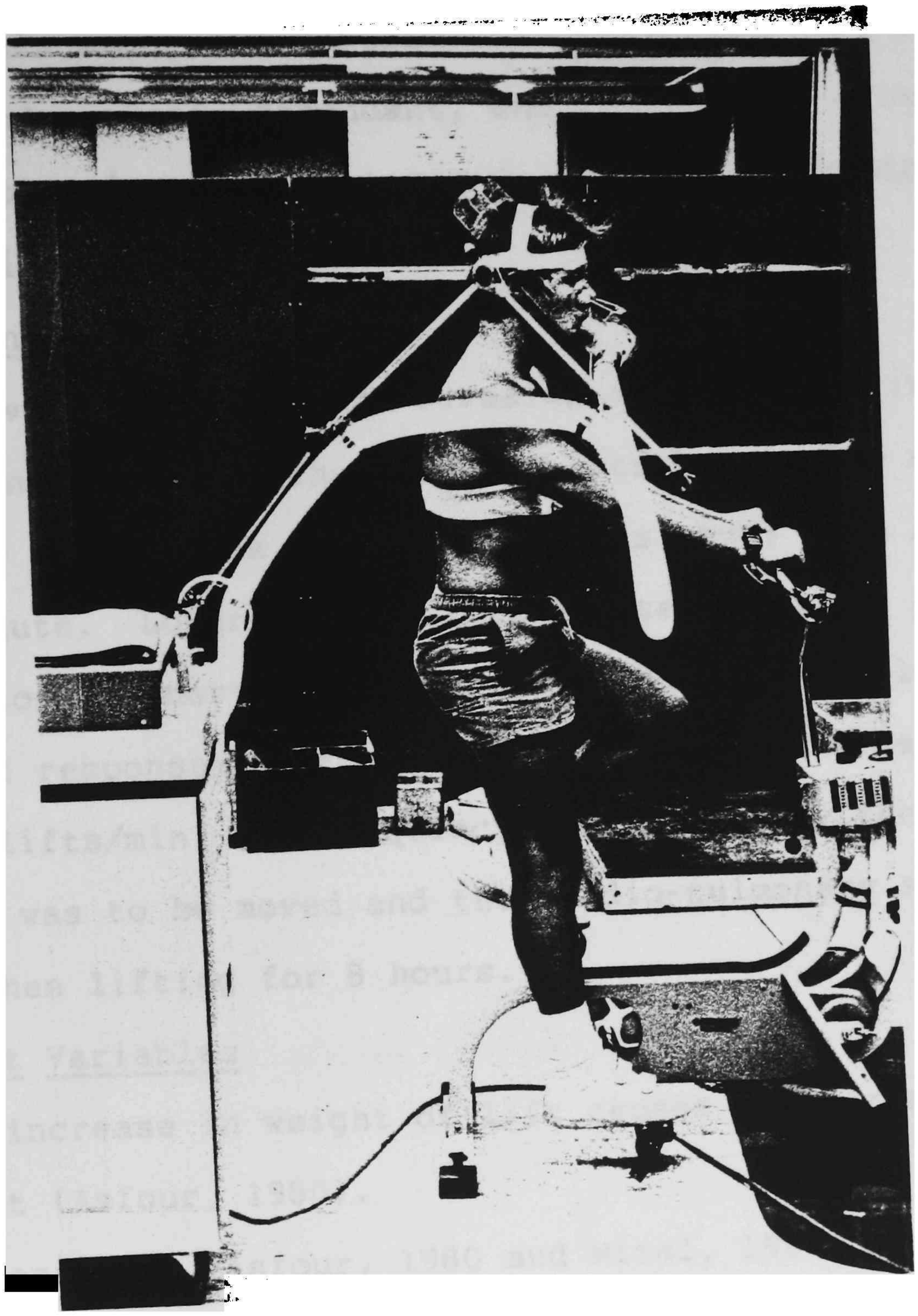

Figure 15: Set-up for bicycle PWC

Experimental Variables

In this study the experimental variables were classified as independent, dependent, and controlled. A summary of the variables is shown in table 2. A short discussion of these variables follows:

Independent Variables

A review of literature revealed that with an increase in frequency of lift, there was an increase in the energy cost. The frequencies selected for this study were 2 and 8 lifts/minute. Lower than 2 lifts/minute would not stress the cardio-pulmonary system enough, producing too low physiological responses (Intaranont, 1983). On the other hand, above 8 lifts/min. the frequency was limited by the distance the load was to be moved and the cardio-pulmonary stress involved when lifting for 8 hours.

Dependent Variables

An increase in weight of lift causes an increase in energy cost (Asfour, 1980).

Researchers (Asfour, 1980 and Mital, 1980) stated that an increase in physical effort causes an increase in heart rate. Heart rate is a reasonable indicator of the amount of strain imposed on the cardio-pulmonary system of an individual during muscular activity. They also indicated that heart rate is readily affected by factors such as

TABLE 2

Summary of Independent, Dependent, and Controlled Variables for the Experiment

Independent variables	Frequency of lift	2,8 lifts/min.
Dependent variables	Weight of load	
	Heart rate	
	Oxygen consumption	
Controlled variables	Population	College students
	Sex	Males
	Height range	Floor-knuckle ht. (0 to 30")
	Box dimensions	18*11.5*12"
	Coupling	Box with handles
	Lifting technique	Free-style
	Lifting plane	sagittal

emotions and heat stress. In this study, heart rate at steady state was measured as an indicator of the degree of severity of the task.

The oxygen consumption of an individual increases as the external load increases. In this study, oxygen consumption (l/min.) was measured by the Metabolic Measurement Cart (MMC).

<u>Controlled Variables</u>

A modest but meaningful experiment was developed with the following variables controlled:

a. Population _ only college students used

b. Sex _ males

c. Box Dimensions _ 18 * 11.5 * 12" with handles

d. Height of lift _ floor to knuckle height (0 to 30")

e. Lifting technique _ free-style

f. Lifting plane _ sagittal

Psychophysical Lifting Phase

The subjects were asked to lift from floor to knuckle height. The starting weight was randomly set at relatively heavy or relatively light. Subjects were allowed to adjust the weight of load to the maximum that they could lift without strain, discomfort, without becoming tired, weakened, overheated or out of breath. The adjustment period lasted for 25 minutes. The final weight at the end of the period was considered the "maximum acceptable weight of lift (MAWOL)". The mouthpiece and the nose-clip were attached and the subject was then asked to lift for another 10 minutes or until steady state was reached in order to measure oxygen consumption and heart rate. Steady state values were recorded every minute for 5 minutes. For future reference in this study, MAWOL for the two frequencies will be labeled S1 and S2; the oxygen consumption and heart rate will be labeled S1O, S2O, and S1H, and S2H respectively. The MAWOL was measured again immediately after the 8-hour sessions. The instructions were the same except for the added instruction to estimate with their experience.

Physiological Lifting Phase

In this section of the study the oxygen consumption was measured at various weight of lifts for the two frequencies. The physiological criteria stated that an individual can work at 33% of his PWC for an eight hour period; therefore, knowing an individual's PWC, the load (weight of lift) was varied and oxygen consumption and heart rate were measured at steady states. A pocket calculator was utilized to determine whether the load should be increased or decreased. After necessary interpolation, the weight and oxygen consumption were determined, which will be labeled P1, P2, P10, and P20 respectively, for the two frequencies.

Eight-hour Adjustment-allowed Lifting Phase

The starting weight for the eight hour adjustment allowed lifting phase was the MAWOL (i.e. S1 and S2) using the psychophysical methodology. All subjects were given regular break periods of 15 minutes after 2 hours, 30 minutes after 4 hours (for lunch), and 15 minutes after 6 hours. The subjects were also permitted to stop for a couple of minutes during work sessions if they wanted to drink water or go to the restroom (Mital, 1983). A record of the number of breaks and the duration of each break were made. Adjustment of the weight was allowed throughout the day. A record of the time of the weight adjustments and the weight adjusted over the 8-hour period was made. Weight of lift, oxygen consumption, and heart rate were recorded every hour; a 3 minute average was taken for oxygen consumption and heart rate. These measurements were determined by the experimenter by asking the subject to insert the mouthpiece 10 minutes before the hour. The exersentry was attached and activated throughout this session. Weights, oxygen consumptions, and heart rates measured every hour were labeled A1W1,

A1W2,.....A1W8, A1O1, A1O2,.....A1O8, A1H1, A1H2,.....A1H8 respectively for frequency 1; similar notations for frequency 2 were also used.

The lifting machine was not used for all the 8-hour sessions. Helpers lowered the box and two work-stations were utilized as shown in figure 16. Communication between subjects and helpers was kept to a minimum and discussion of the experiment was prohibited. The theories of social facilitation are presented in detail by Zajonc (1965), Sanders, et al. (1978), Baron, et al. (1978), and Sanders (1981). Selan (1986) showed that there was no significant difference between MAWOL with subjects working alone and working with a helper/co-actor.

The literature cited above suggest social facilitation only in the presence of evaluation; any evaluation present came from the experimenter, who was present in all conditions. In view of the findings of Selan (1986), the decision was made to include helpers and utilize two work stations with barriers in this study.

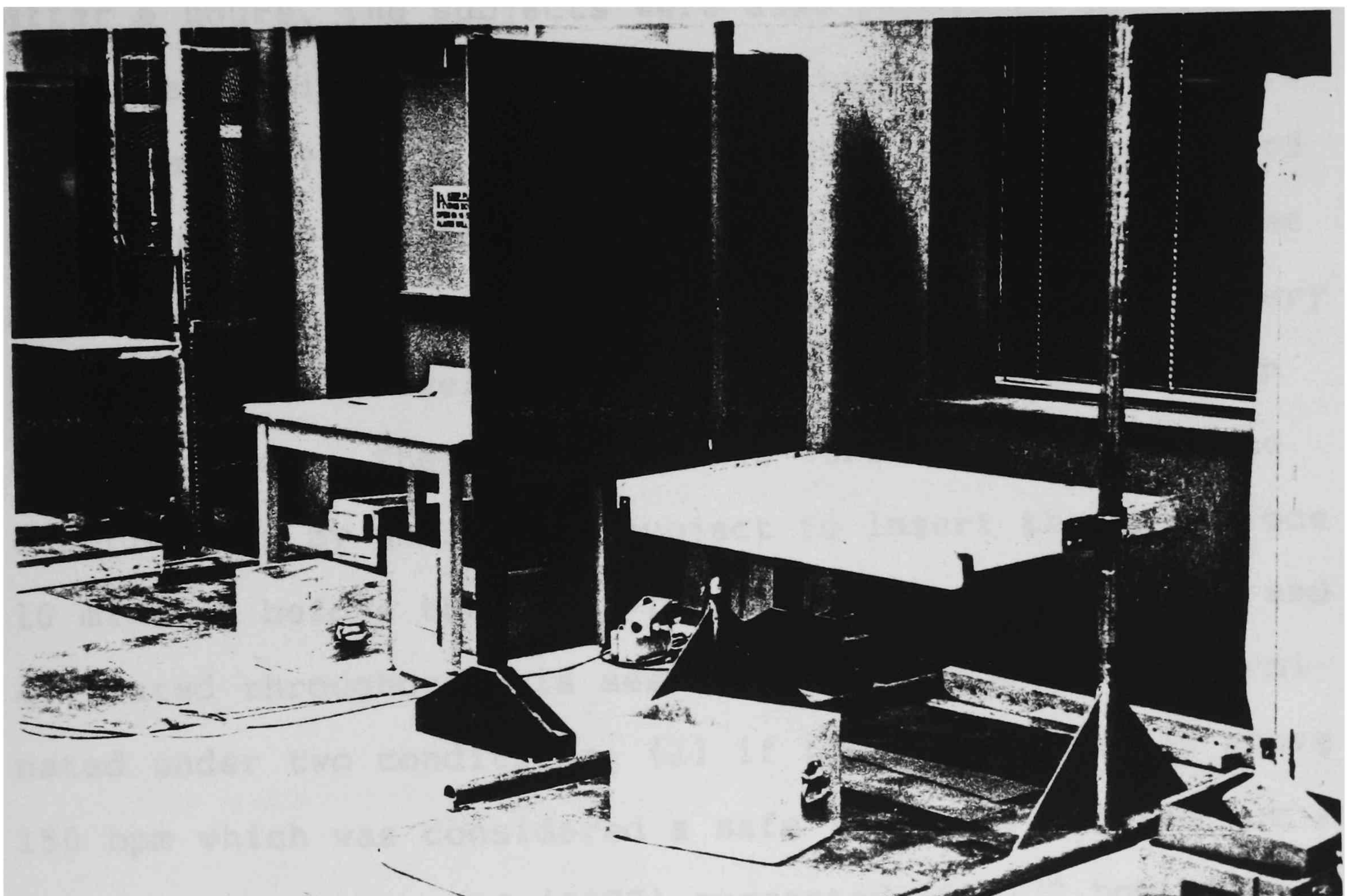

Figure 16: Experimental set-up for the 8 hour periods

Eight-hour No-adjustment-allowed Lifting Phase

The weight for the eight hour no adjustment allowed lifting phase was the MAWOL (i.e. S1 and S2). All subjects were given regular break periods of 15 minutes after 2 hours, 30 minutes after 4 hours (for lunch), and 15 minutes after 6 hours. The subjects were also permitted to stop for a couple of minutes during work sessions if they wanted to drink water or go to the restroom (Mital, 1983). A record of the number of breaks and the duration of each break was made. Oxygen consumption and heart rate were recorded every hour; a 3 minute average was taken for oxygen consumption and heart rate. These measurements were determined by the experimenter by asking the subject to insert the mouthpiece 10 minutes before the hour. The exersentry was attached and activated throughout this session. This session was terminated under two conditions: (1) if the heart rate was above 150 bpm which was considered a safe limit for lifting for an 8-hour period; Astrand (1977) suggested 160-170 bpm to be an appropriate limit, and (2) if the subject felt he could not continue the session due to fatigue, stress or excessive pain. Oxygen consumptions and heart rates measured every hour were labeled B1O1, B1O2,.....B1O8, B1H1, B1H2,.....B1H8 respectively for frequency 1; similiar notations for frequency 2 were also used.

One-time maximum lift

The psychophysical approach was utilized with the subject lifting from floor to knuckle height, frequency being the one-time max. lift with the MAWOL being the one-time maximum weight.

Six-foot incremental lift

The subject was instructed to lift his maximum weight to a height of six feet using the modified Air-Force incremental weight lifting machine. This isoinertial strength test predicts lifting capacity with a variability of 65% or higher (Ayoub, 1985) and therefore served as a quick, inexpensive and reasonably accurate measure of predicting lifting capacity.

Experimental Design

The experiment was divided into three parts; experiment 1 was the comparison of physiological responses while lifting using the psychophysical and physiological approaches. The experimental design was a randomized complete block design with subjects as blocks. The order of the tests were randomized for each subject. The order, as obtained from the 'PROC PLAN' procedure in the SAS utility, and experimental layout is shown in table 3.

TABLE 3

Experimental Layout and Order of Experiment 1

	TREATMENTS			
BLOCK	S1	S2	P1	P2
1	1	4	3	2
2	2	1	4	3
3	3	4	2	1
4	2	3	1	4
5	2	3	1	4
6	1	4	2	3
7	1	3	2	4
8	1	2	3	4
9	1	3	2	4
10	3	1	4	2
11	1	2	3	4
12	2	1	4	3

where S1 = 25 min. psychophysical lifting at 2 lifts/min.

S2 = 25 min. psychophysical lifting at 8 lifts/min.

P1 = Lifting to determine physiological lifting capacity at 2 lifts/min.

P2 = Lifting to determine physiological lifting capacity at 8 lifts/min.

BLOCKS = Subjects 1 to 12

The model used was

$$Y_{ij} = \mu + \tau_i + \beta_j + \epsilon_{ij} \qquad i=1,2$$

$$j=1,2....12$$

where μ = overall mean

τ_i = effect of the ith treatment

β_j = effect of the jth subject

ϵ_{ij} = random error term.

Prior to experiment 1, on day 5 of the familiarization period the PWC (bicycling, PWC at 6 lifts/min), one-time max-lift and the 6-foot incremental lift were measured. The PWC (bicycling and PWC at 2, 6 and 8 lifts/min), one-time max-lift and the 6-foot incremental lift were measured at the end of experiment 3; this addresses the effect of training. Experiment 2 was the 8-hour lifting sessions with the weight adjustments. The experimental design was a split-plot design, with subjects as blocks. The main plot treatments were A1 and A2; the secondary plot was the weights and physiological responses over the 8-hour period. Randomizing was restricted by virtue of the times. The experimental layout is depicted in table 4. The order of the tests for each subject was randomized, using the 'PROC PLAN' procedure in the SAS utility, as shown in table 5.

The model used was

$$Y_{ijk} = \mu + \tau_i + \beta_j + (\tau\beta)_{ij} + \gamma_k + (\tau\gamma)_{ik} + (\beta\gamma)_{jk} + (\tau\beta\gamma)_{ijk}$$

$i=1,2;\ j=1,2...12;\ k=1,2...8$

where μ = overall mean

τ_i = effect of the ith treatment

β_j = effect of the jth subject

γ_k = effect of the kth hour

Experiment 3 was the 8-hour lifting with no adjustment allowed. The experimental design was a split plot design with subjects as blocks. Due to the physiological limits of the experiment, some subjects were not able to complete lifting for the 8-hour period, creating missing values. Therefore, the data were analyzed using t-tests. The experiment layout was similiar to experiment 2. The order of the test for each subject was randomized as shown in table 6, obtained by using the PROC PLAN procedure in the SAS utility.

TABLE 4

Experimental Layout for Experiment 2

SUBJECTS	1		2	3	4	5	6	7	8	9	10	11	12
	A1	A2											
	1	1											
	2	2											
	3	3	layout similiar for										
	4	4	subject 2,...12										
	5	5											
	6	6											
	7	7											
	8	8											

where A1 = lifting for 8-hour adjustment allowed at 2 lifts/minute.

A2 = lifting for 8-hour adjustment allowed at 8 lifts/minute.

TABLE 5

Experimental Order for Experiment 2

	TREATMENTS	
BLOCK	A1	A2
1	2	1
2	2	1
3	1	2
4	2	1
5	2	1
6	2	1
7	1	2
8	1	2
9	1	2
10	2	1
11	1	2
12	1	2

where A1 = lifting for 8-hour adjustment allowed at 2 lifts/minute.

A2 = lifting for 8-hour adjustment allowed at 8 lifts/minute.

TABLE 6

Experimental Order for Experiment 3

	TREATMENTS	
BLOCK	B1	B2
1	1	2
2	2	1
3	1	2
4	1	2
5	2	1
6	1	2
7	1	2
8	1	2
9	1	2
10	1	2
11	1	2
12	1	2

where B1 = lifting for 8-hour no-adjustment allowed at 2 lifts/minute.

B2 = lifting for 8-hour no-adjustment allowed at 8 lifts/minute.

CHAPTER V

RESULTS AND DISCUSSION

The results of the study together with the pertinent statistical analysis will be reported and discussed in the following order.

1. Comparison of the Physical Work Capacity.
2. Comparison of the psychophysical and the physiological approaches in determining lifting capacity of individuals (experiment 1).
3. Results of the 8-hour adjustment allowed period (experiment 2).
4. Results of the 8-hour no adjustment allowed period (experiment 3).
5. Comparison of the MAWOL, six-foot incremental lift and one-time maximum; determined before experiment 2 and at the end of the experiment 3.
6. Development of prediction equations for MAWOL and weight lifted over the eight hours.

Comparison of Physical Work Capacities

Physical work capacity was determined both by bicycling and by lifting. A summary of the results are shown in table 7.

TABLE 7

Summary of Physical Work Capacities

	MEAN (ml/min)	SD. (ml/min)
Before PWC bicycling	2940.716	780.612
After PWC bicycling	3254.993	695.063
Before PWC,6 lift/min	2863.357	674.462
After PWC,6 lifts/min	2929.270	539.643
PWC,2 lifts/min	2064.865	605.086
PWC,8 lifts/min	2720.161	859.480

There was a 2.6% difference between before bicycling PWC and before lifting PWC. This agrees with the findings of Intaranont (1983).

Training resulted in an increase of 10.68% in bicycling PWC and an increase of 2.30% in lifting PWC at six lifts/minute, which was consistent with the results of Asfour (1980). There was no significant difference between the before and after bicycling and lifting PWC (frequency=6) at the 5% level. At the 5% level the before bicycling and lifting PWC (frequency=6) were not significantly different but the after PWC (bicycling and lifting) were significantly different. Bicycling and lifting involve different muscle masses. The difference between the increase in bicycling PWC and lifting PWC could possibly be attributed to the training of the specific muscle groups.

The PWC at two lifts per minute was significantly different from the PWC at six lifts and PWC at eight lifts per minute. This difference could be attributed to the fact that the physiological system was not stressed enough in the two lifts per minute case (Intaranont, 1983). The PWC at 8 lifts per minute, though not significantly different at the 5% level, was lower than the PWC at 6 lifts/minute; this was due to the lifting style. Figure 17 shows the PWC at the three lifting frequencies. The lifting style in the case of two lifts/minute was generally a squat lift, but it changed to a stoop lift for the eight lifts/minute. The lifting style the subject chose for the PWC at six lifts/minute was the squat; however, at times the stoop. The author felt that this was the border line of squat and stoop lifting style. PWC depends on task, frequency, range, and also on style of lifting (squat or stoop).

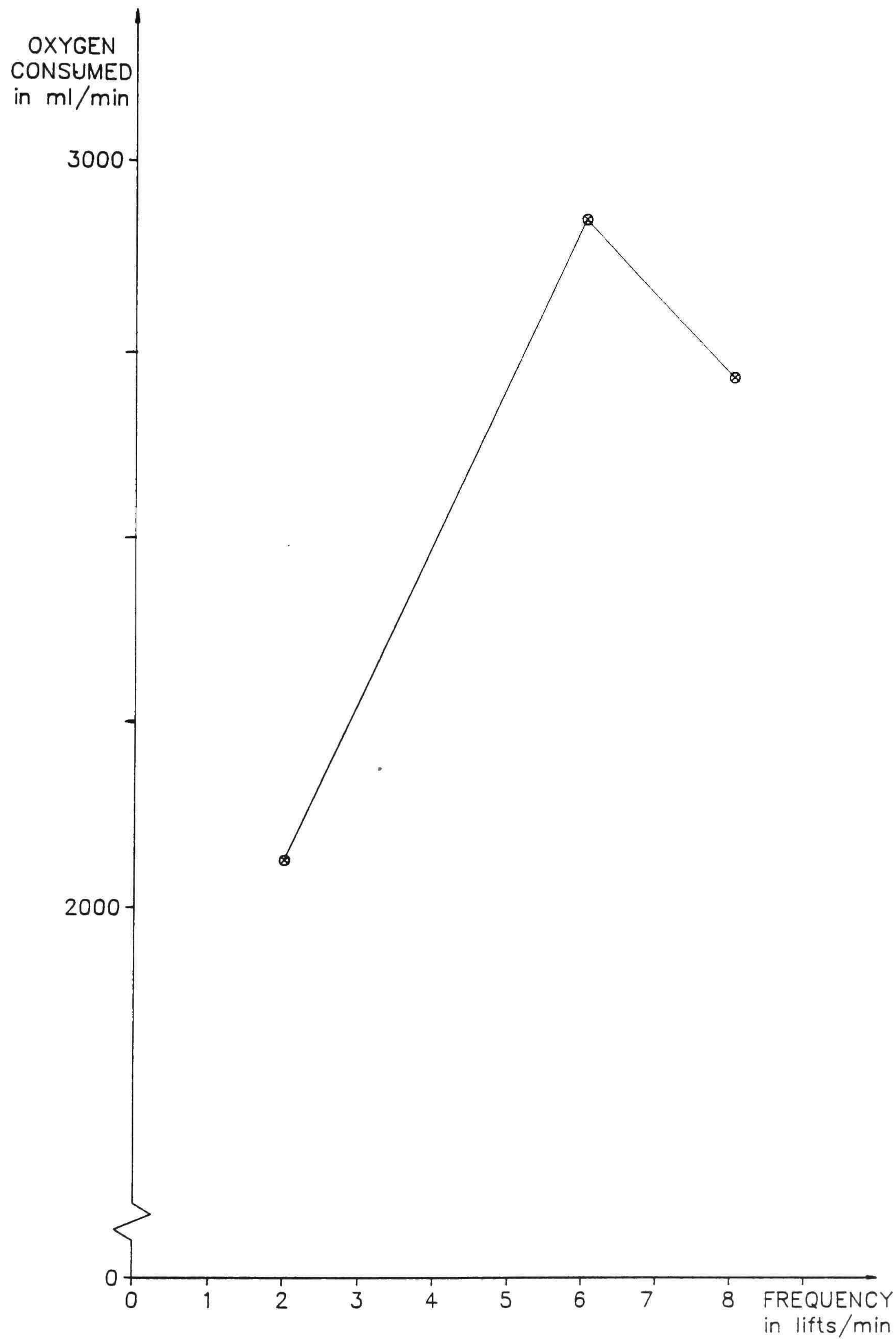

Figure 17: Graphical interpretation of physical work capacity at the three lifting frequencies

Comparison of the psychophysical and the physiological approaches in the lifting capacity

Experiment 1 was the comparison of the psychophysical and the physiological approaches in a lifting task. Table 8 shows the comparison of the MAWOL of the present study with a few previous studies.

TABLE 8

Comparison of MAWOL of Present Study With Previous Studies

	Mean (lbs.)	s.d. (lbs.)	Freq. (1/min)	Box width	n
Present study	53.75	13.14	2	12"	12
Selan (1986)	50.62	13.84	2	12"	8
Asfour (1980)	68.94	12.66	3	15"	10
Present study	30.42	6.13	8	12"	12
Selan (1986)	36.62	14.54	8	12"	8
Asfour (1980)	46.19	7.88	8	15"	10

The MAWOL of the present study was found to be significantly different from Asfour's study at the 1% level, however the present study and Selan's (1986) study were not found to be significantly different. The higher values obtained in Asfour's study could be attributed to the training of the subjects.

TABLE 9

Summary of the Psychophysical and Physiological Approaches in Determining Lifting Capacity

	Freq.	Lift. Cap.(lbs)		%PWC	
	(1/min)	Mean	s.d.	Mean	s.d
Psychophysical	2	53.75	13.14	31%	9.97%
Psychophysical	8	30.42	6.13	38%	6.53%
Physiological	2	67.38	33.02	33%	16.17%
Physiological	8	21.65	14.20	33%	21.37%

A summary of the MAWOL and the lifting capacity using the 1/3 PWC criteria for the physiological approach is presented in table 9. Percentage PWC at 2 and 8 lifts/minute were similar to the findings of Selan (1986).

For the interpolation of physiological lifting capacity at 2 lifts/ minute, the PWC at 2 lifts/minute was utilized; in the same manner, the PWC at 8 lifts/minute was utilized for the lifting capacity at 8 lifts/minute as shown in figures 18 and 19.

Figure 20 shows the lifting capacity based on the psychophysical and the physiological approaches. This study was conducted over two frequencies (2 and 8 lifts/minute); therefore, the straight line fit. The lifting capacity based on the physiological criteria overestimated the lifting

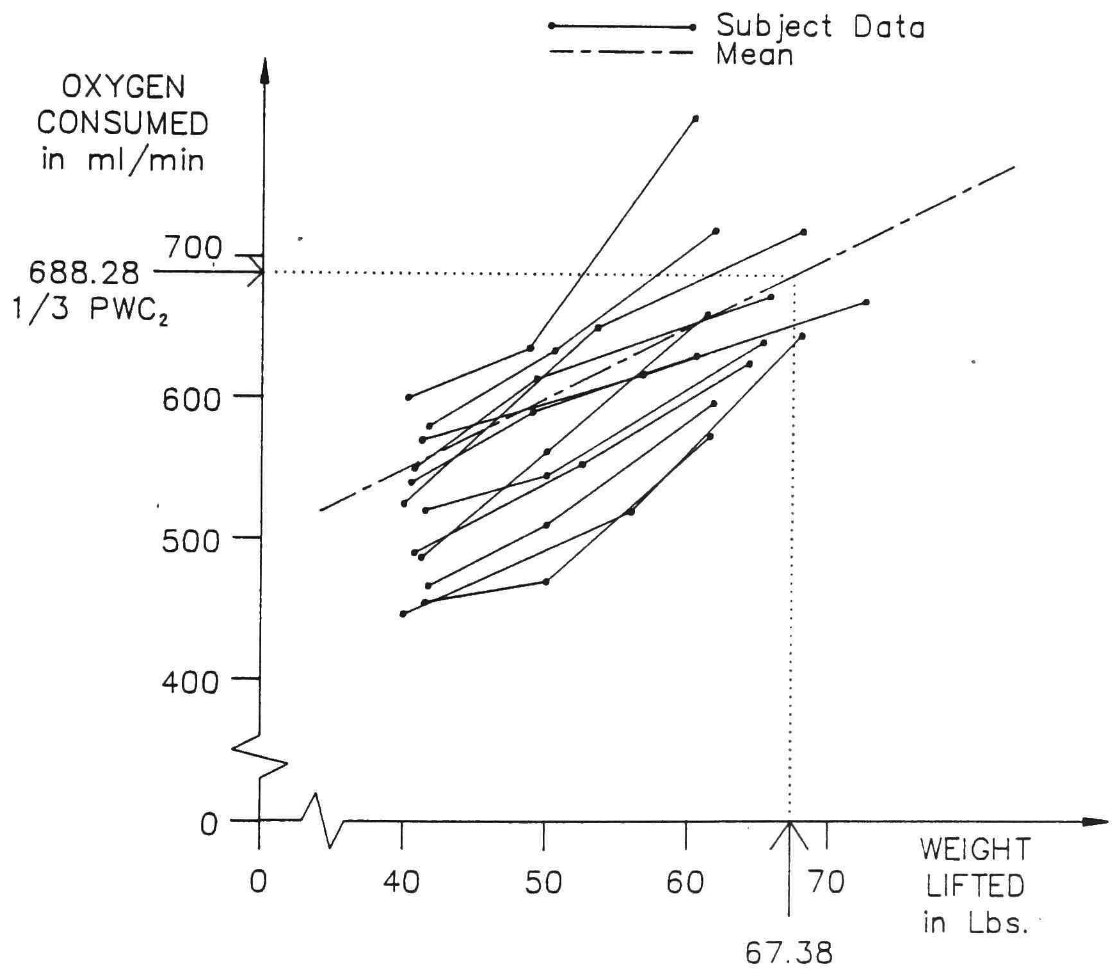

Figure 18: Graphical interpretation of physiological lifting capacity at 2 lifts/minute

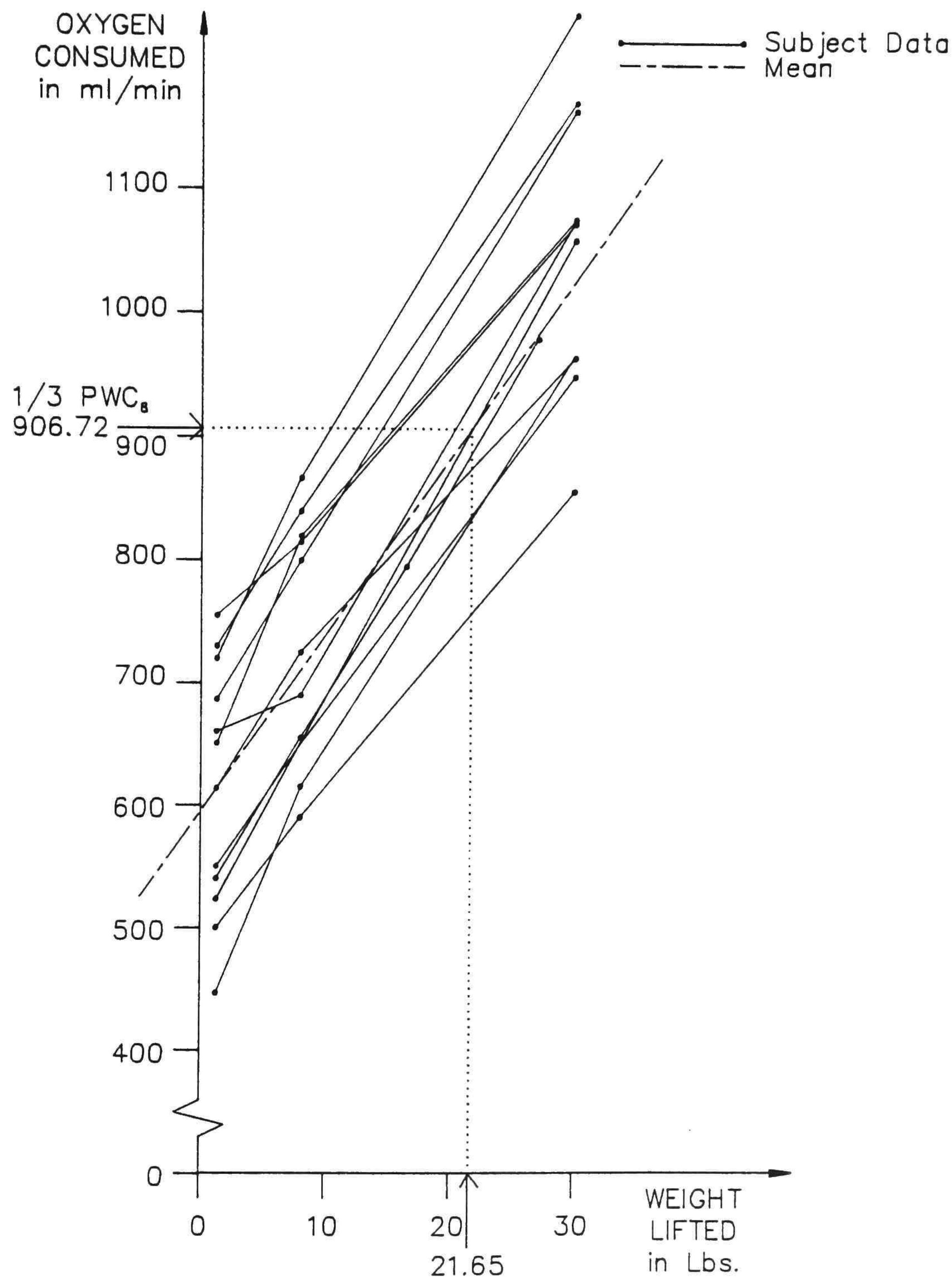

Figure 19: Graphical interpretation of physiological lifting capacity at 8 lifts/minute

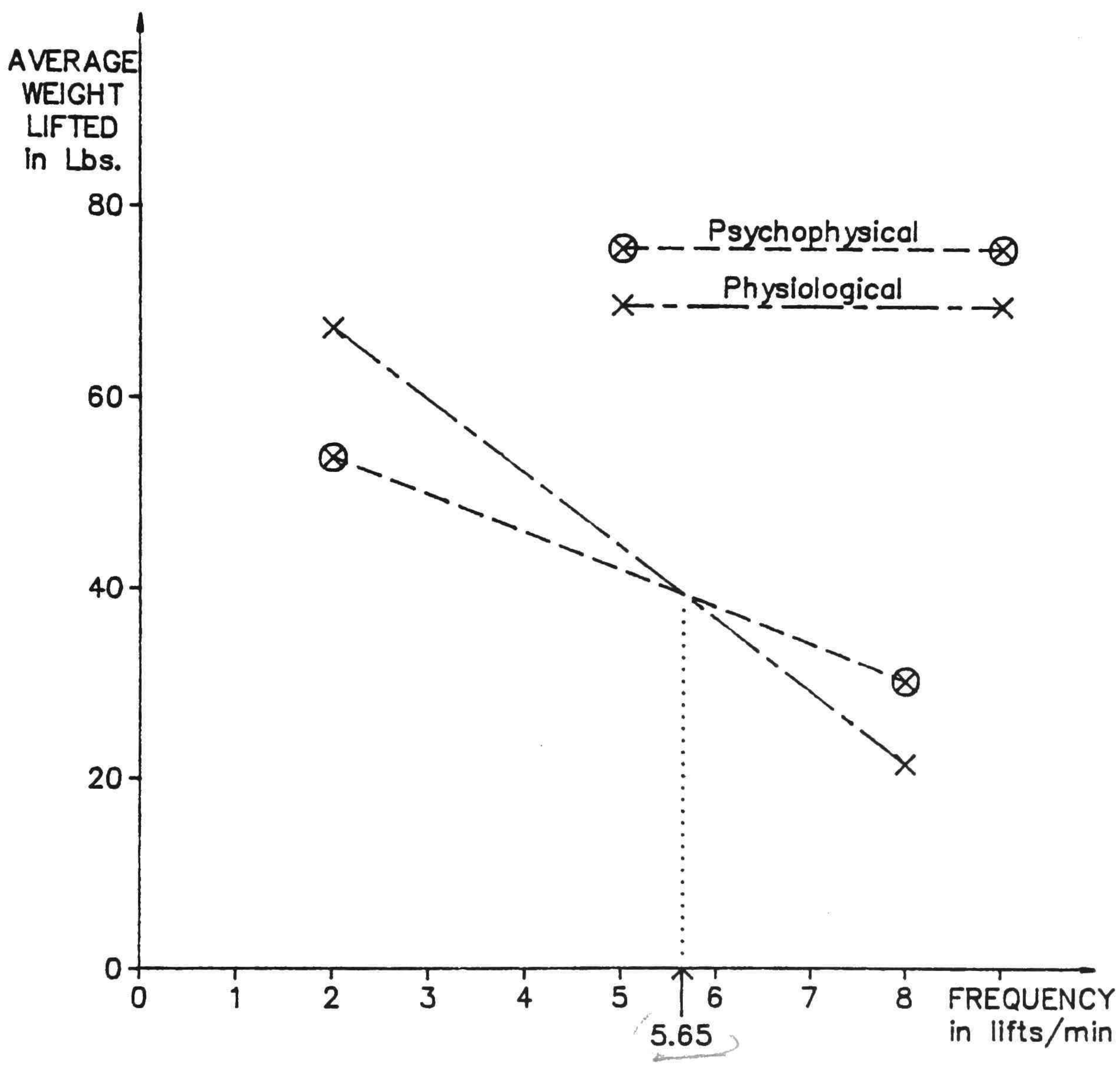

Figure 20: Comparison of the lifting capacity based on the psychophysical and physiological approaches

capacity based on the psychophysical criteria at 2 lifts/minute by 25.36%. However, at 8 lifts/minute, the lifting capacity based on the physiological criteria underestimated the lifting capacity based on the psychophysical criteria by 28.83%. This is contrary to Mital's (1985) results which stated that the lifting capacity based on the physiological criteria overestimated the lifting capacity based on the psychophysical criteria over the frequency range of 1 to 12 lifts/minute. The results of the present study support the conclusions of Garg and Ayoub (1980).

The linear fit of the curve in figure 20 is not characteristic over the whole frequency range. At the low frequency from 0.1 to 2 lifts/minute the curve is negatively exponential, but from 2 to 12 lifts/minute it is approximately linear (Ayoub, 1983a). From figure 20, at 5.65 lifts per minute the lifting capacity based on the two criteria coincide, which is similar to the conclusions of Garg and Ayoub (1980).

At the low frequency of 2 lifts/minute the physiological system is not stressed enough; therefore, the physiological criteria is a gross overestimation of the lifting capacity. At low frequencies the biomechanical criteria is more appropriate, while at high frequencies the physiological criteria is more appropriate. The overestimation of the physiological criteria at 8 lifts per minute by the psychophysical criteria is due to the psychophysical methodology where the subject probably does not have enough time to estimate how fatigued he could get after working the whole day. Therefore, utilizing the psychophysical approach to estimate lifting capacity is appropriate over the entire frequency range when compared to utilizing the physiological or the biomechanical criteria.

Figure 21 shows the MAWOL at 6 lifts/minute from Selan (1986) and the physiological and psychophysical lifting capacity criteria of the present study. The MAWOL at 6 lifts/minute is 39.73 lbs. (n=30), which is 3.8% higher than the interpolated value of 38.2 lbs.

Figure 22 shows the lifting capacity based on the psychophysical criteria adjusted for the 8 hours, with the lifting capacity based on the physiological criteria. The MAWOL utilized in this figure was the weight at the end of hour 8 at 2 and 8 lifts/minute. It is evident from figure 22 that at the low frequency, the physiological criteria still overestimates the psychophysical criteria; also at the high frequency the physiological criteria still underestimates the psychophysical criteria. The frequency where both criteria estimate the same weight is 7.07 lifts/minute.

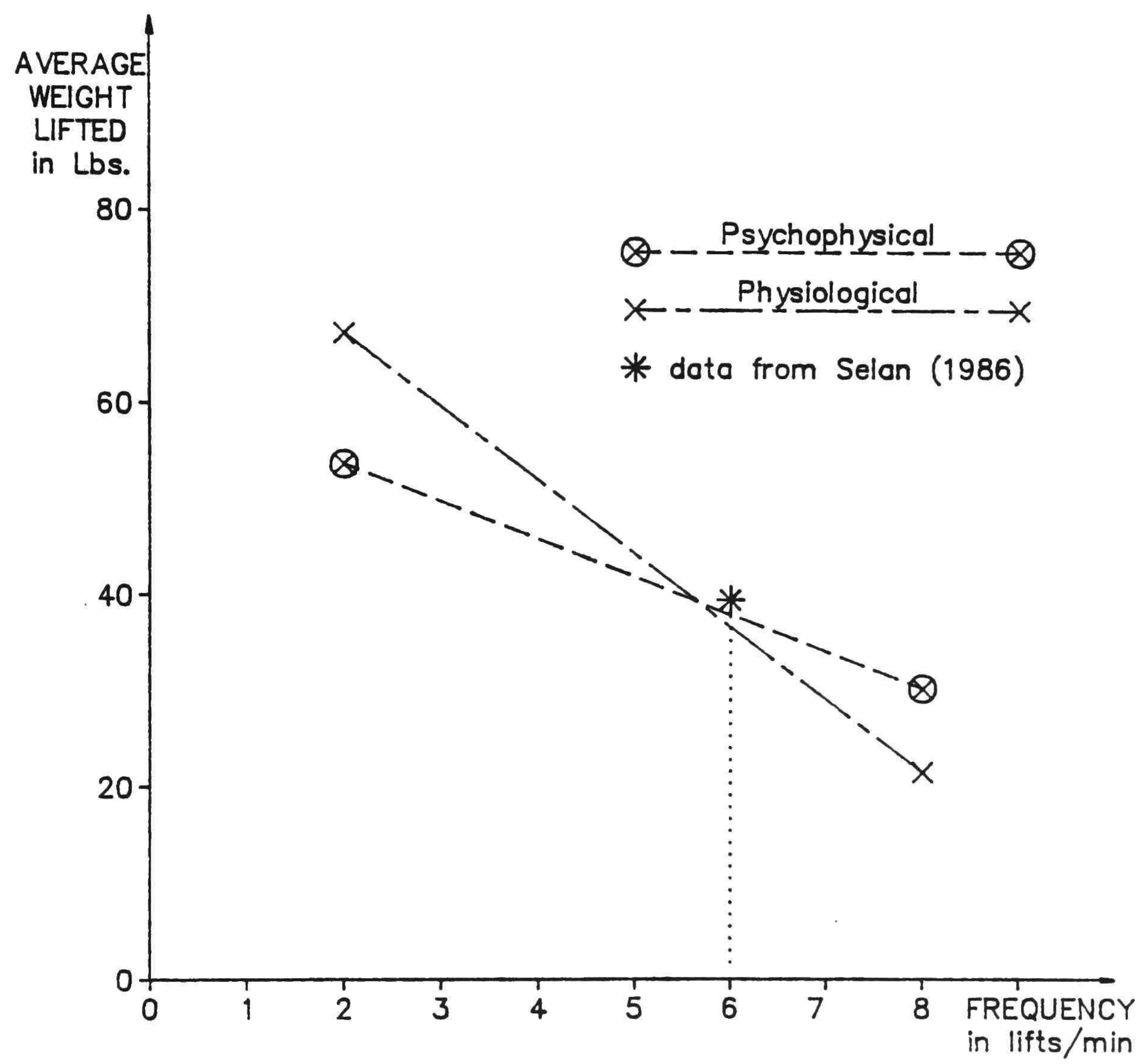

Figure 21: Comparison of the lifting capacity based on the psychophysical data at 6 lifts/minute (Selan 1986)

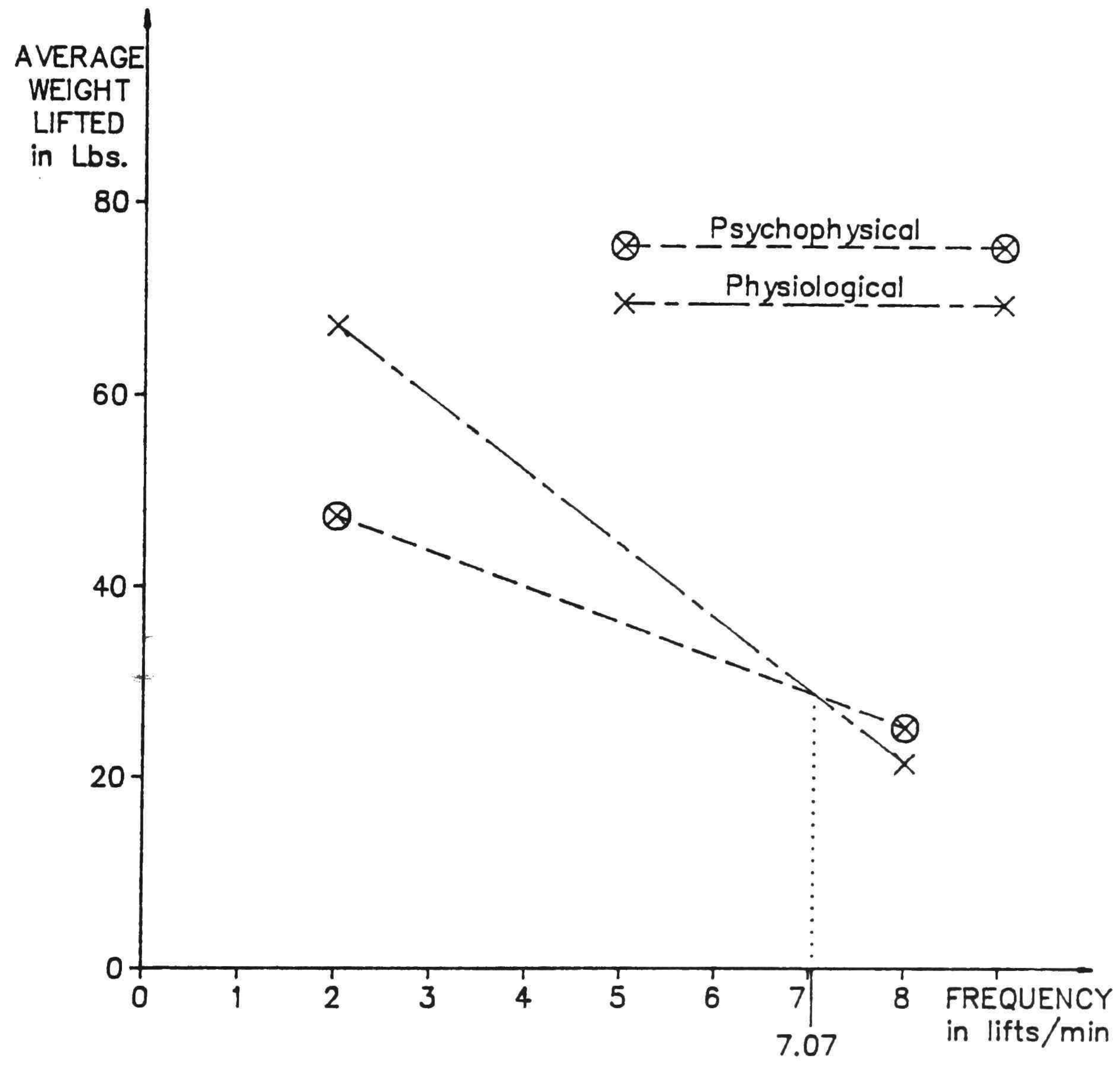

Figure 22: Comparison of the lifting capacity based on the adjusted psychophysical and physiological approaches

The analysis of variance with weight, oxygen consumption and heart rate as the main effects is presented in appendix C. The results reveal that there was no significant difference between subjects with weight and oxygen consumption as the dependent variables but was significant with heart rate as the dependent variable. There was a significant difference within each main treatment (weight, oxygen consumption and heart rate). Performing the Duncan Multiple test revealed that there was no difference between the psychophysical and the physiological approaches for weights, but there was a difference between the frequencies at the 5% level. With oxygen consumption as the main treatment, it was found that there was a significant difference between the psychophysical and physiological approaches at the 8 lifts/minute level but not at the 2 lifts/minute level.

Results of the 8-hour adjustment allowed period

The subjects were allowed to adjust the weight over the 8 hours. Table 10 is a summary of the weight lifted, the oxygen consumption, and heart rate over the 8 hours.

Figures 23 through 28 show the effect of time on weight lifted, oxygen consumption, and heart rate for the two frequencies. The weight decreased to 88.32% for the 2 lifts/

TABLE 10

Summary of the 8-hour Adjustment Allowed Periods

	Freq.=2 lifts/min			Freq.=8 lifts/min		
Hour	Wt(lb)	Oxy(ml/min)	HR(bpm)	Wt(lb)	Oxy(ml/min)	HR(bpm)
1	49.79	602.80	95.71	28.33	1071.42	115.05
2	49.00	623.05	92.86	27.73	1094.21	112.71
3	48.06	597.36	93.08	27.29	1192.21	114.59
4	48.06	569.72	90.67	26.98	1122.09	115.99
			LUNCH			
5	47.83	612.19	96.33	25.54	1154.83	119.29
6	46.83	599.16	91.97	25.54	1118.36	114.10
7	47.14	609.72	90.87	25.20	1146.76	114.90
8	47.14	601.38	91.05	25.21	1140.85	115.87

minute lifting and decreased to 83.62% for the 8 lifts/minute 8-hour lifting sessions. The average decrease in weight for the two frequencies was to 85.97% of MAWOL. This differs from Mital's (1983) conclusions where the weight for an 8-hour period decreased to 65%.

The average duration of a break was two minutes and the timing of the breaks were random. The number of breaks were

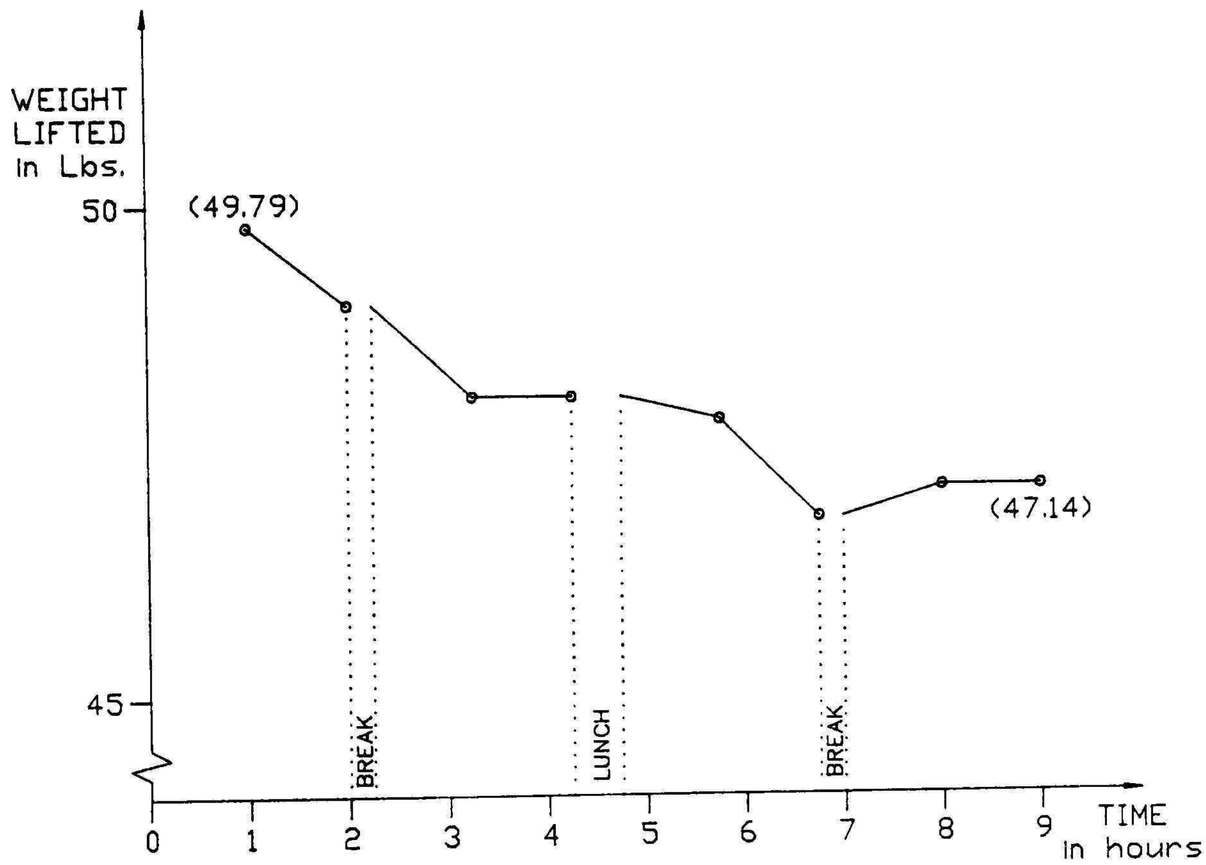

Figure 23: Change in MAWOL with time at 2 lifts/minute (Experiment 2)

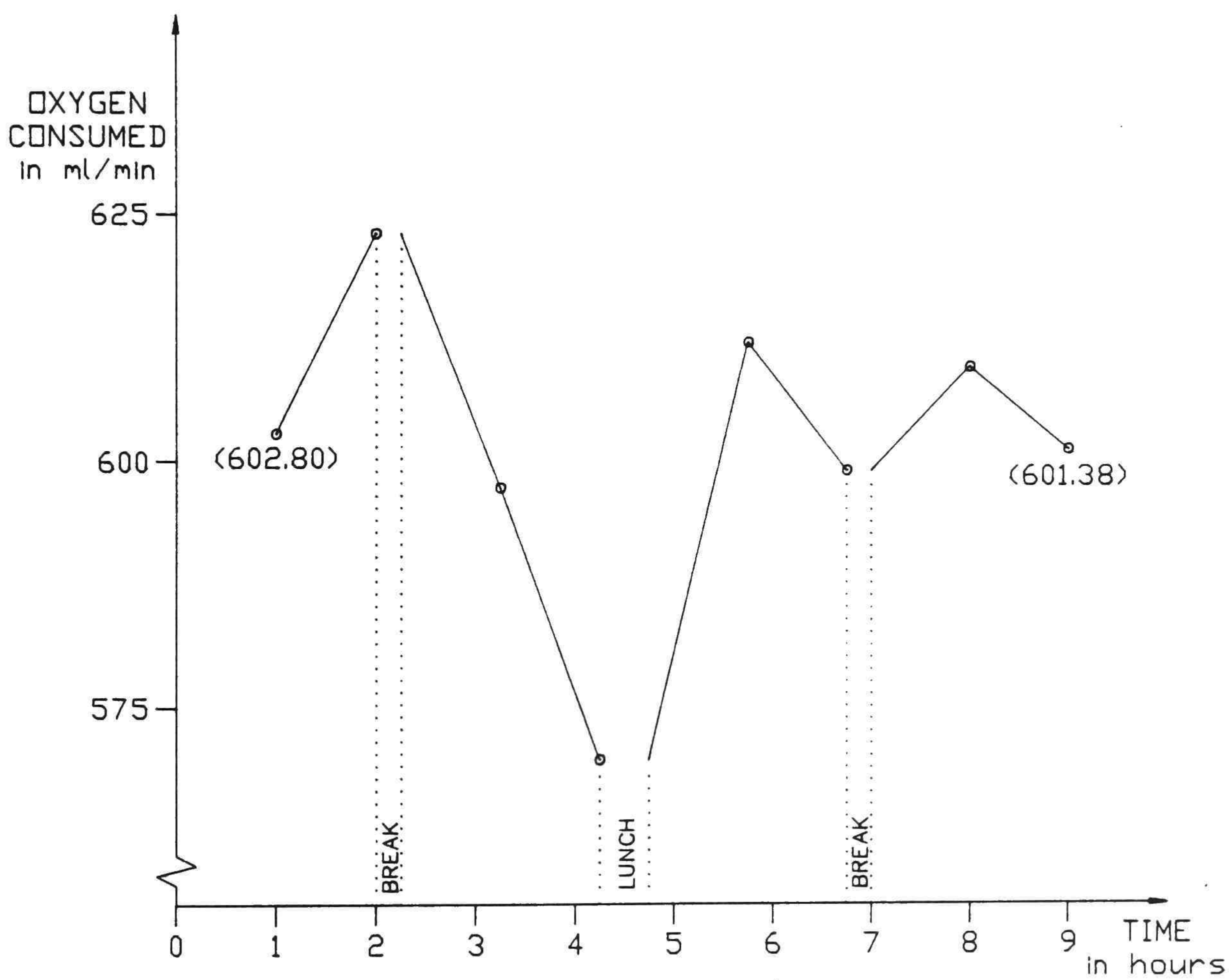

Figure 24: Change in oxygen consumption with time at 2 lifts/minute (Experiment 2)

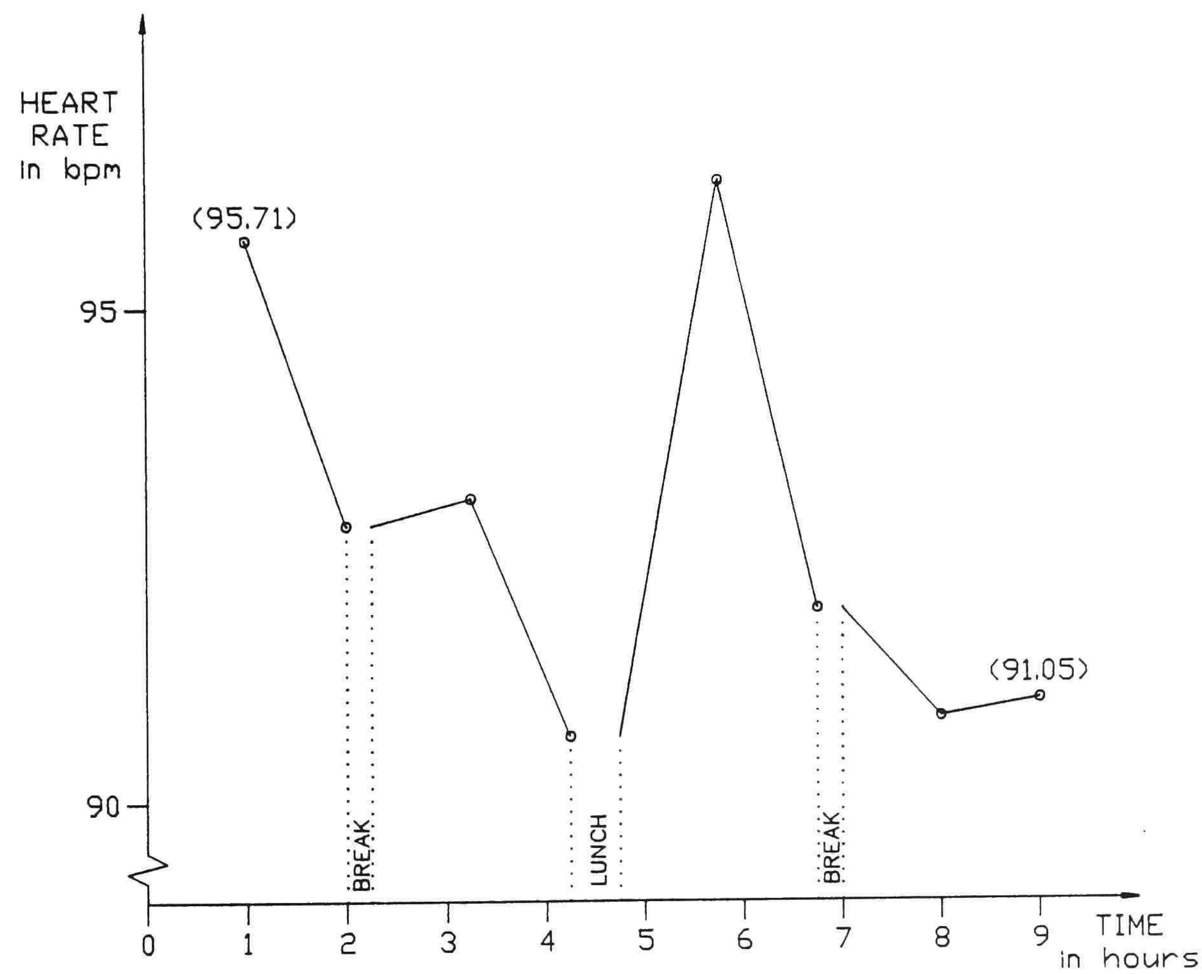

Figure 25: Change in heart rate with time at 2 lifts/minute (Experiment 2)

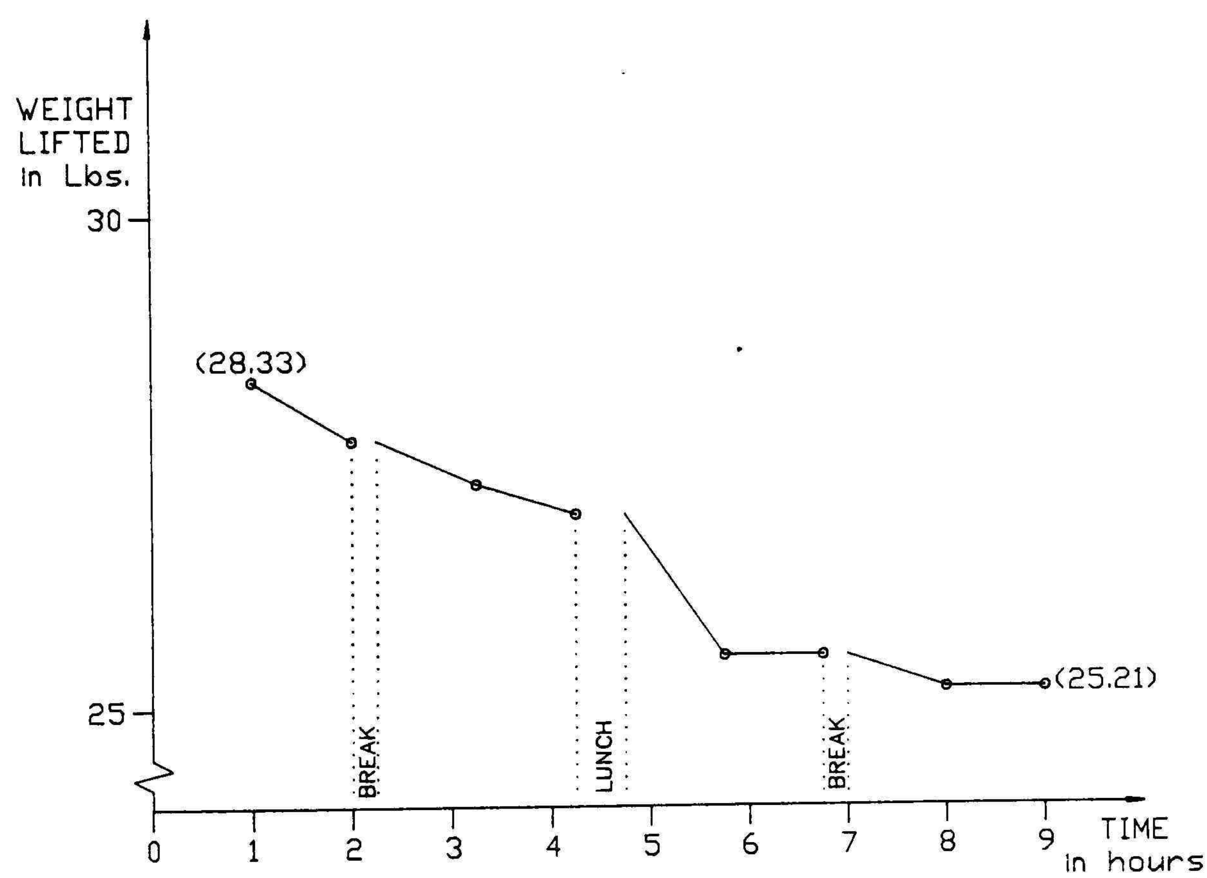

Figure 26: Change in MAWOL with time at 8 lifts/minute (Experiment 2)

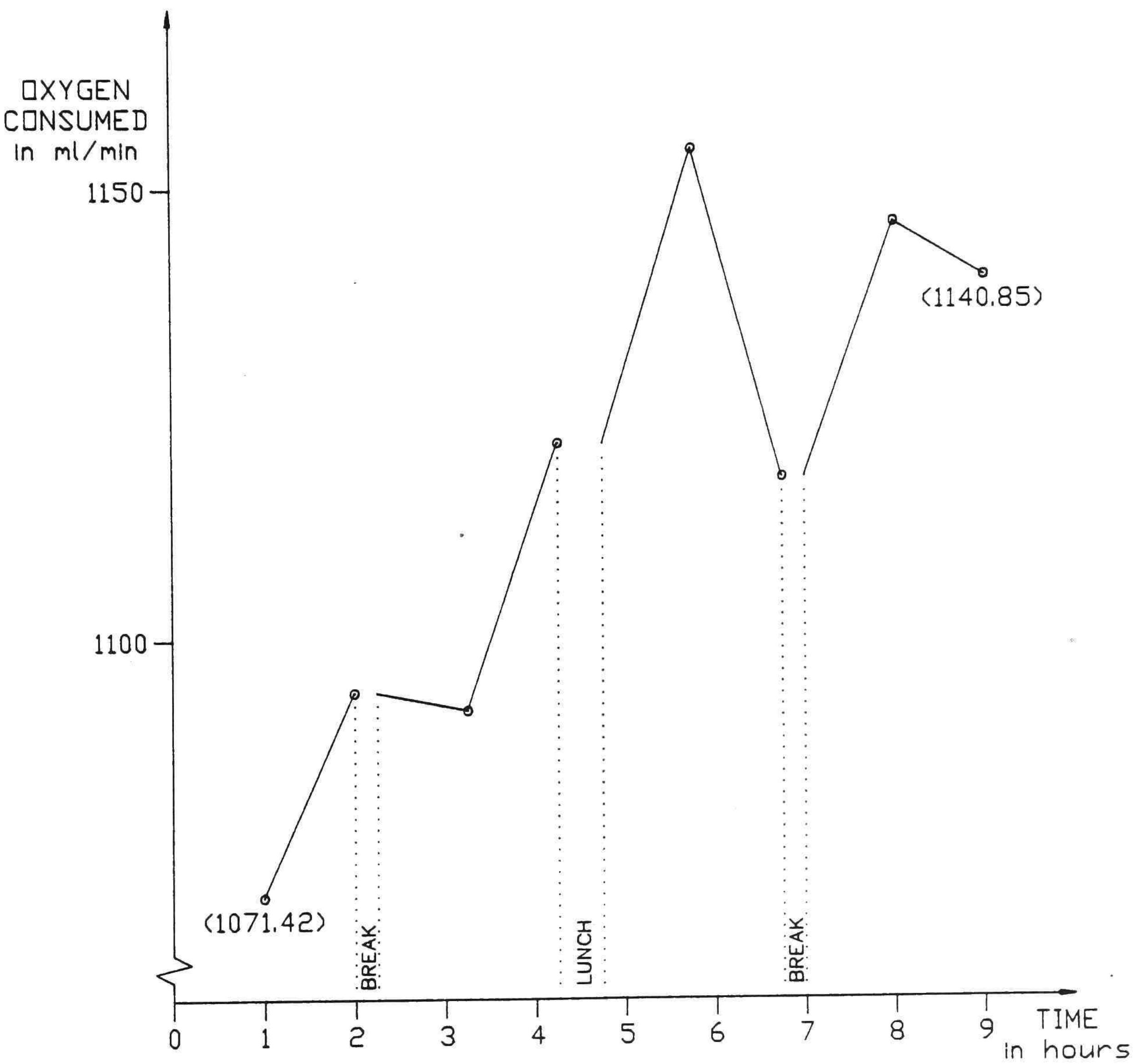

Figure 27: Change in oxygen consumption with time at 8 lifts/minute (Experiment 2)

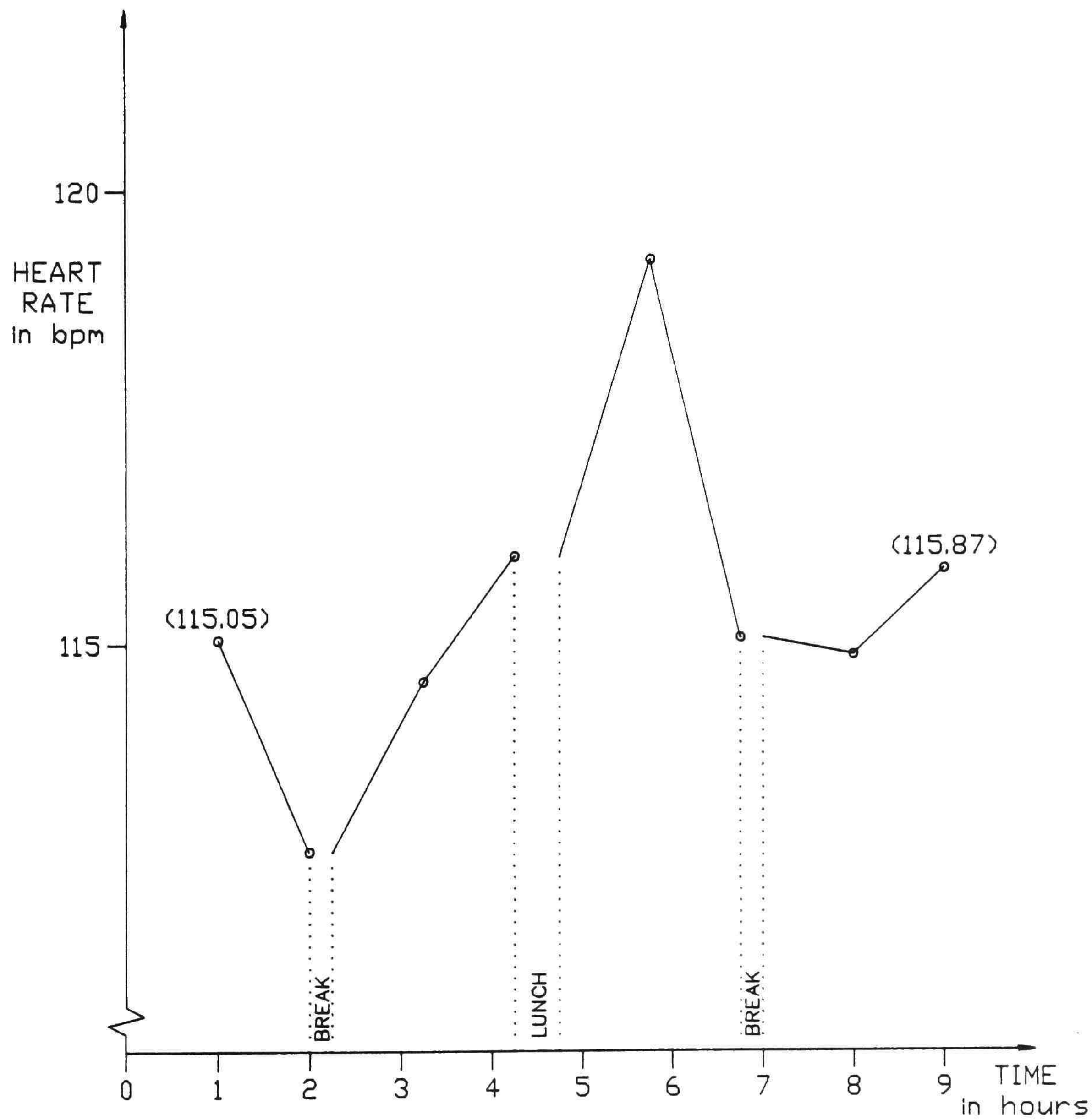

Figure 28: Change in heart rate with time at 8 lifts/minute (Experiment 2)

higher for the 8 lifts per minute sessions and not significantly different at the 5% level from the number of breaks for the 2 lifts per minute sessions.

Seventy percent of the total number of weight adjustments were made in the first hour of work or the first hour after lunch (5th hour). The first hour adjustments could be attributed to the fact that the weight was overestimated. After lunch, with the body doing internal work (redirecting blood for digestion), the external work (weight lifted) was adjusted. Six subjects made no weight adjustment at two lifts/minute, and only two subjects made no weight adjustment at eight lifts/minute. After lunch, the oxygen consumption and heart rate increased; this could be due to digestion. Six subjects did not make any adjustments over the entire eight-hour period for the two lifts/minute sessions. On the other hand, only two subjects made no adjustments for the eight lifts/minute sessions over an eight-hour period. From the figures it can be observed that from hour 1 to hour 2 with a weight decrease, there was a corresponding heart rate decrease. However, the oxygen consumption increased; this is due to the body adjustment over time. This phenomena was observed by the German researcher Wolfgang Laurig when testing industrial workers (Laurig, 1986).

Between the breaks, the working time was two hours. The responses over the two hours were such that the heart rate and oxygen consumption were lower at the end of the second hour compared to the first. Part of this decrease could have been the contribution of weight adjustment; it could also be due to the cardio-pulmonary adjustment over time.

In explaining body adjustment over time, one must consider the relationship between cardiac output and oxygen consumption. The Ficks equation (West, 1985) states that:

Oxygen Consumption = Cardiac Output * A-VO2

where A-VO2 = Arterial-venous oxygen difference. The components of cardiac output are heart rate and stroke volume. Possible explanation for the changes in oxygen consumption and heart rate might include adjustments in stroke volume, changes in A-VO2 difference, or redistribution of cardiac output over time.

Four types of prediction equations to predict weight lifted over the eight hours were developed. These were linear, exponential, logarithmic, and power. The regression equations with the R-square values are presented in table 11.

Appendix C shows the analysis of variance with weight lifted, oxygen consumed, and heart rate as the dependent variables. The difference in weight lifted and heart rate

TABLE 11

Prediction Equations to Predict Psychophysical Weight Lifted Over the Eight Hours

		Freq.= 2 l/min.	Freq.= 8 l/min.
Linear			
	wt = a + Hour*b	a = 49.6832	a = 28.5300
		b = -0.3782	b = -0.4693
		R-sq= 0.8479	R-sq = 0.8454
Exponential			
	wt = a*exp(Hour*b)	a = 49.6900	a = 28.7400
		b = -0.0078	b = -0.0184
		R-sq= 0.8496	R-sq = 0.9259
Logarithmic			
	wt = a + b*ln(Hour)	a = 49.8495	a = 28.7170
		b = -1.4273	b = -1.6899
		R-sq= 0.9424	R-sq = 0.9066
Power			
	wt = a * Hour**b	a = 49.8732	a = 28.6260
		b = -0.0314	b = -0.0639
		R-sq= 0.9186	R-sq = 0.9087

where Hour = 1, 2, ... 8

over the 8 hours were significant at the 1% level; however, the oxygen consumed was not. When the heart rate for hour 5 (1st hour after lunch) was disregarded, the difference in the heart rates over the period was not significant. Utilizing a Scheffe's test comparing the heart rate at hour 5 with the heart rates at the other seven hours, proved to be not significant at the 5% level. The significance in heart rate could be due to digestion of food and not the weight lifted.

Results from the t-test show that the MAWOL (determined in a 25 minute bout) at two lifts/minute was not significantly different at the 5% level from the weight lifted at the 1st hour mark of the 8 hour adjustment allowed 2 lifts/minute session. However, MAWOL (determined in a 25 minute bout) at 8 lifts/minute was significantly different at the 1% level from the weight lifted at the 1st hour mark of the 8 hour adjustment allowed 8 lifts/minute session.

Results of the 8-hour no-adjustment allowed period

The subjects were not allowed to adjust the weight over the eight hours. Table 12 is a summary of the oxygen consumption, heart rate, and the number of subjects working over the eight hours.

TABLE 12

Summary of the 8-hour No Adjustment Allowed Periods

	Frequency = 2 lifts/min. Ave. Wt. = 53.75 lbs			Frequency = 8 lifts/min. Ave. Wt. = 30.42 lbs		
Hours	OXY	HR	N	OXY	HR	N
1	627.23	96.74	12	1090.29	112.42	12
2	654.72	94.20	12	1033.89	107.56	12
3	649.02	93.97	12	1032.84	113.48	12
4	633.05	92.35	12	1068.34	112.02	11
LUNCH						
5	686.64	98.11	12	1156.66	121.12	11
6	669.72	94.91	12	1141.67	118.40	4
7	642.77	91.34	12	1131.13	116.13	3
8	640.27	92.71	12	1187.80	120.00	3

where OXY = oxygen consumption in ml/min.

HR = heart rate in bpm.

N = no. of subjects working at the end of specific hours.

All twelve subjects lasted the 8 hour no-adjustment allowed period with the frequency at 2 lifts/minute. On the other hand, nine subjects quit the 8 lifts/minute 8 hour session complaining of soreness in the lower back, upper legs, and shoulders. This soreness disappeared after 1-2 days. Eight subjects quit soon after lunch, the reason for which could be attributed to digestion of food, which was additional work for the body.

Figures 29 through 32 show the effect of time on oxygen consumption and heart rate for the frequencies of 2 and 8 lifts/minute. The figures reveal that the oxygen consumption and heart rate increased after lunch at the 5th hour. The oxygen consumption and heart rate decreased in the 2nd hour compared to the first hour for the first three 2 hour sessions. This was due to body adjustment over time. However, oxygen consumption and heart rate of the last hour was higher than the 7th hour which could be attributed to fatigue. During the second hour of work, there was a decrease in heart rate but increase in oxygen consumption at the 2 lifts/minute frequency. This was different for the 8 lifts/minute case, where a decrease in heart rate was associated with a decrease in oxygen consumption.

The average duration of a break was two minutes and the number of breaks for the 8 lifts per minute session was higher and significantly different at the 5% level than the number of breaks for the 2 lifts per minute sessions. The

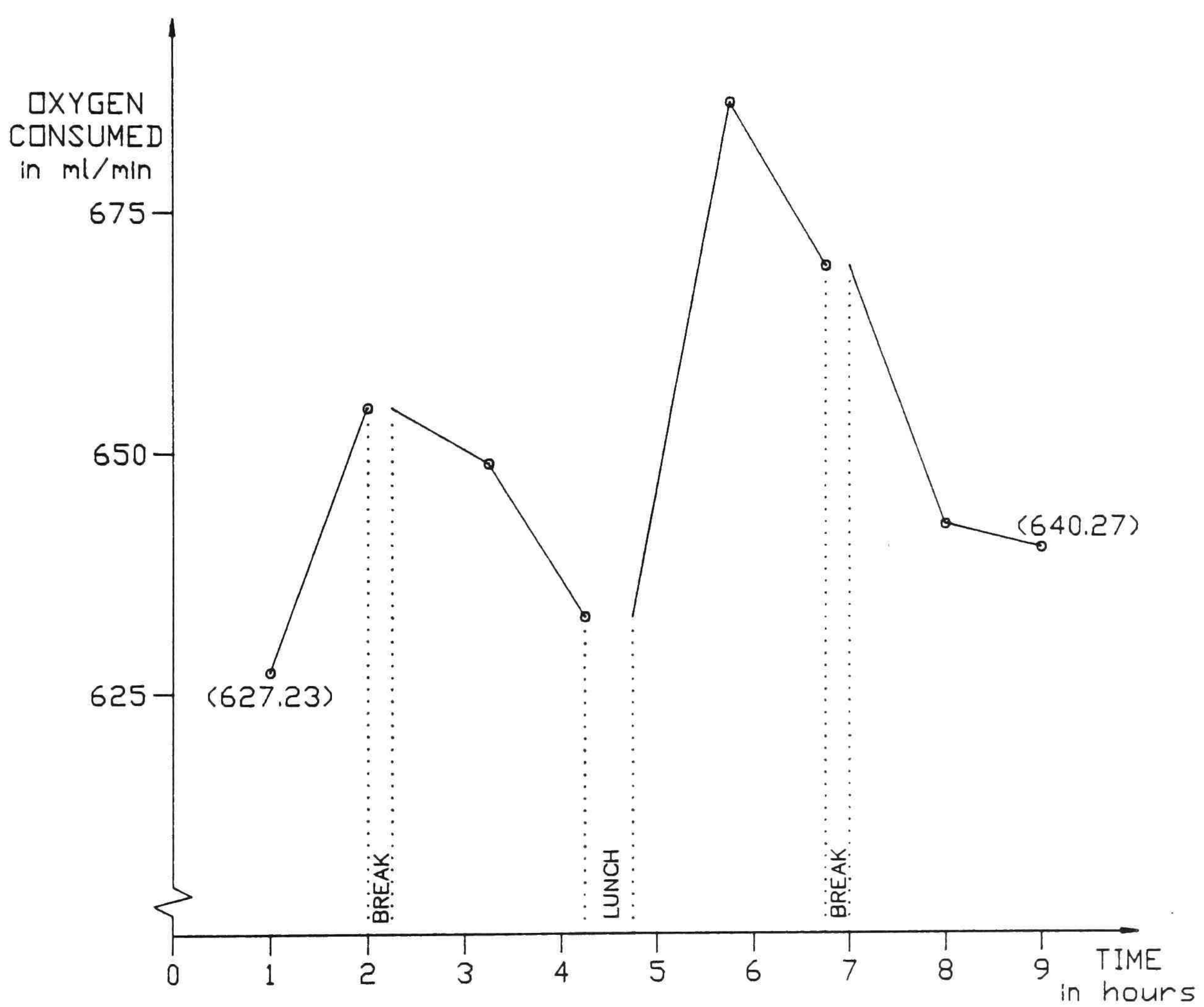

Figure 29: Change in oxygen consumption with time at 2 lifts/minute (Experiment 3)

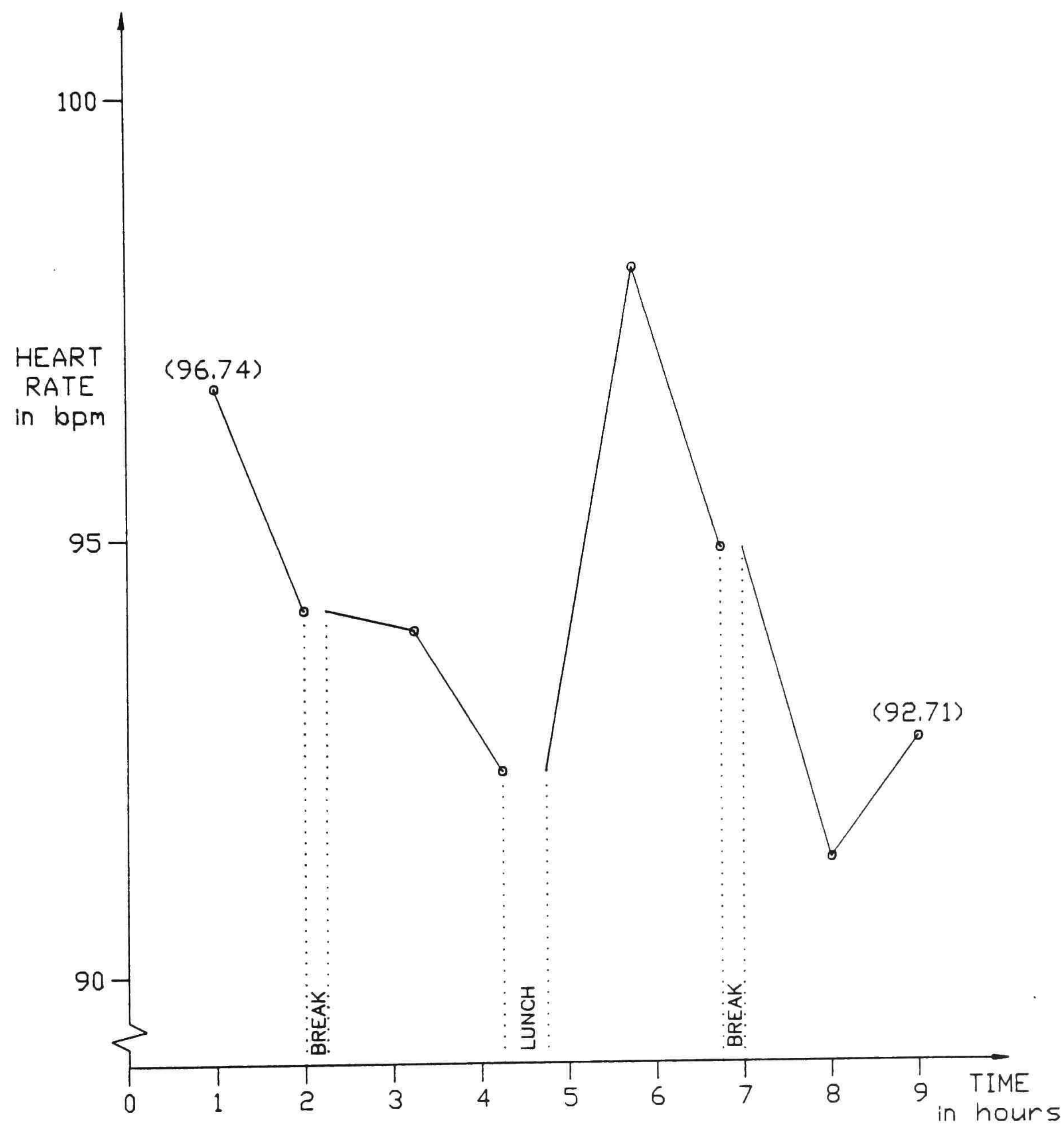

Figure 30: Change in heart rate with time at 2 lifts/minute (Experiment 3)

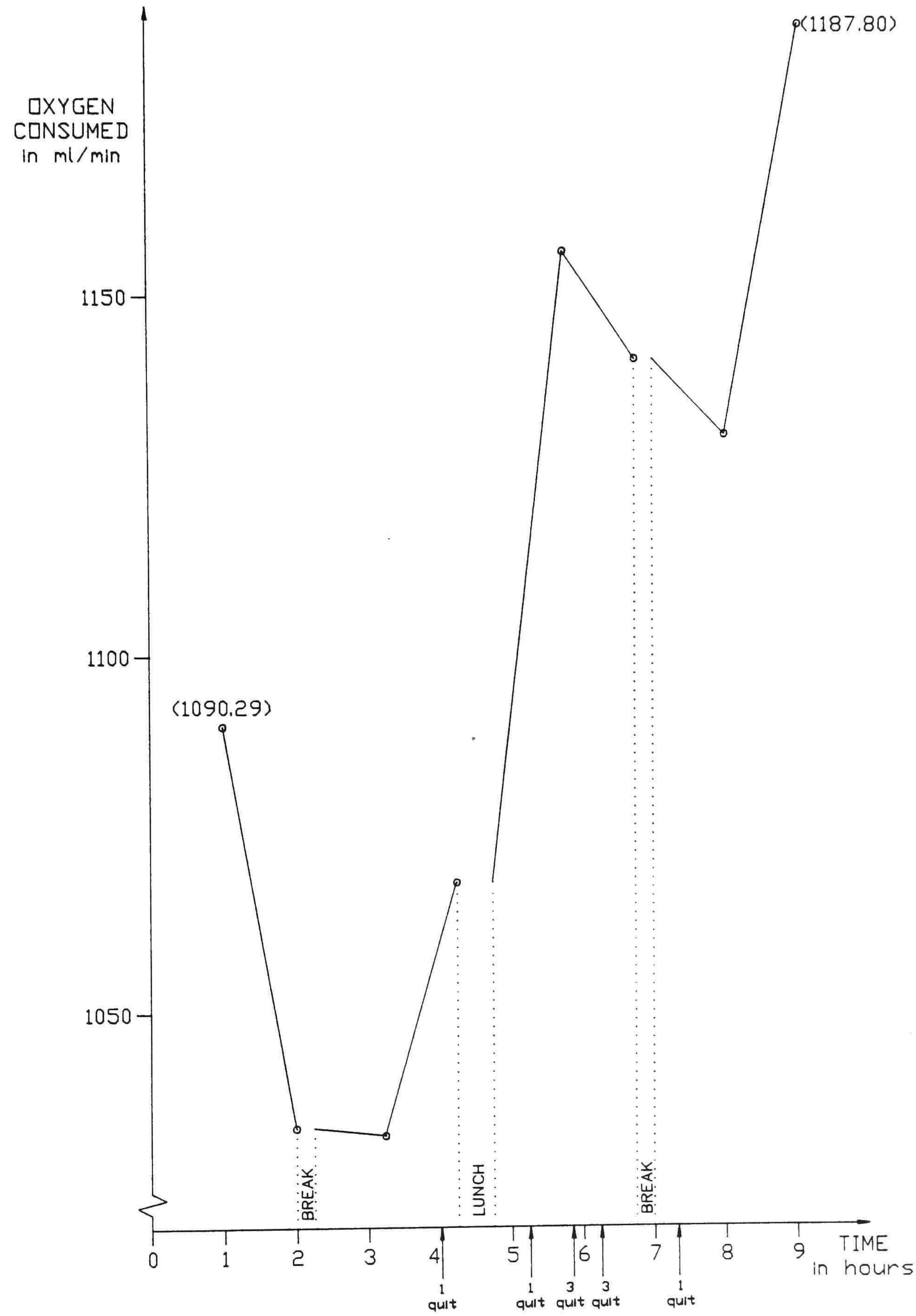

Figure 31: Change in oxygen consumption with time at 8 lifts/minute (Experiment 3)

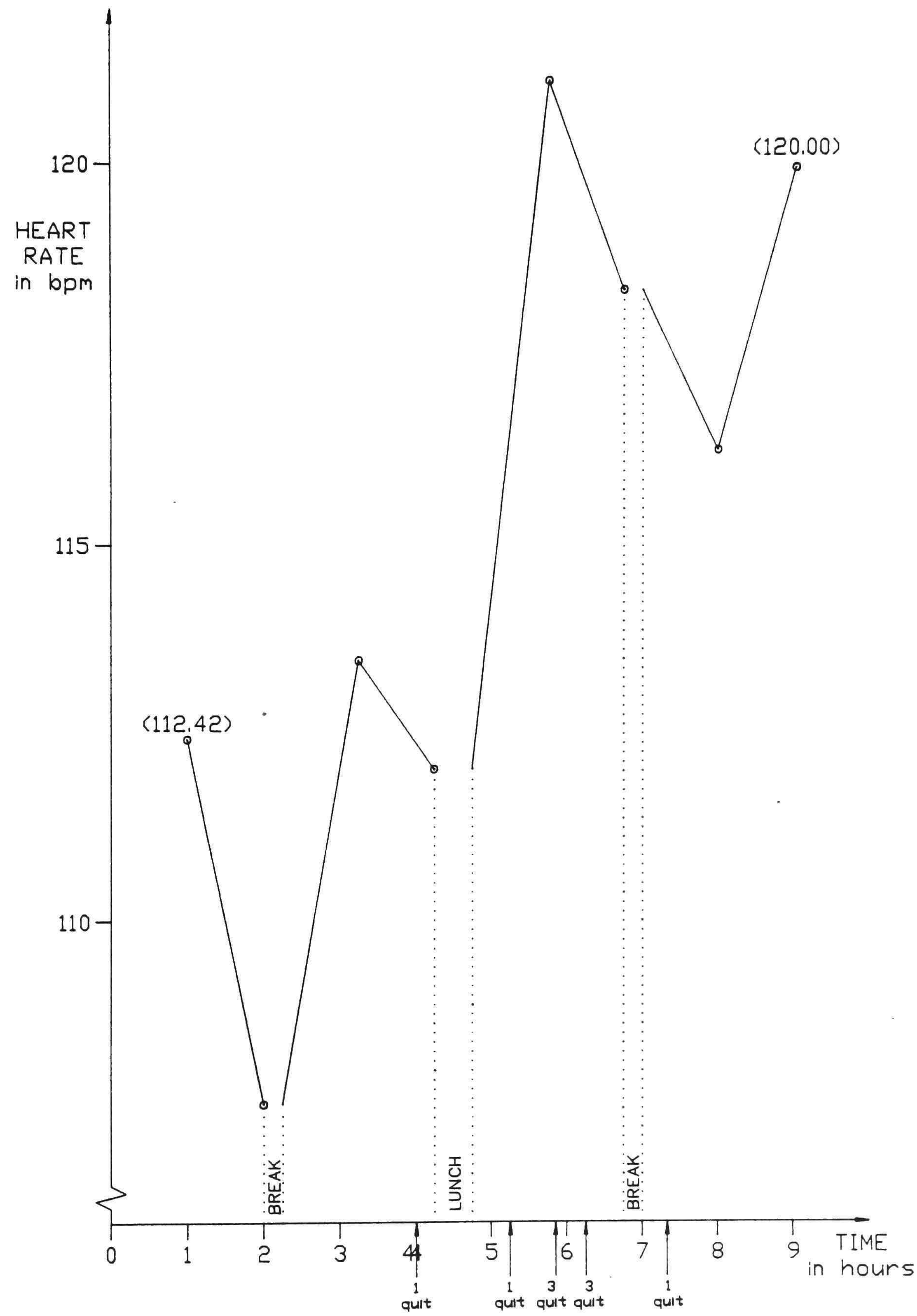

Figure 32: Change in heart rate with time at 8 lifts/minute (Experiment 3)

subjects who quit took one to three breaks one hour prior to quitting; this could have been due to fatigue.

The data of the three subjects that lasted the 8 hours, 8 lifts per minute session when compared to the nine subjects that quit showed no significant difference nor was there any trend difference. The resting heart rate and the resting oxygen consumption of the three that did not quit was lower than the other nine, implying that the three were possibly in better physiological condition.

Appendix C shows the analysis of variance with oxygen consumption and heart rate as the dependent variables over only three hours of the experiment. The analysis revealed that heart rate was significantly different over the 3 hours at the 1% level.

Multiple t-tests were utilized to analyze the data and are presented in tables 13 through 14. It is evident from these tables that there was a significant difference at the 1% level between hour 4 and 5 for oxygen consumption and heart rate for 2 and 8 lifts per minute. In addition, there was a significant difference at the 5% level between hour 5-6 and hour 6-7 for the heart rate at 2 lifts/minute; this was due to the digestion of lunch and the low heart rates. This was not noticed in the case of 8 lifts/minute as the heart rates were higher which overshadowed this effect.

TABLE 13

Summary of t-tests for 8-hour No Adjustment Allowed, 2 Lifts

Treatment	Difference Between Hour Number	T	PR > |T|
OXY	1 - 2	-1.53	0.1551
OXY	2 - 3	0.57	0.5806
OXY	3 - 4	1.09	0.2987
OXY	4 - 5	-2.53	0.0282
OXY	5 - 6	1.25	0.2380
OXY	6 - 7	1.01	0.3320
OXY	7 - 8	0.21	0.8352
HR	1 - 2	2.39	0.0356
HR	2 - 3	0.20	0.8483
HR	3 - 4	0.83	0.4236
HR	4 - 5	-3.77	0.0031
HR	5 - 6	2.49	0.0302
HR	6 - 7	2.95	0.0133
HR	7 - 8	-1.37	0.1992

TABLE 14

Summary of t-tests for 8-hour No Adjustment Allowed, 8 Lifts

Treatment	Difference Between Hour Number	T	PR > |T|
OXY	1 - 2	2.85	0.0158
OXY	2 - 3	0.05	0.9583
OXY	3 - 4	-0.90	0.3877
OXY	4 - 5	-5.40	0.0003
OXY	5 - 6	0.33	0.7606
OXY	6 - 7	-1.46	0.2821
OXY	7 - 8	-1.21	0.3486
HR	1 - 2	5.36	0.0002
HR	2 - 3	-4.18	0.0015
HR	3 - 4	1.03	0.3261
HR	4 - 5	-9.52	0.0001
HR	5 - 6	-0.03	0.9776
HR	6 - 7	-3.45	0.0748
HR	7 - 8	-1.31	0.3199

There was also a significant difference in the heart rate and oxygen consumption between the hour 1 and hour 2 of work at 8 lifts/minute at the 5% level. This was due to the body adjusting over time. Experiment 2 shows an overestimation of MAWOL on the part of the subjects, which does not cause any dire effects like quitting at the 2 lifts/minute level but had an effect at the 8 lifts/minute level.

Comparison of MAWOL, one-time maximum and 6-foot lift

Table 15 shows the correlation between the MAWOL, 6-foot incremental lift and the one-time maximum lift. The MAWOL at 8 lifts/minute being poorly strength-related had a low correlation with the strength test. The one-time max had a high correlation with MAWOL at 2 lifts/minute but low correlation at 8 lifts/minute.

Table 16 presents a summary of MAWOL, 6-foot incremental lift and the one-time max. It is observed from the table that there was an increase of 0.54% for MAWOL at 2 lifts/minute and an increase of 4.17% for MAWOL at 8 lifts/minute. Table 16 also reveals an increase of 6.58% in the isoinertial strength test, the 6-foot strength test. An increase of 9.93% was observed for the one-time max. The increase in the 6-foot incremental lift and the one-time max can be attributed to training.

TABLE 15

Correlation Matrix of MAWOL, 6-foot Lift and One-time Max

	S1	S2	AS1	AS2	L6B	L6A	OTMB	OTMA
S1	--	0.256	0.692	0.608	0.664	0.526	0.814	0.401
S2		--	0.241	0.169	-0.154	-0.172	0.327	-0.289
AS1			--	0.466	0.649	0.473	0.703	0.592
AS2				--	0.739	0.595	0.498	0.481
L6B					--	0.935	0.727	0.814
L6A						--	0.745	0.838
OTMB							--	0.656
OTMA								--

where S1 = MAWOL, 2 lifts/min.

S2 = MAWOL, 8 lifts/min.

AS1 = After MAWOL, 2 lifts/min.

AS2 = After MAWOL, 8 lifts/min.

L6B = 6-foot lift, before 8-hour periods

L6A = 6-foot lift, after 8-hour periods

OTMB = One time max., before 8-hour periods

OTMA = One time max., after 8-hour periods

TABLE 16

Summary of MAWOL, 6-foot Lift and One-time Max

	Mean	s.d.	Min. value	Max. value
S1	53.375	13.139	34.50	74.50
S2	30.417	6.133	21.50	39.25
AS1	53.667	8.636	37.50	65.25
AS2	31.687	4.609	22.25	36.75
L6B	126.667	16.143	100.00	150.00
L6A	135.005	14.459	120.00	160.00
OTMB	134.521	10.533	122.00	151.25
OTMA	147.875	19.095	127.50	186.25

where S1 = MAWOL, 2 lifts/min.

S2 = MAWOL, 8 lifts/min.

AS1 = After MAWOL, 2 lifts/min.

AS2 = After MAWOL, 8 lifts/min.

L6B = 6-foot lift, before 8-hour periods

L6A = 6-foot lift, after 8-hour periods

OTMB = One time max., before 8-hour periods

OTMA = One time max., after 8-hour periods

Development of prediction equations of MAWOL and weight lifted over the 8 hours

A correlation matrix was constructed and it was found that the correlation was highest between the 6-foot incremental lift, lean weight and height. The prediction equations with one predictor, the 6-foot incremental lift, and the prediction equations with three predictors, the 6-foot incremental lift, lean weight, and height are presented in Appendix D.

The R-square values were high for the 2 lifts/minute lifts but low for the 8 lifts/minute case. The 6-foot lifts which predicted strength, has a high influence in the 2 lifts/minute case but has a low influence in the 8 lifts/minute lifts. This has been reported in tasks which are highly repetitive and not directly related to strength (Ayoub, 1985b).

There was a high correlation between the MAWOL before and after at 2 lifts/minute; this was not true at 8 lifts/minute. However, the after MAWOL at 8 lifts/minute had a higher R-square compared to the before MAWOL. This could be attributed to better estimation of lifting capacity the second time. The low correlation between MAWOL at 8 lifts/minute before and after could be due to a dual influence on the subjects. On one hand, the subjects felt that they were in better shape (the effect of training) but that the quitting in experiment 3 caused an adverse effect, one causing the subjects to want to increase and the other to decrease the MAWOL.

Prediction equations were also developed using Physical Work Capacity and the six-foot lift as the predictors for MAWOL for the 25 minute bouts. The results are as follows:

S1 = -26.568 + 0.573*L6 + 0.003*PWC2   R-SQ = 0.4662

S2 = 33.799 - 0.060*L6 + 0.001*PWC8   R-SQ = 0.0724

where S1 = MAWOL at 2 lifts/minute

S2 = MAWOL at 8 lifts/minute

PWC2 = Physical Work Capacity at 2 lifts/min.

PWC8 = Physical Work Capacity at 8 lifts/min.

L6 = Six foot lift

When the 'Stepwise procedure' in the SAS utility was used, the MAWOL at 2 lifts/minute had the six foot lift as the first variable to enter the model, while the PWC entered the model in the case of MAWOL at 8 lifts/minute. This could possibly be attributed to the lifting at 2 lifts/minute being a strength oriented task and lifting at 8 lifts/minute an aerobic oriented task.

Additional study

Originally it was planned that the box would be lowered by the lifting machine. Due to mechanical wear and other constraints the machine was not used for any 8 hour sessions except for three. Instead helpers were utilized to lower the box. A study to disprove the hypothesis that social facilitation affected MAWOL was therefore found to be pertinent.

This study is divided into two sections: (1) the test of the hypothesis that social facilitation did not affect the determination of MAWOL; (2) the validation that the subjects who quit in the no-adjustment allowed periods did so because of overestimation and managed to lift a lighter weight for the whole 8 hours.

The sessions where only three subjects lifted at the lifting machine for the 8 hour periods were repeated with helpers lowering the box. The t-test results showed that there was no significant difference in the the MAWOL. There was significant difference in heart rate and oxygen consumption, which could be attributed to the training effect and day-to-day variation. It can therefore be concluded that social facilitation did not affect the determination of MAWOL (Saunders, et. al, 1978).

Two subjects who had quit the no-adjustment allowed period at 8 lifts/minute were asked to repeat the 8 hour no-adjustment period at 8 lifts/minute. The weight lifted was not the MAWOL estimated at the 25 minute period; instead, it was the MAWOL estimated at the 8 hour adjustment allowed period at 8 lifts/minute as shown in tables 17 and 18. The subjects did not know the weight of the box and the instructions and protocol was the same as the other 8 hour periods. Both subjects lasted the whole eight hours. The results show that the oxygen consumption and heart rate were lower than both the adjusting and the no-adjustment 8 hour periods at 8 lifts/minute. This indicates that the subjects, in fact, could not lift the MAWOL at the time they quit since they had overestimated the weight. The weight lifted the second time was below their physiological limits. The weight estimated over the 8 hour day and lifted the second time was underestimated. The subjects became fatigued during the earlier part of the adjustment allowed 8 hour day because they lifted heavier weights. The fatigue caused them to decrease the weight lifted in the latter part of the session. The estimation at the end of the day was lower than a weight they were capable of handling.

TABLE 17

Physiological Responses of Subject Number 6 in Additional Study

Subject No: 6   Wt Lifted: 21 lbs   Freq: 8 lifts / min

Hour	Heart Rate bpm	Oxygen Consumption ml / min
1	102	746.7
2	106.3	726.7
3	107	753.3
4	106	820.0
	LUNCH	
5	110.3	813.3
6	106.7	763.3
7	105.7	743.3
8	109	763.3

TABLE 18

Physiological Responses of Subject Number 5 in Additional Study

Subject No: 5 Wt Lifted: 22.5 lbs Freq: 8 lifts / min

Hour	Heart Rate bpm	Oxygen Consumption ml / min
1	101.3	996.7
2	105	1070
3	104.3	1153.3
4	102.7	1120
	LUNCH	
5	107.3	1286.7
6	102	1146.7
7	98	1100
8	104.3	1133.3

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations for future research are presented in this chapter.

Conclusions

The conclusions drawn from the results of this study are as follows:

1. The physiological approach overestimates the lifting capacity compared to the psychophysical approach at 2 lifts/minute by 25.36%, while the physiological approach underestimates the lifting capacity compared to the psychophysical approach at 8 lifts/minute by 28.83% as shown in figure 20. This is consistent with previous conclusions by Garg and Ayoub (1980).

2. The subjects were allowed to adjust the MAWOL in experiment 2 over the 8-hour period. At 2 lifts/minute the MAWOL decreased to 88.32% MAWOL on the average, with a max of 100% MAWOL and a minimum of 65.4% MAWOL. At 8 lifts/minute the MAWOL decreased to 83.62% MAWOL on the average, with a max. of 100% MAWOL and a minimum of 59.6% MAWOL. The weight lifted over the 8-hours decreased to 85.97% MAWOL on the

average; the psychophysical approach is therefore a good method to measure lifting capacity, as the decrement is not significant over time.

3. Oxygen consumption and heart rate were measured every hour. These two physiological responses showed a decrease in the fourth, sixth and eighth hour when compared to the third, fifth and seventh hour respectively, as shown in figures 23 to 28. While in the second hour the oxygen consumption increased with a decrease in heart rate when compared to the responses of the first hour. These changes can be attributed to the body getting accustomed to the work; in other words, the cardio-pulmonary system adjusted over time due to work.

4. In experiment 2, the adjusting 8-hour sessions, the subjects adjusted the MAWOL over the eight hours. Seventy percent of the total number of weight adjustments were made in the first or fifth hour of work. The adjustment in the first hour was perhaps due to overestimation on the part of the subject, while the adjustment in the fifth hour (first hour after lunch) could be due to the body adjusting the food, this being an additional load.

5. The lifting technique was different for various frequencies. For frequencies 2 to 6 lifts/minute, the technique was squat, but for the frequencies 6 to 8 lifts/minute the technique was stoop. The lifting PWC at 2 lifts/minute was significantly different from lifting PWC at 6 and 8 lifts/minute. The cause of the difference being that the physiological system was not stressed at 2 lifts/minute. There was a lowering of PWC at 8 lifts/minute when compared to PWC at 6 lifts/minute due to the lifting technique.

6. Bicycling and lifting involve different muscle groups and training is muscle group specific. The bicycling PWC increased 10.68% and lifting PWC at 6 lifts/minute increased 2.3% when measured before and after the 8-hour sessions. This difference in increase could be due to the training of specific muscle group during the experiment.

7. MAWOL determined for 25 minutes was measured at the beginning of the experiment and at the end of the 8-hour sessions. The results of a t-test showed that there was no significant difference between the means of the MAWOL before and after the experiment at the 5% significance level for the frequencies 2 lifts/minute and 8 lifts/minute. This shows that the estimation was not affected by the practice and experience obtained during the 8 hour sessions.

Recommendations for future research

It is felt the following topics should be explored in the future:

1. Investigation of Lifting Physical Work Capacity at lifting frequencies covering the frequency range of 0.1 to 12 lifts/minute.

2. Investigation of the weight adjusted and physiological responses for MMH activities over extended periods for the female population.

3. Investigation of the weight adjusted and physiological responses for MMH activities over extended periods, with a constrained diet for the subjects.

4. Investigation of the lifting technique at various set frequencies over the 8-hour day by biomechanical analysis.

5. Investigation of the physiological responses and weight adjusted over an eight hour period with the starting weight set between the MAWOL (determined in a 25 minute bout) and weight estimated during an eight hour adjustment allowed session (starting weight being MAWOL).

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APPENDIX A

PERSONAL DATA AND CONSENT FORM

Name: Date :

-- -------

Name and phone number of individual to be contacted in case of emergency:

____

Name and phone # of physician and physician's hospital:

____

CHECK IF SUSCEPTIBLE TO:

Shortness of Breath: Dizzyness: Headaches:

Fatigue: Pain in arm, shoulder, or chest:

IF SO, EXPLAIN:

____

Are you currently taking any type of medicine?

If so, explain:

____

Have you had or do you now have any problem with your blood pressure? If so, explain:

____

In the last six months, have you had any type of surgery or serious illness? If so, explain:

____

In the last six months, have you had any back pain, particularly in the lower back? If so, explain:

____

Have you had or do you now have a hernia?

Corrective date : ________________________________

Have you had your normal amount of sleep within the past 24 hours?

Have you had your normal amount of food within the past 24 hours?

PLEASE READ CAREFULLY

I have truthfully answered the questions to the best of my knowledge, pertaining to my personal data. I hereby give my consent for my participation in the project entitled: (Psychophysicals over extended periods). I understand that the person responsible for this project is Dr. M.M. Ayoub (806) 742-3543. He or his authorized representative (806) 742-3429 has explained that these studies are part of a project that has the objective: comparison of physiological response during a lifting task, utilizing the physiological & psychophysical approaches.

Dr. M.M. Ayoub or his representative has agreed to answer any inquiries I may have concerning the procedures and has informed me that I may contact the Texas Tech University Institutional Review Board for the Protection of Human Subjects by writing them in care of the Office of Research Services, Texas Tech University, Lubbock Texas 79409, or by calling (806) 742-3384.

He or his authorized representative has (1) explained the procedures to be followed and identified those which are experimental and (2) described the attendant discomforts and risks:

(1) Briefly these procedures involve one or more following : (a) A four hour familiarization session. (b) measurement of psychophysical lifting capacity. (c) measurement of physiological responses. To measure your psychophysical lifting capacity, you was asked to lift a container given specific task parameters and adjust the total weight until you feel it represents your maximum safe weight of lift. To measure the physiological responses (oxygen uptake & heart rate) you was asked to lift a container given specific task parameters and oxygen was measure via the metabolic measurement cart and heart rate measured with the heart rate monitor.

(2) The risks have been explained to me as follows: muscle strain or sprains, pulled tendons, back pains or sprain, or hernia. There are also possible changes such as abnormalities of blood pressure or heart rate, or ineffective "heart function," and in rare instances "heart attacks," or "cardiac arrest," strokes, or pulmonary embolism.

If this research project causes any physical injury to participants in this project, treatment is not necessarily available at Texas Tech University or the Student Health Center, nor is there necessarily any insurance carried by the University or its personnel applicable to cover any such injury. Financial compensation for any such injury must be provided through the participant's own insurance program. Further information about these matters may be obtained from the Office of Research Service, 742-3884, Room 203 Holden Hall, Texas Tech University, Lubbock, Texas 79409.

I understand that I will not derive any therapeutic treatment from participation in this study. I understand that I may discontinue my participation in the study at any time I choose without prejudice.

I understand that all data was kept confidential and that my name will not be used in any reports, written or unwritten.

SIGNATURE OF SUBJECT:______________________ DATE:__________

Signature of Project Director or

his authorized representive:

____

Signature of Witness to Oral Presentation:________________

APPENDIX B

INSTRUCTION OF PSYCHOPHYSICAL APPROACH FOR SUBJECTS

Briefly the objectives of this study was to compare the physiological responses in a lifting task using the psychophysical and the physiological approaches; and compare the weights lifted and the physiological responses during the 8-hour sessions.

THIS IS NOT A TEST TO DETERMINE YOUR MAXIMUM WEIGHT LIFTING CAPACITY. I repeat, THIS IS NOT A TEST TO DETERMINE 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 loading a truck during a normal working day, getting paid for the amount of work that you do. In other words, the more weight you handle the more money you make. You are expected to work continuously for at least 1/2 hour, 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 one-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

EVERYONE IS NOT EXPECTED TO DO THE SAME AMOUNT OF WORK.

WE WANT YOUR JUDGMENT ON HOW HARD YOU CAN WORK WITHOUT BECOMING UNUSUALLY TIRED.

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 C

ANALYSIS OF VARIANCE

ANOVA WITH WEIGHT AS THE DEPENDENT VARIABLE FOR EXPERIMENT 1.

Source	DF	S.S	M.S	F-value
Model	14	21016.59	1501.18	4.39
Error	33	11292.98	342.21	
Total	47	32309.58		

Source	DF	ANOVA SS	F-value	PR > F
SN	11	5203.18	1.38	0.2271
WT	3	15813.41	15.40	0.0001

ANOVA WITH OXYGEN CONSUMPTION AS THE DEPENDENT VARIABLE FOR EXPERIMENT 1.

Source	DF	S.S	M.S	F-value
Model	14	2094369.41	149597.81	6.17
Error	33	800549.43	24259.07	
Total	47	2894918.85		

Source	DF	ANOVA SS	F-value	PR > F
SN	11	486635.06	1.82	0.0897
OXY	3	1607734.35	22.09	0.0001

ANOVA WITH HEART RATE AS THE DEPENDENT VARIABLE FOR EXPERIMENT 1.

Source	DF	S.S	M.S	F-value
Model	12	6967.40	580.62	21.35
Error	11	299.16	27.19	
Total	23	7266.57		

Source	DF	ANOVA SS	F-value	PR > F
SN	11	2893.18	9.67	0.0004
HR	1	4074.22	149.81	0.0001

ANOVA WITH WEIGHT AS THE DEPENDENT VARIABLE FOR EXPERIMENT 2.

Source	DF	SS	M.S.
Model	191	37375.18	195.6816
Error	0	0.00	
Total	191	37375.18	

Source	DF	ANOVA SS
SN	11	9147.58
WT	1	22198.75
SN*WT	11	5302.42
HOUR	7	204.67
SN*HOUR	77	181.49
WT*HOUR	7	10.87
SN*WT*HOUR	77	329.38

Test of hypothesis

Source	DF	ANOVA SS	F Value	PR>F
WT	1	22198.75	46.05	0.0001
HOUR	7	204.67	12.41	0.0001
WT*HOUR	7	10.87	0.36	0.92

ANOVA WITH OXYGEN CONSUMPTION AS THE DEPENDENT VARIABLE FOR EXPERIMENT 2.

Source	DF	SS	M.S.
Model	191	16596312.63	86891.69
Error	0	0.00	
Total	191	16596312.63	

Source	DF	ANOVA SS
SN	11	1912724.06
OXY	1	12763678.20
SN*OXY	11	1168182.63
HOUR	7	47195.24
SN*HOUR	77	403271.51
OXY*HOUR	7	46454.15
SN*OXY*HOUR	77	254806.82

Test of hypothesis

Source	DF	ANOVA SS	F Value	PR>F
OXY	1	12763678.20	120.19	0.0001
HOUR	7	47195.24	1.29	0.2678
OXY*HOUR	7	46454.15	2.01	0.0650

ANOVA WITH HEART RATE AS THE DEPENDENT VARIABLE FOR EXPERIMENT 2.

Source	DF	SS	M.S.
Model	191	52762.11	276.24
Error	0	0.00	0.00
Total	191	52762.11	

Source	DF	ANOVA SS
SN	11	13054.84
HR	1	24561.70
SN*HR	11	11406.35
HOUR	7	479.74
SN*HOUR	77	1908.64
HR*HOUR	7	205.41
SN*HR*HOUR	77	1145.43

Test of hypothesis

Source	DF	ANOVA SS	F Value	PR>F
HR	1	24561.70	23.69	0.0005
HOUR	7	479.54	2.76	0.0129
HR*HOUR	7	205.41	1.97	0.0696

ANOVA WITH OXYGEN CONSUMPTION AS THE DEPENDENT VARIABLE FOR EXPERIMENT 3.

Source	DF	SS	M.S.
Model	71	3938230.19	55468.03
Error	0	0.00	
Total	71	3938230.19	

Source	DF	ANOVA SS
SN	11	408562.49
OXY	1	3006356.34
SN*OXY	11	388304.41
HOUR	2	4305.54
SN*HOUR	22	44133.86
OXY*HOUR	2	26677.35
SN*OXY*HOUR	22	59890.19

Test of hypothesis

Source	DF	ANOVA SS	F Value	PR>F
OXY	1	3006356.70	85.16	0.0001
HOUR	2	4305.54	1.07	0.3592
OXY*HOUR	2	26677.35	4.90	0.0174

ANOVA WITH HEART RATE AS THE DEPENDENT VARIABLE FOR EXPERIMENT 3.

Source	DF	SS	M.S.
Model	71	7959.73	112.11
Error	0	0.00	
Total	71	7959.73	

Source	DF	ANOVA SS
SN	11	1813.11
HR	1	4715.82
SN*HR	11	693.60
HOUR	2	179.71
SN*HOUR	22	341.07
HR*HOUR	2	115.82
SN*HR*HOUR	22	100.59

Test of hypothesis

Source	DF	ANOVA SS	F Value	PR>F
HR	1	4715.82	74.79	0.0001
HOUR	2	179.71	5.80	0.0095
HR*HOUR	2	115.82	12.67	0.0002

APPENDIX D

PREDICTION EQUATIONS

PREDICTION EQUATIONS WITH 6-FOOT LIFT AS THE PREDICTOR.

Variable	Prediction Equation	R-Square
S1	-15.113 + L6 * 0.540	0.441
S2	37.855 - L6 * 0.058	0.024
A1W1	-15.787 + L6 * 0.517	0.562
A1W2	-18.715 + L6 * 0.535	0.652
A1W3	-17.332 + L6 * 0.516	0.618
A1W4	-17.332 + L6 * 0.516	0.618
A1W5	-18.924 + L6 * 0.527	0.609
A1W6	-23.459 + L6 * 0.555	0.681
A1W7	-22.042 + L6 * 0.546	0.656
A1W8	-22.042 + L6 * 0.546	0.656
A2W1	30.947 - L6 * 0.021	0.002
A2W2	26.440 + L6 * 0.010	0.0005
A2W3	26.887 + L6 * 0.003	0.0001
A2W4	27.126 - L6 * 0.001	0.0001
A2W5	27.125 - L6 * 0.012	0.0008
A2W6	27.125 - L6 * 0.012	0.0008
A2W7	27.381 - L6 * 0.017	0.0014
A2W8	27.381 - L6 * 0.017	0.0014
AS1	9.628 + L6 * 0.347	0.422
AS2	4.955 + L6 * 0.211	0.546

Where S1 = MAWOL, 2 lifts/min.
S2 = MAWOL, 8 lifts/min.
A1W1 = Wt. Lifted at end of 1st hour, 2 lifts/min.
A1W2 = Wt. Lifted at end of 2nd hour, 2 lifts/min.
A1W3 = Wt. Lifted at end of 3rd hour, 2 lifts/min.
A1W4 = Wt. Lifted at end of 4th hour, 2 lifts/min.
A1W5 = Wt. Lifted at end of 5th hour, 2 lifts/min.
A1W6 = Wt. Lifted at end of 6th hour, 2 lifts/min.
A1W7 = Wt. Lifted at end of 7th hour, 2 lifts/min.
A1W8 = Wt. Lifted at end of 8th hour, 2 lifts/min.
A2W1 = Wt. Lifted at end of 1st hour, 8 lifts/min.
A2W2 = Wt. Lifted at end of 2nd hour, 8 lifts/min.
A2W3 = Wt. Lifted at end of 3rd hour, 8 lifts/min.
A2W4 = Wt. Lifted at end of 4th hour, 8 lifts/min.
A2W5 = Wt. Lifted at end of 5th hour, 8 lifts/min.
A2W6 = Wt. Lifted at end of 6th hour, 8 lifts/min.
A2W7 = Wt. Lifted at end of 7th hour, 8 lifts/min.

A2W8 = Wt. Lifted at end of 8th hour, 8 lifts/min.
AS1 = After MAWOL, 2 lifts/min.
AS2 = After MAWOL, 8 lifts/min.

PREDICTION EQUATIONS WITH 6-FOOT LIFT, LEAN WEIGHT AND HEIGHT AS THE PREDICTORS'

Variable	Prediction Equation	R-Square
S1	-248.15+L6*0.630+HT*1.602-LWT*0.460	0.658
S2	85.27+L6*0.137-HT*0.188-LWT*0.267	0.171
A1W1	-197.05+L6*0.284+HT*1.052+LWT*0.154	0.748
A1W2	-138.38+L6*0.314+HT*0.652+LWT*0.214	0.762
A1W3	-153.09+L6*0.238+HT*0.722+LWT*0.291	0.775
A1W4	-153.09+L6*0.238+HT*0.722+LWT*0.291	0.775
A1W5	-152.18+L6*0.251+HT*0.706+LWT*0.291	0.754
A1W6	-54.99+L6*0.316+HT*0.055+LWT*0.363	0.744
A1W7	-94.65+L6*0.289+HT*0.316+LWT*0.338	0.740
A1W8	-94.65+L6*0.289+HT*0.316+LWT*0.338	0.740
A2W1	99.18+L6*0.186-HT*0.319-LWT*0.259	0.131
A2W2	104.25+L6*0.206-HT*0.391-LWT*0.227	0.142
A2W3	104.34+L6*0.146-HT*0.421-LWT*0.139	0.107
A2W4	89.02+L6*0.111-HT*0.338-LWT*0.108	0.064
A2W5	82.51+L6*0.090-HT*0.301-LWT*0.101	0.051
A2W6	82.51+L6*0.090-HT*0.301-LWT*0.101	0.051
A2W7	94.14+L6*0.043-HT*0.404-LWT*0.014	0.053
A2W8	94.14+L6*0.043-HT*0.404-LWT*0.014	0.053
AS1	-7.95+L6*0.538+HT*0.238-LWT*0.345	0.495
AS2	29.97+L6*0.327-HT*0.092-LWT*0.162	0.634

Where S1 = MAWOL, 2 lifts/min.
S2 = MAWOL, 8 lifts/min.
A1W1 = Wt. Lifted at end of 1st hour, 2 lifts/min.
A1W2 = Wt. Lifted at end of 2nd hour, 2 lifts/min.
A1W3 = Wt. Lifted at end of 3rd hour, 2 lifts/min.
A1W4 = Wt. Lifted at end of 4th hour, 2 lifts/min.
A1W5 = Wt. Lifted at end of 5th hour, 2 lifts/min.
A1W6 = Wt. Lifted at end of 6th hour, 2 lifts/min.
A1W7 = Wt. Lifted at end of 7th hour, 2 lifts/min.
A1W8 = Wt. Lifted at end of 8th hour, 2 lifts/min.
A2W1 = Wt. Lifted at end of 1st hour, 8 lifts/min.
A2W2 = Wt. Lifted at end of 2nd hour, 8 lifts/min.
A2W3 = Wt. Lifted at end of 3rd hour, 8 lifts/min.
A2W4 = Wt. Lifted at end of 4th hour, 8 lifts/min.
A2W5 = Wt. Lifted at end of 5th hour, 8 lifts/min.
A2W6 = Wt. Lifted at end of 6th hour, 8 lifts/min.
A2W7 = Wt. Lifted at end of 7th hour, 8 lifts/min.
A2W8 = Wt. Lifted at end of 8th hour, 8 lifts/min.
AS1 = After MAWOL, 2 lifts/min.
AS2 = After MAWOL, 8 lifts/min.

APPENDIX E

RAW DATA

OBS	NAME	AGE	HT	WT	PFAT
1	KS	27	179.5	167.50	18.21
2	TH	24	174.8	161.50	14.86
3	GA	33	187.7	196.50	27.88
4	BD	30	181.1	195.00	19.11
5	BT	22	184.1	232.50	24.83
6	AW	23	181.9	164.50	17.59
7	MH	19	176.5	147.25	10.33
8	DJ	28	177.7	167.75	14.31
9	JS	22	177.6	165.75	14.42
10	DM	22	170.6	145.25	11.23
11	NE	23	183.2	183.50	18.93
12	DS	24	178.4	154.75	12.34

where

HT = Height

WT = Weight

PFAT = Percentage fat.

SN	RHR	RVO2
1	75	210.0
2	58	193.3
3	75	185.0
4	58	270.0
5	68	203.0
6	81	223.0
7	66	163.0
8	48	160.0
8	62	203.0
10	61	197.0
11	65	200.0
12	73	240.0

where

RHR = Resting heart rate

RVO2 = Resting oxygen consumption.

SN	L6B	OTMB	L6A	OTMA
1	120	125.50	130	162.75
2	130	126.00	140	138.75
3	120	129.75	130	131.50
4	150	134.00	150	166.25
5	150	149.50	160	186.25
6	130	145.00	130	145.25
7	100	128.00	120	127.50
8	140	151.25	150	170.25
8	120	129.25	120	133.25
10	110	122.00	120	133.50
11	140	146.75	150	148.25
12	110	127.25	120	131.00

where L6B = 6-foot lift, before 8 hour sessions

L6A = 6-foot lift, after 8 hour sessions

OTMB = One time max, before 8 hour sessions

OTMA = One time max, after 8 hour sessions.

SN	BBPWC	BLPWC	ABPWC	ALPWC
1	2140.74	2068.45	3870.95	3164.87
2	2133.56	2166.50	2120.16	2114.37
3	2791.58	2765.31	2966.40	2849.07
4	3189.04	2413.51	3010.34	2915.36
5	4580.83	4199.69	4719.90	3808.39
6	2418.40	2423.78	2743.29	2136.03
7	2798.68	2758.89	3003.86	2865.93
8	1974.06	2831.31	2819.95	2767.02
8	3283.29	3336.02	3454.93	3273.04
10	3968.60	3911.29	4048.31	3742.38
11	3342.56	3150.70	3427.27	3078.59
12	2667.25	2334.83	2874.56	2436.19

where BBPWC = Bicycling PWC, before 8 hour sessions

BLPWC = Lifting PWC, before 8 hour sessions

ABPWC = Bicycling PWC, after 8 hour sessions

ALPWC = Lifting PWC, after 8 hour sessions.

SN	P1	PWC2	P2	PWC8
1	38.26	1687.26	19.11	2522.86
2	63.30	1883.62	3.93	657.57
3	08.86	2751.76	6.02	2392.09
4	22.71	1306.05	6.41	2442.17
5	57.03	2261.56	42.49	4108.69
6	42.94	1418.91	25.83	2418.58
7	60.86	1702.68	37.62	3265.40
8	90.34	2352.60	17.76	2582.55
9	11.97	3309.00	37.14	3142.14
10	20.70	2619.39	36.25	3529.34
11	32.13	1553.58	21.26	3274.94
12	59.41	1931.97	5.97	2305.60

where P1 = weight calculated with physiological criteria at 2 lifts/min.

PWC2 = PWC at 2 lifts/min.

P2 = weight calculated with physiological criteria at 8 lifts/min.

PWC8 = PWC at 8 lifts/min.

SN	A1W1	A1W2	A1W3	A1W4	A1W5	A1W6	A1W7	A1W8
1	36.75	36.75	35.25	35.25	33.75	33.75	32.50	32.50
2	42.50	41.00	41.00	41.00	41.00	41.00	41.00	41.00
3	61.75	53.75	53.75	53.75	53.75	41.75	46.75	46.75
4	58.25	58.25	58.25	58.25	58.25	58.25	58.25	58.25
5	63.75	63.75	63.75	63.75	63.75	63.75	63.75	63.75
6	48.75	48.75	48.75	48.75	48.75	48.75	48.75	48.75
7	37.25	37.25	37.25	37.25	37.25	37.25	37.25	37.25
8	59.25	59.25	51.75	51.75	51.75	51.75	51.75	51.75
9	56.25	56.25	56.25	56.25	56.25	56.25	56.25	56.25
10	34.50	34.50	34.50	34.50	34.50	34.50	34.50	34.50
11	59.50	59.50	59.50	59.50	59.50	59.50	59.50	59.50
12	39.00	39.00	36.75	36.75	35.50	35.50	35.50	35.50

where

A1W1 = Wt. Lifted at end of 1st hour, 2 lifts/min.

A1W2 = Wt. Lifted at end of 2nd hour, 2 lifts/min.

A1W3 = Wt. Lifted at end of 3rd hour, 2 lifts/min.

A1W4 = Wt. Lifted at end of 4th hour, 2 lifts/min.

A1W5 = Wt. Lifted at end of 5th hour, 2 lifts/min.

A1W6 = Wt. Lifted at end of 6th hour, 2 lifts/min.

A1W7 = Wt. Lifted at end of 7th hour, 2 lifts/min.

A1W8 = Wt. Lifted at end of 8th hour, 2 lifts/min.

SN	A1H1	A1H2	A1H3	A1H4	A1H5	A1H6	A1H7	A1H8
1	85.0	90.7	92.7	88.3	87.3	90.3	93.3	83.0
2	106.7	94.0	96.7	93.0	111.0	97.0	99.3	101.0
3	119.0	120.0	124.0	126.3	138.3	129.7	130.3	134.3
4	98.3	90.0	95.3	86.0	91.6	90.7	88.0	85.7
5	88.0	86.7	82.7	86.3	88.3	77.0	81.7	81.3
6	102.3	98.3	96.0	101.0	111.0	103.0	102.0	100.0
7	94.0	89.0	83.0	77.3	84.0	84.3	74.0	79.0
8	73.6	75.0	76.0	76.0	75.6	76.3	72.6	77.3
9	93.3	85.3	87.0	85.3	77.3	73.3	73.0	71.7
10	96.3	96.0	94.3	85.3	91.6	85.0	81.0	83.3
11	94.0	92.7	92.0	89.3	98.0	96.7	93.5	94.0
12	98.0	96.7	97.3	94.0	102.0	100.3	101.7	102.0

where

A1H1 = Heart rate at end of 1st hour, 2 lifts/min.

A1H2 = Heart rate at end of 2nd hour, 2 lifts/min.

A1H3 = Heart rate at end of 3rd hour, 2 lifts/min.

A1H4 = Heart rate at end of 4th hour, 2 lifts/min.

A1H5 = Heart rate at end of 5th hour, 2 lifts/min.

A1H6 = Heart rate at end of 6th hour, 2 lifts/min.

A1H7 = Heart rate at end of 7th hour, 2 lifts/min.

A1H8 = Heart rate at end of 8th hour, 2 lifts/min.

SN	A101	A102	A103	A104	A105	A106	A107	A108
1	540.0	553.3	570.0	503.3	523.3	553.3	583.3	526.7
2	533.3	590.0	483.3	430.0	546.7	570.0	686.7	670.0
3	953.3	986.7	826.7	766.7	806.7	933.3	830.0	790.0
4	690.0	740.0	755.0	730.0	683.0	656.7	616.7	613.3
5	673.3	663.3	703.3	690.0	630.0	520.0	713.3	730.0
6	496.7	533.3	550.0	550.0	513.3	503.3	510.0	546.7
7	467.0	516.7	533.3	520.0	500.0	453.3	470.0	473.3
8	606.7	570.0	550.0	593.3	560.0	530.0	553.3	503.3
9	593.3	500.0	460.0	453.3	593.3	560.0	516.7	563.3
10	523.3	620.0	576.7	513.3	566.7	570.0	533.3	536.7
11	650.0	683.3	660.0	600.0	743.3	710.0	686.7	643.3
12	506.7	520.0	500.0	486.7	680.0	630.0	616.7	620.0

where

A101 = O2 consumed at end of 1st hour, 2 lifts/min.

A102 = O2 consumed at end of 2nd hour, 2 lifts/min.

A103 = O2 consumed at end of 3rd hour, 2 lifts/min.

A104 = O2 consumed at end of 4th hour, 2 lifts/min.

A105 = O2 consumed at end of 5th hour, 2 lifts/min.

A106 = O2 consumed at end of 6th hour, 2 lifts/min.

A107 = O2 consumed at end of 7th hour, 2 lifts/min.

A108 = O2 consumed at end of 8th hour, 2 lifts/min.

SN	S1	S1O	S1H	S2	S2O	S2H
1	36.75	700.0	105.7	21.75	1246.7	142.0
2	44.25	703.3	104.0	28.00	1083.3	139.7
3	61.75	820.0	113.0	27.25	1066.7	130.7
4	58.25	763.3	97.3	21.50	1256.7	131.7
5	63.75	1026.7	102.0	25.25	1193.3	116.3
6	74.50	683.3	103.7	35.25	943.3	132.3
7	37.25	473.3	87.0	33.25	996.7	109.0
8	67.00	746.7	88.0	39.25	1240.0	112.0
9	56.25	640.0	84.0	37.25	1040.0	104.7
10	34.50	603.3	74.3	34.25	1173.3	107.3
11	59.50	790.0	97.0	35.75	1276.7	120.0
12	46.75	540.0	104.0	26.25	1080.0	127.0

where

S1 = MAWOL at 2 lifts/min.

S1O = O2 consumed at S1

S1H = Heart rate at S1

S2 = MAWOL at 8 lifts/min.

S2O = O2 consumed at S2

S2H = Heart rate at S2.

SN	A2W1	A2W2	A2W3	A2W4	A2W5	A2W6	A2W7	A2W8
1	16.25	16.25	16.50	16.50	15.25	15.25	15.25	15.25
2	28.00	28.00	25.75	22.00	20.25	20.25	20.25	20.25
3	23.50	23.50	23.50	23.50	23.50	23.50	23.50	23.50
4	17.50	17.50	17.50	17.50	17.50	17.50	17.50	17.50
5	25.25	25.25	25.25	25.25	22.25	22.25	22.25	22.25
6	35.25	31.75	28.50	28.50	25.00	25.00	21.00	21.00
7	30.50	26.75	26.75	26.75	26.75	26.75	26.75	26.75
8	39.25	39.25	39.25	39.25	39.25	39.25	39.25	39.25
9	37.25	37.25	37.25	37.25	37.25	37.25	37.25	37.25
10	31.00	31.00	31.00	31.00	28.00	28.00	28.00	28.00
11	33.00	33.00	33.00	33.00	30.25	30.25	30.25	30.25
12	23.25	23.25	23.25	23.25	21.25	21.25	21.25	21.25

where

A2W1 = Wt. Lifted at end of 1st hour, 8 lifts/min.

A2W2 = Wt. Lifted at end of 2nd hour, 8 lifts/min.

A2W3 = Wt. Lifted at end of 3rd hour, 8 lifts/min.

A2W4 = Wt. Lifted at end of 4th hour, 8 lifts/min.

A2W5 = Wt. Lifted at end of 5th hour, 8 lifts/min.

A2W6 = Wt. Lifted at end of 6th hour, 8 lifts/min.

A2W7 = Wt. Lifted at end of 7th hour, 8 lifts/min.

A2W8 = Wt. Lifted at end of 8th hour, 8 lifts/min.

SN	A2H1	A2H2	A2H3	A2H4	A2H5	A2H6	A2H7	A2H8
1	121.0	132.0	133.0	136.0	146.7	137.7	140.3	136.0
2	118.3	110.7	115.3	111.0	117.0	113.0	115.7	115.3
3	104.7	100.7	104.7	111.3	115.3	114.0	107.7	112.7
4	125.0	124.3	125.0	125.3	129.7	125.7	125.7	133.3
5	115.7	115.3	112.0	112.3	107.0	100.0	102.0	100.0
6	127.3	122.3	129.0	140.7	128.0	123.7	125.7	125.7
7	110.7	108.3	109.7	111.3	115.7	112.3	106.7	108.0
8	111.3	109.6	111.0	109.3	116.7	108.3	110.0	117.3
9	112.3	102.7	104.0	102.7	110.7	107.6	108.7	106.7
10	104.3	102.0	103.7	104.0	107.7	105.6	104.7	105.3
11	112.0	110.3	111.7	114.0	116.0	113.0	113.7	114.5
12	118.0	114.3	116.0	114.0	121.0	120.3	118.0	115.7

where

A2H1 = Heart rate at end of 1st hour, 8 lifts/min.

A2H2 = Heart rate at end of 2nd hour, 8 lifts/min.

A2H3 = Heart rate at end of 3rd hour, 8 lifts/min.

A2H4 = Heart rate at end of 4th hour, 8 lifts/min.

A2H5 = Heart rate at end of 5th hour, 8 lifts/min.

A2H6 = Heart rate at end of 6th hour, 8 lifts/min.

A2H7 = Heart rate at end of 7th hour, 8 lifts/min.

A2H8 = Heart rate at end of 8th hour, 8 lifts/min.

SN	A201	A202	A203	A204	A205	A206	A207	A208
1	953.3	1206.7	1276.7	1346.7	1463.3	1346.7	1453.3	1446.7
2	1100.0	1020.0	966.7	953.3	1013.3	1006.7	990.0	980.0
3	1010.0	966.7	1033.3	1006.7	1020.0	1096.7	1050.0	1036.7
4	1323.3	1443.3	1450.0	1373.3	1356.7	1333.3	1410.0	1376.7
5	1020.0	1263.3	1213.3	1396.7	1267.7	1110.3	1203.3	1186.7
6	963.7	906.7	1013.3	1076.7	963.7	870.0	868.3	890.0
7	833.3	786.7	790.0	813.3	846.7	830.0	796.3	813.3
8	1066.7	1103.3	1036.7	1030.0	1123.3	1053.3	1126.7	1196.7
9	1223.3	1053.3	1043.3	1075.0	1203.3	1176.7	1220.0	1190.0
10	1120.0	1100.0	1083.3	1120.0	1176.7	1146.6	1173.3	1126.7
11	1156.7	1160.0	1123.3	1166.7	1180.0	1230.0	1246.7	1256.7
12	1086.7	1120.0	1076.7	1106.7	1243.3	1220.0	1223.3	1190.0

where

A201 = O2 consumed at end of 1st hour, 8 lifts/min.

A202 = O2 consumed at end of 2nd hour, 8 lifts/min.

A203 = O2 consumed at end of 3rd hour, 8 lifts/min.

A204 = O2 consumed at end of 4th hour, 8 lifts/min.

A205 = O2 consumed at end of 5th hour, 8 lifts/min.

A206 = O2 consumed at end of 6th hour, 8 lifts/min.

A207 = O2 consumed at end of 7th hour, 8 lifts/min.

A208 = O2 consumed at end of 8th hour, 8 lifts/min.

SN	B1H1	B1H2	B1H3	B1H4	B1H5	B1H6	B1H7	B1H8
1	90.7	90.3	85.3	92.0	95.7	92.0	82.3	82.0
2	100.0	96.7	94.7	95.3	108.0	108.0	104.7	114.6
3	100.7	105.3	113.3	125.7	136.6	127.3	125.3	129.0
4	98.3	90.0	95.3	86.0	91.6	90.7	88.0	85.7
5	88.0	86.7	82.7	86.3	88.3	77.0	81.7	81.3
6	108.3	107.7	109.7	105.0	109.0	114.3	106.3	104.3
7	94.0	89.0	83.0	77.3	84.0	84.3	74.0	79.0
8	96.3	90.7	92.0	82.7	90.3	86.3	83.0	82.7
9	93.3	85.3	87.0	85.3	77.3	73.3	73.0	71.7
10	96.3	96.0	94.3	85.3	91.6	85.0	81.0	83.3
11	94.0	92.7	92.0	89.3	98.0	96.7	93.5	94.0
12	101.0	100.0	98.3	98.0	107.0	104.0	103.3	105.0

where

B1H1 = Heart rate at end of 1st hour, 2 lifts/min.

B1H2 = Heart rate at end of 2nd hour, 2 lifts/min.

B1H3 = Heart rate at end of 3rd hour, 2 lifts/min.

B1H4 = Heart rate at end of 4th hour, 2 lifts/min.

B1H5 = Heart rate at end of 5th hour, 2 lifts/min.

B1H6 = Heart rate at end of 6th hour, 2 lifts/min.

B1H7 = Heart rate at end of 7th hour, 2 lifts/min.

B1H8 = Heart rate at end of 8th hour, 2 lifts/min.

SN	B1O1	B1O2	B1O3	B1O4	B1O5	B1O6	B1O7	B1O8
1	533.3	686.7	713.3	766.6	846.7	823.3	746.6	656.6
2	763.3	790.0	790.0	870.0	986.7	956.7	736.7	736.7
3	693.3	716.7	756.7	766.7	773.3	790.0	733.3	756.7
4	690.0	740.0	755.0	730.0	683.0	656.7	616.7	613.3
5	673.3	663.3	703.3	690.0	630.0	520.0	713.3	730.0
6	680.0	636.7	636.7	573.3	640.0	633.3	640.0	600.0
7	467.0	516.7	533.3	520.0	500.0	453.3	470.0	473.3
8	636.7	663.3	623.3	526.7	550.0	643.3	633.3	626.7
9	593.3	500.0	460.0	453.3	593.3	560.0	516.7	563.3
10	523.3	620.0	576.7	513.3	566.7	570.0	533.3	536.7
11	650.0	683.3	660.0	600.0	743.3	710.0	686.7	643.3
12	623.3	640.0	580.0	586.7	726.7	720.0	686.7	746.7

where

B1O1 = O2 consumed at end of 1st hour, 2 lifts/min.

B1O2 = O2 consumed at end of 2nd hour, 2 lifts/min.

B1O3 = O2 consumed at end of 3rd hour, 2 lifts/min.

B1O4 = O2 consumed at end of 4th hour, 2 lifts/min.

B1O5 = O2 consumed at end of 5th hour, 2 lifts/min.

B1O6 = O2 consumed at end of 6th hour, 2 lifts/min.

B1O7 = O2 consumed at end of 7th hour, 2 lifts/min.

B1O8 = O2 consumed at end of 8th hour, 2 lifts/min.

SN	B2H1	B2H2	B2H3	B2H4	B2H5	B2H6	B2H7	B2H8
1	114.7	110.3	113.7	115.0	125.7	126.7	129.7	136.0
2	117.7	116.3	124.7	126.3	129.3	.	.	.
3	108.0	101.3	118.0	112.7	125.0	.	.	.
4	114.0	105.0	112.7	115.3	128.0	.	.	.
5	106.0	98.7	108.0	104.0	116.0	.	.	.
6	114.3	109.3	120.7	.	.	.	.	.
7	110.0	102.3	107.7	108.0	113.3	.	.	.
8	111.3	109.6	111.0	109.3	116.7	108.3	110.0	117.3
9	112.3	102.7	104.0	102.7	110.7	107.6	108.7	106.7
10	106.7	104.3	107.3	105.0	115.7	.	.	.
11	114.0	112.7	115.0	113.0	120.0	131.0	.	.
12	120.0	118.3	119.0	121.0	132.0	.	.	.

where

B2H1 = Heart rate at end of 1st hour, 8 lifts/min.

B2H2 = Heart rate at end of 2nd hour, 8 lifts/min.

B2H3 = Heart rate at end of 3rd hour, 8 lifts/min.

B2H4 = Heart rate at end of 4th hour, 8 lifts/min.

B2H5 = Heart rate at end of 5th hour, 8 lifts/min.

B2H6 = Heart rate at end of 6th hour, 8 lifts/min.

B2H7 = Heart rate at end of 7th hour, 8 lifts/min.

B2H8 = Heart rate at end of 8th hour, 8 lifts/min.

SN	B201	B202	B203	B204	B205	B206	B207	B208
1	1023.3	936.7	836.7	1016.7	1016.7	1056.7	1046.7	1176.7
2	1000.0	973.3	1013.3	1076.7	1153.3	.	.	.
3	1146.7	1090.0	1046.7	1080.0	1160.0	.	.	.
4	1056.7	963.3	876.7	1010.0	1066.7	.	.	.
5	1100.0	1086.7	1187.3	1080.0	1253.3	.	.	.
6	906.7	916.7	906.7	.	.	.	.	.
7	866.7	750.0	796.7	846.7	873.3	.	.	.
8	1066.7	1103.3	1036.7	1030.0	1123.3	1053.3	1126.7	1196.7
9	1223.3	1053.3	1043.3	1075.0	1203.3	1176.7	1220.0	1190.0
10	1286.7	1126.7	1233.3	1140.0	1310.0	.	.	.
11	1180.0	1176.7	1210.0	1150.0	1256.7	1280.0	.	.
12	1226.7	1230.0	1206.7	1246.7	1306.7	.	.	.

where

B201 = O2 consumed at end of 1st hour, 8 lifts/min.

B202 = O2 consumed at end of 2nd hour, 8 lifts/min.

B203 = O2 consumed at end of 3rd hour, 8 lifts/min.

B204 = O2 consumed at end of 4th hour, 8 lifts/min.

B205 = O2 consumed at end of 5th hour, 8 lifts/min.

B206 = O2 consumed at end of 6th hour, 8 lifts/min.

B207 = O2 consumed at end of 7th hour, 8 lifts/min.

B208 = O2 consumed at end of 8th hour, 8 lifts/min.

SN	AS1	AS1H	AS2	AS2H
1	53.75	96	29.00	130
2	40.75	77	36.00	118
3	48.25	107	30.25	124
4	59.50	79	36.75	111
5	57.75	90	33.50	107
6	65.25	95	35.25	120
7	37.50	77	27.00	90
8	64.00	87	36.25	111
9	54.75	84	35.25	100
10	53.75	73	27.25	102
11	60.25	95	31.50	113
12	48.50	98	22.25	102

where

AS1 = After MAWOL at 2 lifts/min.

AS1H = Heart rate at AS1

AS2 = After MAWOL at 8 lifts/min.

AS1H = Heart rate at AS2.