

Physiological Basis for Manual Lifting Guidelines

S. H. Rodgers, Ph.D. and J. W. Yates

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The Physiological Basis of the Manual Lifting Guidelines

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Authors: A. Garg, Ph.D.
S.H. Rodgers, Ph.D.
J.W. Yates, Ph.D.

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The Physiological Basis of the Manual Lifting Guidelines

The goal in designing a lifting task is to avoid the accumulation of fatigue that may result in an overexertion injury. This fatigue can be in specific muscle groups or it can be whole body or upper body fatigue relating to the aerobic capacities available to sustain work. Both types of fatigue are discussed in this section and the physiological limits for safe lifting tasks are reviewed.

I. Factors Affecting Local Muscle Strength and Fatigue

A. Biomechanical

The amount of force that a muscle can develop to perform or support a lifting task is related to biomechanical and physiological factors. The biomechanical factors have been detailed in an earlier chapter and include: the cross-sectional area of the muscle, the posture in which the muscle work is performed, the speed of lifting, which muscles are available (because of the lift heights and distances), and whether one or two hands are used. The force required to lift can be related to the maximum effort capacities of the active muscles in the same posture; the result is expressed as a percent of maximum voluntary contraction strength (% MVC).

B. Physiological

The physiological factors that affect the suitability of a lifting

task at the local muscle effort level are the duration of force exertion and its frequency of repetition per minute. These factors affect the availability of energy for the muscle's use because they influence the delivery of oxygen and glucose to the cells by the blood.

The amount of restriction of blood flow through a working muscle is related to the tension in the muscle as it relates to the muscle's capacity for work in that posture. Blood flow is not affected significantly until an effort level of about 40% of maximum voluntary contraction strength is reached. At 100% of MVC, blood flow is essentially stopped. In between those levels there is progressively more reduction in flow (Lind and McNichol, 1967). Stronger muscles tend to occlude blood flow at lower % MVC values than do weaker ones (Carlson, 1969; Hayward and McCreary, 1978).

Muscle fatigue results from the accumulation of incompletely oxidized metabolic breakdown products of glycogen, or muscle starch. Lactic acid is the primary fatigue product formed from pyruvic acid if there is not enough oxygen in the cell for oxidative metabolism. The muscle cannot use the lactic acid as a substrate for further energy generation; so once it is formed, the lactic acid has to be returned to the liver by the blood supply to be reconstituted to blood glucose or stored as glycogen. This takes time; a 6 second maximum effort needs 6.5 minutes of recovery time to re-establish the resting, non-fatigued state (Rohmert, 1973a).

If a muscle's effort is heavy but very short (under 3 seconds continuous duration) and occurs less than 6 times per minute, it can

obtain most of its energy from glycogen and oxygen already stored in the muscle cells. Therefore, the temporary blood supply interruption that occurs with a short, heavy force exertion does not result in significant fatigue. Fatigue will develop if the heavy effort is sustained for longer periods, and the muscle will need a substantially longer recovery period to return to its previous state.

Lighter muscle effort levels require less recovery time because less restriction of blood flow occurs and because more of the energy can be supplied by the blood going to the active muscle cells. Less lactic acid forms, so the needed recovery times are shorter and the work can be sustained for longer periods before the muscle's effort capability is affected.

1. Duration - Work/ Recovery

Figure 1 describes the effect of the reduced availability of oxygen and substrates for muscle work (Rohmert, 1973a). The higher the % MVC used, the less time it can be sustained continuously before muscle fatigue occurs. When the muscle can no longer sustain that specific effort level, it will require an even longer time to recover. Figure 2 illustrates the recovery times needed based on isometric holding times for different % MVC values (Rohmert, 1973b). These data suggest that optimal work patterns for lifting tasks would be either to reduce the load so it remains at a low % MVC for the active muscles or to reduce the continuous holding time so fatigue does not accumulate.

2. Lifting Frequency

Lifting frequency also influences the acceptability of a task. It determines how much time the muscles have to re-establish blood flow and to recover from any previous effort where energy was "borrowed" by using anaerobic (without oxygen) metabolism. At frequencies above 15 per minute, for example, a lift time of 3 seconds would leave only 1 second for relaxation; this may not be enough time to relax the muscles fully. The heavier the effort at high frequencies, the more likely it will be that the muscles will not fully relax between efforts and that blood flow will not be fully re-established.

3. Estimating Effort Levels

In Figures 1 and 2, the level of effort is expressed as a % of maximum voluntary contraction strength (or % MVC) in the position required by the task. It is this percent of maximum strength that is sensed when people give psychophysical ratings in lifting tasks. Since the maximum strength capacity of the muscle or muscle groups will vary with the biomechanics of the task, it is often difficult to directly measure a true force and relate it to the person's maximum strength on a similar standardized test. People's rating for specific muscle effort levels on lifting tasks can be quantified by using the Borg Large Muscle Group Activity Psychophysical Scale (Figure 3; Borg, 1980; Borg, Hassmen, and Lagerstrom, 1987). At ratings up to 30%, the effort level can be considered "light", from 40 to 60% as "moderate", and at 70% and above as "heavy". Individuals will rate the same lifting task

lifting task differently depending on their strength capacities, so several people should rate the task effort level in order to see how much variability is present. It is also important to separate the endurance and frequency components of the task from the muscle effort level rating. The psychophysical rating of the effort level (% MVC) is used to help assess the suitability of the duration and frequency variables.

4. The Interaction of Factors

Based on the local energy demands of muscle work and the need for blood flow to satisfy them, one can estimate maximum lifting frequencies that can be sustained without accumulating significant amounts of lactic acid in the muscle cell. This will depend on the % of MVC used, the continuous time of strength application, and the repetition rate per minute. The total duration of the effort and the location of the lift (below or above waist level) will also affect the acceptability of the lifting task and is considered later in this chapter. Figure 4 illustrates the relationship between effort times, total cycle time of the lifting task, and the muscle's effort level. (Rodgers, 1987) It is derived from Figure 2. Assuming that lifts are made within a 3 second time frame, it is apparent that only heavy effort lifts will limit acceptable frequencies substantially (to about 8 to 9 per minute from 20/minute for lighter lifts). If lift and carry combinations are used and effort time for the muscle increase to 6 seconds, for example, the acceptable frequency will decrease as a function of weight. For light loads, acceptable lift frequency will be a little less than 10 per minute, but for moderate

loads the acceptable frequency drops to less than 5 per minute and for heavy loads it is about 2.5 lifts per minute. As holding time increases, these differences between heavy, moderate and light lifts becomes greater; when the muscles are active for 20 seconds, heavy lifting and handling acceptable frequencies are 1 per 4 minutes compared to an acceptable frequency of just under 1 per minute for moderate effort and about 2.5/min. for light effort. In designing lifting tasks, it is important to reduce the static work (or continuous duration effort time) to as low a value as possible, especially when moderate to heavy effort is required.

In the guidelines for manual lifting presented in this monograph, the assumption was made that the time per lift is 3 seconds or less. Consequently, local muscle fatigue is not of concern unless very high lifting rates are present or heavy loads are handled. In analyzing a lifting task where some holding or carrying is present, however, one should assess the local fatigue effect by using the data in Figure 4. Small changes in workplace layout or handling heights can often solve a lifting problem through a reduction in holding duration. In addition, local muscle fatigue associated with maintaining awkward postures or with constant bending can reduce the capacity of the muscles needed for lifting and, therefore, increase the risk for an overexertion injury to occur.

II. Metabolic Limits in Lifting Tasks

Although local muscle fatigue may limit the acceptable weights in lifting tasks that are done for short, intensive periods during a work shift,

it is the energy expenditure demands of repetitive lifting tasks that have the most profound effect on acceptability. The location of the lift (above or below 30 inches or 75 cm) determines how much of the body weight has to be moved with the load (low lifts) and what muscle mass is available (upper body capacity versus whole body capacity). The load weight, frequency of lifting, and duration of continuous work all influence the acceptability of repetitive lifting tasks. A review of research on repetitive lifting and factors that influence the energy expenditure requirements of these tasks follows.

A. Measuring the Metabolic Cost of Lifting Activities

To determine the physiological cost of lifting activities one can measure the oxygen use of manual materials handlers over several minutes at several times during the work shift. Heart rate monitoring helps to establish the lifting pattern and the cardiovascular demands to deliver oxygen to the working muscles. These physiological responses on the job can be related to the responses seen when the same person performs a staged treadmill aerobic capacity test or a staged lifting task in a laboratory setting. By increasing the load in a tray handled between several shelf heights at a rate of at least 18 lifts per minute, for example, one can establish the physiological cost of the added weight. The physiological limit will often be reached from a combination of discomfort in local muscle groups and fatigue associated with the amount of oxygen used and the cardiovascular strain (Eastman Kodak, 1986; Rodgers, 1978).

Some controversy exists concerning the relationship between O_2

uptake and work load during lifting activities. The consensus reached in the 1981 NIOSH Guide was that the relationship was linear. A number of investigators have reported or assumed a linear relationship between power output and VO_2 max for repetitive lifting (Intaranont et al., 1986; Miller et al., 1977; Petrofsky and Lind, 1978a), and this relationship has been shown to be true for exercise intensities less than 50% of VO_2 max (Miller et al, 1977). However, not all data shows a linear relationship. Hake and Michael (1977) found the relationship to be curvilinear when lifts were made from a height of 0.56 m to 1.41 m. This type of lift would involve primarily arm work in contrast to lifts beginning from floor level which would involve leg work. In a more recent study, Sharp and his colleagues (1988) tested 18 men doing treadmill, cycle ergometer, arm cranking and repetitive lifting tasks during a maximum progressive test. When VO_2 data were plotted against power output, the linear relationship was not strong ($r=0.65$). The authors speculated that this finding was probably due to the variation in the relationship between O_2 consumption and workload and lifting efficiency seen among subjects.

One possible explanation for the different findings involves the relationship between lifting frequency and weight of lift. It is known that for a given lift height, the metabolic demands, expressed in kilocalories per footpound of work, changes (Frederik, 1959). Thus, if a progressive test increases the weight of the lift and holds the frequency of lift constant, efficiency changes. This change in efficiency is illustrated by the data of Garg and Herrin (1979). They plotted the lifting frequency that resulted in a metabolic rate

of 5.2 Kcal/min against lift weight in kg (Figure 5). A weight of 25 kg could be lifted over 5 times/min while a weight of 7 kg could be lifted 11 times/min. Over 125 kg of weight can be lifted per minute when lifting 25 kg while only 77 kg of weight is lifted per minute when a 7 kg unit is handled; yet both work loads result in the same metabolic cost. Thus, for this situation, O₂ uptake and work load are not linear.

Other data show that the relationship between the two variables changes with the height of lift and the muscle mass involved (Genaidy et al., 1985). Given the complexity of lifting activities compared to treadmill or cycle ergometer activity, it is not unreasonable to suspect that the relationship between metabolic rate and work load is non-linear in certain situations.

Because it is often difficult to monitor oxygen usage on the job, psychophysical methods have been most frequently employed to estimate the % of aerobic capacity used on a lifting task. Borg's Effort Estimation Scales (Figure 3) correlate well with the heart rate responses to treadmill work and with the % of capacity available from larger muscle groups in the upper body (Borg, 1980; Rodgers, 1988). Most people can define their overall metabolic workload in terms of the work descriptors on the Borg scales, and these can be used to estimate the acceptability of sustained work on the lifting task. For example, lifting tasks that get a moderately heavy effort rating for total workload (not just for local muscle effort) will be difficult to sustain for more than 1 - 2 hours continuously. Those with heavy ratings will be difficult to sustain for more than 15 - 20 minutes continuously. These relationships are discussed in detail later in this chapter.

B. Factors Influencing the Metabolic Costs of Lifting Tasks

1. Beginning Position and the Vertical Travel Distance

When considering the physiological cost of lifting, it is necessary to account for the cost of moving the load as well as the cost of moving the body. When a lift is made from the floor, the worker must lift his/her own body weight in addition to the weight of the box. The cost of lifting the body increases the energy requirements of the task when compared to the energy needed to lift the same weight from a table upward. Therefore, lifts which begin from the floor require more energy expenditure than lifts which begin from table level. For example, Aquilano (1968) published O₂ consumption values for 6 men who were lifting 10 and 25 pound cartons from the floor to waist level and from waist to head height. Estimates from figures published in the article show that lifting a 25 pound carton at a rate of 11 lifts/min required a total energy expenditure of approximately 4.4 Kcal/min for the waist to head lift. However, lifting the same carton from the floor to the waist required a total caloric expenditure of 6.3 Kcal/min, a 43% increase. The data of Frederik (1959) shown in Figure 6, support this point. The most efficient lifting range is from 40 to 60 inches for materials ranging from 20 to 60 pounds. Lifting from 0 to 20 inches results in the greatest energy expenditure for weights ranging from 20 to 55 pounds. These data emphasize the important role played by the beginning position of the lift in determining the total energy expenditure of the task.

The data are quite clear concerning the effect of lifting distance on metabolic rate. As lifting distance increases, so does the energy requirement of the job (Aquilano, 1968; Genaidy et al., 1985; Khalil et al., 1985). When a 11 kg weight was lifted from the floor to waist height (92 cm) or to head height (168 cm) at a pace of 11 and 10 lifts/min respectively, the corresponding energy expenditures were 5.21 and 6.58 Kcal/min. (Aquilano, 1968) The exact relationship between metabolic rate and vertical travel distance is affected by body posture, as has been discussed earlier.

2. Lifting Technique

The method used to lift the weight from the floor also has an impact on the physiological cost (Brown, 1971; Garg and Herrin, 1979). Three body postures used to lift objects from the floor have been studied: squat (straight back, bent knee), stoop (bent back, straight knee), and free style (as chosen by the worker). The squat lift results in higher levels of energy expenditure than the other forms of lifting. Garg and Saxena (1979a) showed that at a work load of 60 kgm/min, the free style lift resulted in a metabolic rate of approximately 4.2 Kcal/min while the squat lift required a metabolic rate of 5.7 Kcal/min. This 36% increase in energy expenditure is partially the result of raising and lowering the center of gravity of the body during the squat lift. The differences in metabolic rates between the styles of lifting relate to the total work performed, including the lifting frequency. At a work rate of 30 kgm/min, only a 14% difference exists between the two lifting styles (3.15 Kcal/min vs. 3.60 Kcal/min). Garg and Saxena followed

up on this study by evaluating the lifting techniques of 6 male industrial subjects filling dry grocery orders in a warehouse (1979). They reported that the energy expenditure rate was 5.8 Kcal/min when using the free style technique compared to 7.5 Kcal/min with the squat technique. In addition, the workers were able to meet their performance index using the free style technique, but failed to meet the standard using the squat technique. Brown (1971) plotted the relationship between the weight of the lift and energy expenditure in Kcal/kg body wt·min. This method of expressing the energy expenditure serves to normalize the data relative to the body weight of the subject. The free style of lifting was still found to be more efficient than the squat lift.

Kumar (1984) reported that the stoop technique was less metabolically expensive than either the free style or the squat technique. This investigator measured the O₂ consumed while lifting a 10 kg weight from a beginning position of 13.5 cm to a final position of 91 cm, at a frequency of 6 lifts/min. The O₂ consumption values for the stoop, free style and squat techniques of lifting were 0.676, 0.804, and 1.06 liters/min, respectively. On a subjective basis, most people rated the squat technique as the most tiring and the free style technique the least tiring. Even though the stoop technique resulted in a lower metabolic rate, it was more tiring, subjectively, than the free style technique.

3. Effects of Workload (Frequency and Weight) on Metabolic Rate

Lifting frequency and the weight of the lift are so intertwined that it is impossible to separate them when discussing their impact on physiological parameters. Manipulation of either one of these factors will change the total work performed by the worker and, hence, their energy expenditure (O_2 consumed). The efficiency of the work performed is also a function of the weight-frequency combination used during the lifting task.

Frederik (1959) was one of the first to publish data concerning the metabolic cost of lifting (see Figure 6). His data indicate that the cost of lifting loads is a function of the weight of the object and the starting location of the lift. Hamilton and Chase (1969) also collected data concerning the relationship between O_2 consumption and the work rate when lifting 10 to 25 pounds at a height of 10 in. These authors stated that the relationship between the variables was linear over the range measured. The authors incorrectly interpreted this finding to mean that no optimal work load exists over the range of variables measured. However, their data clearly show that when two combinations of frequency and load result in the same work rate, the combination with the greatest weight and lowest frequency results in a lower metabolic rate. For example, lifting a 25 pound carton 9 times/min (a total weight of 225 pounds/min) yielded an energy expenditure of 5.85 Kcal/min (1.17 liter O_2 /min). However, a lift involving a 15 pound carton and a frequency of 15/min (also 225 pounds/min) resulted in a metabolic

rate of 6.88 Kcal/min (an 18% increase). The lift involved raising a carton from a table and placing it on a conveyor belt 10 inches above the table. Even though this study used a vertical lifting distance of only 10 inches, all of the weights studied (10, 15, 20, and 25 lbs) resulted in a metabolic rate greater than 5 Kcal/min when lifted at a frequency of 15/min. At 12 lifts/min only the 10 pound weight yielded a metabolic rate of less than 5 Kcal/min. At 6 lifts/min all of the weights were acceptable when based on a metabolic workload limit of 5 Kcal/min.

Data from Snook (1971) and Garg and Herrin (1979) suggests that there is a trade-off between metabolic and biomechanical stresses. According to Garg and Herrin (1979), biomechanical criteria to reduce muscle and vertebrae stresses suggest minimizing the load by using lighter weights and more frequent lifts. Metabolic criterion to reduce energy expenditure suggests lifting heavier weights at less frequent intervals. In other words, to reduce physiological fatigue workers are better off lifting heavier weights at low frequencies than lifting lighter weights at higher frequencies. Lifting more than one light item at a time is often seen in workplaces where workers have some control over the lifting pattern. However, this behavior may produce unacceptable levels of stresses on a worker's low back.

A number of investigations have determined the relationship between work load and oxygen uptake during lifting. When workloads are matched between cycling and lifting activities, O₂ uptake is always higher during lifting activities than during cycling,

but VO_2 max is almost always lower for lifting than for cycling (Petrofsky and Lind, 1978a). Williams and colleagues (1982) reported that when a group of females lifted using the squat technique, O_2 uptake for heavy loads was equal to VO_2 max on the cycle ergometer. Petrofsky and Lind (1978a) also reported that the VO_2 max achieved during a lifting task was directly related to the weight being lifted. As the weight of the item increases, so does the VO_2 max. Heart rate and minute ventilation (V_E) follow a pattern similar to that for O_2 uptake. At the same submaximal work loads, HR and V_E are lower during cycle ergometry than during lifting. As the weight of the lift increases, so does the peak HR and V_E . However, the values achieved during lifting do not reach the highest values seen while riding the cycle ergometer.

In an attempt to evaluate time standards set for industrial tasks, Aquilano (1968) had male subjects lift cartons of 10 and 25 pounds from the floor to waist height, floor to head height, and waist to head height. Depending upon the height of the lift, lifting frequencies ranged from 4 to 26/min. As the subjects increased the lifting frequency for a given weight, O_2 consumption increased in a linear fashion. However, the slope of the increase varied depending upon the weight being lifted and the location of the lift. For a given increase in work performed, the increase in energy expenditure was less for the heavier weight. This finding was related to the lesser change in frequency necessary for the heavier weight in order to result in the same absolute increase in workload. Data of Mital,

Asfour and Ayoub (1982) support this principle.

Genaidy and Asfour (1989) measured the endurance times for a group of 11 young males during a lifting task. The subjects were asked to lift boxes weighing 5, 10, 15, and 20 kg from the floor to a table at frequencies of 4, 6, 8, and 10/min. Subjects continued lifting using the squat method (up to 8 hours) until they were unable to continue due to fatigue. The average endurance time for a lift of 5 kg at a frequency of 4/min was 471 minutes (7.85 hours). However, subjects were able to continue for only 27 minutes when lifting 20 kg at 10/min. Endurance times were 400 and 132 minutes for a load of 15 kg at 4 and 8 lifts/min, respectively. These data were not in agreement with those published by Mital (1984). Using the psychophysical method Mital reported that subjects were willing to lift 15.42 and 14.99 kg for 8 hours at 4 and 8/min, respectively. However, subjects in Mital's study used the free style technique while the squat method of lifting was used by Genaidy and Asfour. This difference could account for some of the differences between the two studies. Legg and Pateman (1984) reported that eight soldiers were able to lift 22.4 kg, 12 times/min for 54 min before becoming exhausted. Furthermore, these same subjects lifted 44.8 kg at a rate of 4/min for one hour and estimated they could have lifted that load for a total of 104 minutes.

Khalil et al. (1985) used a progressive resistance lifting test to estimate VO_2 max for different combinations of weight, frequency and lift height. The authors then used 33% of the predicted VO_2

max to recommend the lift load for combinations of frequency and lift height; however, the exact method used to arrive at these values is unclear. These data suggested that no lifting work should be performed at frequencies above 10/min for any height of lift. These data are not supported by others. Garg and Herrin (1979) found that a weight of approximately 7 kg resulted in a metabolic expenditure of 5.2 Kcal/min when lifted 11 times/min from the floor to knuckle height. Mital (1984) reported a O₂ uptake of 0.92 liters/min (4.6 Kcal/min) when subjects lifted a weight of 11.3 kg from knuckle to shoulder height at 12/min. Samanta and Chatterjee (1981) published data showing a metabolic rate of 4.89 Kcal/min when lifting a 9 kg load a vertical distance of 0.66 meters at 12 times/min.

It is unclear why such dramatic differences exist between the data of Khalil et al. (1985) and those of others. However, it is reasonable to assume that some errors result when VO₂ max is estimated from submaximal work loads. When performing this calculation it is assumed that the relationship between HR and work load and HR and O₂ uptake are linear. This relationship is under dispute and will be discussed in some detail below.

Jorgensen and Poulsen (1974) tested four males and four females while lifting loads of 10, 25, 50, and 75% of maximum capacity for a single lift. Each of these loads was lifted for 20 min at frequencies ranging from 2 to 12 L/min while HR and O₂ uptake were measured. They reported that, on the average, the maximum

lifting capacity of females was 70% of that of males. This work also suggested that during repetitive lifting, capability is determined by maximum aerobic capacity as well as back strength. Doolittle (1989) supports the importance of aerobic capacity in repetitive lifting. He contends that many frequency-mass combinations (as determined from the 1981 NIOSH guide) will result in metabolic rates which exceed a lifting capacity based on 33% of maximum aerobic capacity for an 8-hour day. Thus, even with sound ergonomic design, the aerobic demands of frequent lifting must be considered in designing safe lifting tasks.

4. Lifting Versus Lowering

An eccentric contraction (or negative work) occurs when muscle length increases while contracting. The metabolic requirements of negative work are much less than those for doing an equivalent amount of positive work. When a job requires the lowering of an object, negative work is being done, so, the capacity of an individual to lower objects differs from their capacity to lift objects. This is true for force generation and for metabolic requirements. Many industrial tasks are combinations of negative work and positive work. A task that involves both forms of work is less physiologically demanding than one requiring positive work only. Failure to account for this factor may play a role in the discrepancies that occur between the AL or MPL recommended by the Guide and actual performance seen in industry.

Garg (1976) and Petrofsky and Lind (1978a) measured the effects

of lifting and lowering loads on metabolic rate when lifting and lowering below waist level. For light weight boxes and low work loads, the difference between the two tasks is minimum. However, as the weight of the load increased, lifting required significantly more energy expenditure than did lowering. Investigations using a psychophysical methodology showed that subjects were willing to lower more weight than they would lift (Ciriello and Snook, 1983; Mital et al., 1982). The negative (lowering) work results in an O₂ consumption of approximately 15% less than that of positive (lifting) work (Ciriello and Snook, 1983).

5. Special Lifting Situations

A limited amount of physiological data are available for special lifting situations. These are discussed below:

- a. Sitting - Yates and Karwowski (1987) measured the physiological demands of lifting from a sitting posture and compared them to standing lifts. Eight male subjects used the psychophysical method to choose MAWL (maximum acceptable weight lifted) while lifting at a rate of 1 and 4/min. Subjects lifted significantly less weight (8% to 25%) during sitting positions than during standing lifts. HR during sitting lifts was less than 88 b/min while O₂ consumption was always less than 17% of VO₂ max.
- b. Asymmetric Lifts - If the psychophysical method is used to determine the MAWL during an asymmetrical lift, the resulting load

will be less than that acceptable during a sagittal plane lift (Garg and Banaag, 1988; Mital and Fard, 1986; and Yates and Karwowski, 1987). Even though the MAWL is less during asymmetric lifts, O₂ consumption does not change when the results are compared to symmetrical lifts (Mital and Fard, 1986; Yates and Karwowski, 1987). Garg and Banaag (1988) have observed higher heart rates during asymmetric lifts, however.

c. Special Postures - Morrissey (1987) reviewed the effect of task posture on the physiological demands of lifting. Walking in a stooped posture (such as would occur in a medium or low seam coal mine) will increase O₂ consumption. Walking at a height of 60% of normal almost doubles O₂ requirements. When shovelling at a fixed rate, working in the kneeling posture will increase O₂ uptake over that which occurs while in normal posture. Gallagher and associates (1988) showed that lifting in the kneeling posture is more demanding than lifting in the stooped posture in terms of HR and O₂ uptake.

C. The Relationship Between Psychophysically Acceptable Weights and the Metabolic Cost of Lifting

Determining the maximum acceptable weight during repetitive lifting is a complex task affected by many different factors. In attempting to solve this problem, investigators have taken a number of different approaches. The first approach, which was discussed above,

involved determining the relationship between work rate and O₂ consumption to find which loads resulted in fatigue of the subjects. The occurrence of fatigue was judged by a variety of methods. The second approach involves letting the subject choose the weight which he feels is acceptable to lift at a given frequency and height of lift (psychophysical method). Many investigators have used the psychophysical method to determine acceptable lifting loads and then measured the resulting metabolic rate.

Garg and Saxena (1979) compared a physiological fatigue criterion of 5 Kcal/min with psychophysical fatigue criteria. These authors reported that physiological fatigue criteria resulted in more liberal workload limits at low frequencies of lift while the psychophysical method resulted in higher workload limits at high lifting. This conclusion is supported by others (Asfour et al., 1985; Fernandez and Ayoub, 1988; Karwowski and Yates, 1986). Based on these data, numerous investigators have concluded that the psychophysical methodology is invalid for determining acceptable workloads in high frequency lifting tasks (Asfour et al., 1985; Ciriello and Snook, 1983; Fernandez and Ayoub, 1988; Karwowski and Yates, 1986).

D. Oxygen Consumption Prediction Models

Garg, Chaffin and Herrin (1978) published an extensive prediction model based on measurements of metabolic rate during 28 manual materials handling tasks. A basic assumption of the model was that the job could be divided into simple tasks and that the metabolic expenditure of complex jobs could be predicted by summing the energy

demands of the simple tasks. The metabolic rates predicted by the model were compared to the measured metabolic rates (range = 3.2 to 11.9 Kcal/min) on 48 different jobs. The model validation showed a correlation coefficient of 0.95 between the measured and the predicted metabolic rates and a coefficient of variation of 10.2 percent, which is on the same order as inter-subject variability. The mean absolute difference between the predicted and the measured metabolic rates was 8.6 percent (range = 0.2 to 33%) and 41 out of 48 jobs had a difference of less than 15%. The authors concluded that the model was sufficient for estimating energy expenditure rates of different manual materials handling jobs. One advantage of using such a model is that the partitioning of a job into tasks shows which particular tasks require the highest energy expenditure, and this is a useful focus for job redesign.

Energy prediction models can provide valuable information to an informed user. Often the user is unaware of the assumptions and limitations of the model, however, and misapplication of the data can occur. Therefore, these models should be used with caution and the scope of their application should be limited. Direct measurement of the oxygen usage of people in lifting jobs is preferable when possible.

E. Determining Lifting Task Limits Based on Aerobic Work Capacities

To establish guidelines for frequent lifting tasks that are based on physiological data, one has to find a value of oxygen consumption that should not be exceeded for a given time period (1 hour, 2 hours, 8 hours, or 12 hours, for example). Astrand and Rodahl (1970) predicted the relationship between percent of aerobic capacity that can be used and work duration; this relationship has been confirmed by many other researchers (Christensen, 1963; Eastman Kodak, 1986; NIOSH, 1981; Rodgers, 1976). This basic relationship is illustrated in Figure 7.

Astrand and Rodahl (1970) predicted that men could perform at up to 50% of their bicycle ergometer aerobic work capacity (VO_2 max) in an 8-hour work shift. More recent evidence shows that VO_2 max is task specific, so a person's lifting capacity is not the same as his/her VO_2 max for walking on a treadmill or riding a bicycle ergometer. Some research on aerobic work capacities is reviewed in this section.

1. Aerobic Work Capacities

Petrofsky and Lind (1978) addressed this issue by using a progressive resistance test to measure O_2 consumption on a cycle ergometer and on a staged lifting task using boxes of different weights (.91, 6.82, 22.73, and 36.36 kg) at increasing frequencies. The subjects used the free style method to lift from a height of 6

cm to 60 cm (24 inches). O_2 consumption was linearly related to work load for boxes of all weights; however, the slopes of the relationships were dramatically different. For the two lightest boxes, the limiting factor reported by the subjects was their inability to raise and lower the trunk, head, and box at a faster rate. With the heaviest box, the limiting factor was reported to be fatigue in the arms or hands. VO_2 max was highest for the cycle ergometer and progressively decreased as the weight of the lift decreased. HR followed a pattern similar to O_2 consumption. When the same amount of work was performed lifting boxes as when riding the cycle ergometer, O_2 consumption was significantly greater for lifting boxes than for riding the cycle ergometer. A follow-up study found that 50% of VO_2 max for each specific box weight could be maintained for a 4-hour period with 10 minute recovery periods each hour; however, clear evidence of fatigue was found (Petrofsky and Lind, 1978b). Blood lactate showed little increase up to 40% of VO_2 max but increased dramatically when O_2 levels increased above 1.0 liters/min. These data are in agreement with those of Astrand (1967). As a result of these data, Petrofsky and Lind (1978b) suggested that work rates not exceed one third of cycle ergometer VO_2 max.

Williams et al. (1982) reported slightly different results on seven female students. Measured VO_2 max values for treadmill, cycle ergometer and for lifting boxes of 15.9 and 22.7 kg were not significantly different. The differing results were ascribed to the

fact that the women in this study preferred to use the squat method of lift while the men used the stoop method. Since the squat method of lifting involves the use of the legs and, therefore, requires more energy expenditure, the women achieved higher VO_2 max values for box lifting. Both methods of lifting resulted in a linear relationship between work load and O_2 consumption. Based on loss of grip endurance following the lifting tasks, the authors recommended 30% of VO_2 max be used to set lifting standards.

2. Lifting as a Percent of Aerobic Capacity

Legg and Pateman (1984) took a different approach in an attempt to answer this question. These investigators had 11 soldiers lift loads corresponding to 25, 50, and 75% (22.4, 44.8, and 67.2 kg) of their maximum lifting capacity from the floor to 40% of their height. Maximum lifting capacity was based on a single clean lift. Lifting rates varied from 2 to 12/min. Subjects were asked to lift for 1 hour or until exhausted. If the subjects were able to complete the 1 hour period, they estimated how long they could have continued at the same lifting rate. Lifting times were as short as 30 minutes when lifting 75% of maximum lifting capacity (MLC) at a rate of 4/min and were estimated as long as 158 min when lifting 25% of MLC at 8 lifts/min. Based on these data the authors recommended that lifting activities should not exceed 23% of treadmill VO_2 max.

Based on studies of industrial lifting, Rodgers (1976) supported

a value of 33% of either whole body or upper body capacity. Rodgers suggests that this level of O_2 consumption will involve integration of factors such as biomechanical aspects of the materials to be handled and their location in space, environmental conditions in the work place, individual fitness and skill levels, and static components of the job. The 33% of VO_2 max (treadmill) value was chosen as the upper limit of oxygen consumption for the MPL (Maximum Permissible Limit) in the 1981 NIOSH Work Practices Guide for Manual Lifting and, therefore, has received widespread application. Based on an assumed aerobic capacity of 3.0 liters O_2 /min for an average, young man, this puts the upper limit of O_2 consumption at 1.0 liter O_2 /min for sustained manual materials handling. One liter of O_2 /min is equivalent to 5 Kcal/min. These values are often quoted when determining maximum work capacity for lifting situations. However, as discussed above, VO_2 max is job specific. Therefore, one must be cautious when using the 1.0 liter O_2 /min for all types of jobs. In addition, average VO_2 max for young females is closer to 2.0 l/min; therefore, an upper working limit of 1.0 liters O_2 /min is closer to 50% of VO_2 max for females. Another factor which cannot be ignored is the decline in VO_2 max that naturally occurs with increasing age. As workers age, their maximum work capacity decreases; hence, the workload which results in a given percentage of VO_2 max also decreases. Jobs involving leg work have higher maximum work capacities than jobs involving arm work. Therefore, 33% of treadmill or cycle ergometer

VO_2 max may exceed the capacity of the worker when performing a job consisting primarily of arm work.

3. Psychophysical Data on Total Workload Limits

Many of the studies discussed above measured physiological parameters such as muscular endurance and blood lactate to determine if the work loads were of sufficient intensity to result in fatigue. The purpose of making these measurements was to set a workload, as a percentage of VO_2 max, which would not cause undue fatigue and, thereby, increase the incidence of injuries. Other studies have taken a different approach. Numerous investigators have used the psychophysical method to decide the maximum acceptable weight of lift (MAWL) and have then measured the resulting O_2 consumption. By using this method, the investigators are assuming that the psychophysical method is a valid way of setting lifting limits and that these values will be reflected by the O_2 consumption. Ciriello and Snook (1983) reported that subjects were willing to handle 22 kg when lifting from the floor to knuckle height at a rate of 12/min. This lifting frequency resulted in an O_2 consumption of 1.46 liters O_2 /min. When lifting frequency was reduced to 9 or 6 lifts/min, O_2 consumption decreased to 1.11 and 0.93 liters O_2 /min, respectively. The O_2 consumption resulting from the two highest frequencies is higher than that recommended as the upper limit by the previous NIOSH guideline of 1.0 liters

O₂/min. Garg and Saxena (1979) reported different MAWL's for frequencies of 9 and 12 lifts/min of 0.97 and 1.11 liters O₂/min, respectively.

The difference between the results of Ciriello and Snook (1983) and Garg and Saxena (1979) may be due to the inability of people using the psychophysical method to accurately predict lifting capacity at high lifting frequencies. Numerous authors have come to the conclusion that the psychophysical method overestimates work capacity at high lifting frequencies (Ciriello and Snook, 1983; Karwowski and Ayoub, 1984; Fernandez and Ayoub, 1987; Karwowski and Yates, 1984; 1986; Mital, 1984a; 1984b; 1987). Karwowski and Yates (1984; 1986) showed that female subjects are unwilling to lift the psychophysically chosen weight at frequencies above 6/min over a period of 4 hours if given the chance to change it. At the end of the 4-hour period, subjects had decreased the weight of the lift by 23% from their MAWL which had been predicted at lifting rates of 8 or 12 lifts/min. These data lead to the suggestion of 25% to 30% of treadmill VO₂ max as the recommended upper limit for O₂ consumption when lifting for a continuous 4-hour period; this value is in close agreement with the 28% suggested by Mital (1984) for eight hours of lifting. As can be seen in Figure 7, there is only a small difference between 4 and 8 hours in terms of the percent of aerobic capacity that can be used without accumulating fatigue.

In summarizing the data concerning the limits of work capacity, it becomes clear that jobs requiring 50% of treadmill or cycle

ergometer VO_2 max will exceed the capability of most workers. Values in the range of 40% of the job specific VO_2 max may be tolerated by some workers. However, most data now suggest that the range should be between 25 and 30% of treadmill or cycle ergometer VO_2 max for an 8-hour shift. For shorter or longer work periods, the work as a percent of aerobic capacity should follow the curve in Figure 7.

III. Assumptions Made in Generating Frequency Correction Factors for the Lifting Guidelines

The physiological influence on acceptable lifting weights in the new NIOSH Guide for Manual Lifting is accounted for in the frequency factor corrections. Those factors have been generated from data gathered from a combination of physiological, biomechanical, and psychophysical studies and by using a predictive model to establish lifting task energy expenditures where direct measurements were not available.

A. Components of the Frequency Correction Factor Table

There are three major components of the frequency factor table: corrections for lifting frequency; corrections for the lift location (above or below 30 inches or 76 cm); and an adjustment for the continuous duration of lifting(1, 1-2, Or 2-8 hours). All of these parameters affect the amount of oxygen used to perform the lifting task, and they can also influence the amount of local muscle fatigue that develops in combinations of conditions. The assumptions made in choosing the baseline aerobic capacity and workload limits are reviewed in this section; the technique used to generate the frequency factors is also described.

In order to set some general guidelines for frequent lifting tasks that are reasonable and still protect less strong and less fit workers from overexertion injuries, the tasks have been designed conservatively. At the AL (Action Limit), at least half of the women and most of the men will find the tasks acceptable. Based on strength

alone (infrequent lifts), the AL should accommodate about 75% of the women. To accommodate more women in frequent lifting tasks, one can reduce the workload by interspersing the lifting task with light work activities. This will lower the overall energy demands and permit people with lower aerobic work capacities to work without fatiguing. The continuous work duration columns illustrate that shorter lifting periods require less frequency factor correction, thereby raising the AL value.

B. Baseline Aerobic Capacity Assumptions

The goal of the lifting guidelines is to protect the large majority of workers from the risk of overexertion injuries. Since the workforce includes men and women ranging from 17 to 70 years of age, the aerobic capacity of a less fit worker has been used to establish the AL level. Based on earlier studies included in the 1981 NIOSH Work Practices Guide for Manual Lifting and on industrial studies (Eastman Kodak, 1986, pages 476-478), a value of 34 ml O₂/kg body weight min or 10.5 Kcal/min whole body aerobic work capacity has been used as the baseline for low lifting tasks. This is the aerobic capacity of an average 40 year old women as measured on a staged treadmill test. Some of the difficulties with using a work capacity measured on a treadmill or bicycle ergometer to predict lifting capacity have been discussed earlier in this chapter. It is probable that more than half of the female workforce may find a repetitive lifting task based on a 10.5 Kcal/min aerobic work capacity fatiguing because their lifting capacity will be lower than their walking capacity. The frequency factor corrections have been rounded down to be more conservative and to

balance this overestimate, however. Workers can very often control their lifting pace and vary their activities to reduce accumulated fatigue, too. A design that accommodates 75% of the less fit population would limit workloads to the low moderate effort range for a large majority of the workforce, and that would be an inefficient design.

Whole body work is required when the lifts are below knee and waist level, but lifts above waist level use primarily the upper trunk and limb muscles. That muscle mass is less developed, representing on the average about 70% of whole body aerobic capacity. Consequently, the aerobic capacity basis for lifts above 30 inches (75 cm) is $.7 \times 10.5$ or 7.35 Kcal. This should accommodate about half of the women's and close to 90% of the men's upper body aerobic work capacities.

At the MPL (Maximum Permissible Limit) of the lifting guidelines, an average healthy young male's aerobic capacity of 15 Kcal/min or 43 ml O_2 /kg body weight·min has been used. This represents the upper 25% of the male workforce (Eastman Kodak, 1986; NIOSH, 1981) and is based on treadmill capacity testing. Arm capacity at the MPL for assessing high lifting workloads is $.7 \times 15$ or 10.5 Kcal/min.

C. Workload Criteria - Energy Expenditure Limits vs. Work Duration

Figure 7 (earlier in this chapter) illustrates what percent of aerobic capacity can be used as a function of work duration. The duration values chosen for the frequency correction table are 1 hour, 1 to 2

hours, and 2 to 8 hours, and these can be sustained at loads of 50%, 40% and 33% of aerobic work capacity (measured as treadmill capacity), respectively. Table 1 illustrates the limiting energy expenditure values used to calculate the frequency correction factors for high and low lifting tasks of different durations.

Table 1: Energy Expenditure Limits for Frequent Lifting

Lift Location Height in Inches (cm)	Duration of Lifting					
	<u>1 Hour</u>		<u>1-2 Hours</u>		<u>2-8 Hours</u>	
	<u>AL</u>	<u>MPL</u>	<u>AL</u>	<u>MPL</u>	<u>AL</u>	<u>MPL</u>
V ≤ 30 (75)	4.72	6.75	3.78	5.4	3.12	4.45
V > 30 (75)	3.3	5.4	2.65	4.05	2.18	3.12

The values in Table 1 have been determined by multiplying the aerobic capacities at the AL and MPL levels (10.5 and 15 Kcal/minute) by the percent aerobic capacity value for the respective duration and by correction factors for upper body capacity for lifts above 30 inches.

In order to partially account for differences between lifting capacity and treadmill capacity the values were also reduced 10% (Garg, personal communication, 1989). This correction brings the values closer to 25 to 30% treadmill aerobic capacity for an 8 hour shift which was recommended for lifting tasks earlier in this chapter.

D. Frequency Factor Calculations

The values in Table 1 set the upper limits for calculating the frequency factors using the metabolic model developed by Garg, Chaffin and Herrin (1978). The frequency factor values recommended in this Guide (Chapter 8) are based on the need to satisfy the four separate criteria (epidemiological, biomechanical, psychophysical and physiological). The frequency factor values for a lifting frequency of 0.2 lifts/min or less are based on compressive force on L5/S1 disc or strength considerations. The proportions derived from the psychophysically-determined maximum acceptable weights served as the primary criterion to determine frequency factor values for a lifting frequency of 1 to 4 lifts/min. Energy expenditure was the primary criterion used to determine frequency factor values for a lifting frequency equal to or greater than 5 lifts/min. The following equations from Garg (1976) were used to estimate energy expenditure:

Stoop Lift

$$E = 0.0109 BW + (0.0012 BW + 0.0052 L + 0.0028 S*L) f \quad (1)$$

Squat Lift

$$E = 0.0109 BW + (0.0019 BW + 0.0081 L + 0.0023 S*L) f \quad (2)$$

Arm Lift

$$E = 0.0109 BW + (0.0002 BW + 0.0103 L - 0.0017 S*L) f \quad (3)$$

Where:

- E = energy expenditure (Kcal/min)
- BW = body weight (lbs)
- L = weight of the load (lbs)
- S = sex (female = 0, male = 1)
- f = frequency of lifting (lifts/min)

A stoop lifting technique (equation 1) was used to estimate energy

expenditure for lifting from floor level to 0.8 m height. The use of squat lifting method will result in higher energy expenditure or lower allowable weight. It is worth mentioning that when using the NIOSH recommendations (Chapter 8), certain combinations of task variables may result in somewhat higher or lower energy expenditures than the values recommended. This is expected as the relationship between task variables at a given level of energy is not linear and certain variables have greater effect on compressive force and strength than on energy expenditure.

Table 2 shows the estimated energy costs of lifting at the AL and MPL levels at several frequencies. The correction factors for frequency have been calculated from this and similar conditions and meet the criteria well at lifts above 30 inches (76 cm).

Table 2: Estimated Energy Expenditures (Kcal/min) at V= 30 Inches (76 cm)

Frequency Lifts/Min.	Continuous Work Duration (Hours)					
	≤ 8 Hours		≤ 2 Hours		≤ 1 Hour	
	@ AL	@ MPL	@ AL	@ MPL	@ AL	@ MPL
4	2.2	3.5	2.6	4.6	2.7	4.9
5	2.2	3.3	2.6	4.2	3.0	4.9
6	2.2	3.2	2.6	4.2	3.2	5.3
7	2.2	3.2	2.6	4.2	3.3	5.6
8	2.2	3.2	2.6	4.1	3.3	5.5
9	2.2	3.1	2.6	4.1	3.3	5.5
10	2.2	3.1	2.7	4.1	3.3	5.4
11	---	---	2.6	4.1	3.3	5.4
12	---	---	2.7	4.1	3.3	5.4
13	---	---	---	---	3.3	5.5
14	---	---	---	---	3.3	5.4
15	---	---	---	---	3.3	5.4

Assumptions:

1. 25 cm (10") wide box
2. $H = 20 + 12.5 \text{ cm} = 32.5 \text{ cm}$, $HF = 25/32.5 = 0.769$
3. $V = 75 \text{ cm}$, $VF = 1$
4. $D = 75 \text{ cm}$, $DF = 0.8$
5. Good couplings and symmetric lifting.

Table 3 illustrates the estimated energy expenditures using the frequency factors for low lifting in either a stooped (ST) or squat (SQ) posture. The stoop posture has been used to estimating energy expenditure in the lifting guidelines. That assumption may underestimate the load for people who bend their legs rather than use a free style lift.

Table 3: Estimated Energy Expenditures (Kcal/min) at V=0

Frequency	Continuous Work Duration											
	< 8 Hours				≤ 2 Hours				≤ 1 Hour			
	@ AL		@ MPL		@ AL		@ MPL		@ AL		@ MPL	
	SI	SQ	SI	SQ	SI	SQ	SI	SQ	SI	SQ	SI	SQ
4	2.4	2.9	3.7	4.5	2.6	3.1	4.4	5.4	2.7	3.4	5.1	6.4
5	2.6	3.2	3.7	4.6	2.4	3.4	4.4	5.4	3.0	3.8	5.3	6.7
6	2.7	3.4	3.9	4.8	2.9	3.7	4.6	5.7	3.2	4.2	5.9	7.4
7	2.9	3.7	4.0	5.1	3.0	3.9	4.7	6.0	3.4	4.5	6.3	7.7
8	3.0	3.9	4.2	5.4	3.2	4.2	4.9	6.2	3.6	4.8	6.5	8.0
9	---	---	---	---	3.4	4.4	5.0	6.5	3.7	5.0	6.6	8.5
10	---	---	---	---	3.5	4.7	5.2	6.8	3.9	5.2	6.7	8.7
11	---	---	---	---	---	---	---	---	4.1	5.5	6.9	9.0
12	---	---	---	---	---	---	---	---	4.2	5.7	7.1	9.3

Assumptions:

1. 25 cm (10") wide box
2. $H = 25 + 12.5 = 37.5$ cm, $HF = 25/37.5 = 0.66$ F
3. $V = 0$, $VF = 0.85$
4. $D = 75$ cm, $DF = 0.8$
5. Good couplings and symmetrical lifting

Figure 5 graphically illustrates an MPL level of energy expenditure and the combinations of load and frequency that achieve it when either squat or stoop postures are used.

The frequency factors have also been tested against local muscle

fatigue criteria discussed in the beginning of this chapter. Until more direct measurements can be made on lifting tasks, these correction factors appear to be a close approximation of observed and predicted effects of lift frequency on acceptable handling workloads.

E. Determining the Frequency and Duration of Lifting

Analysis of tasks where lifting is done intermittently or in spurts, rather than repetitively and continuously, may lead to miscalculations of the true frequency. In this version of the Guide for Manual Lifting a third category for continuous lifting duration has been added to overcome some of the problems generated when only 1 hour or 8 hours could be selected. The following guidelines for calculating lifting frequency and using the duration categories are recommended:

1. Measure the lifting frequency over a five minute period if it is done for less than 5 minutes at a time. Examples of such tasks would be unloading a pallet in a shipping task or loading chemicals into a reaction vessel. If 8 lifts are done in 1 minute followed by 4 minutes of light work, for instance, the lifting frequency should be calculated as 8 lifts in 5 minutes, or 1.6 per minute. Examples of light work include ticket work, labelling (without lifting), and monitoring.
2. Add up all of the periods of lifting in one shift to determine which of the duration categories should be used.
3. If high frequency lifting is done for a short time and slower

lifting is done for longer periods, break out the high frequency task and analyze it separately, using the duration category that applies to it alone. When summarizing the job, weight the relative distribution of each task (% of time it is done) and get an overall average lifting rate for the combined durations as well as for each separate task.

Guidelines for using the continuous work duration categories when lifting is done more than 1 hour a shift are described below. If these guidelines are followed, fatigue or overexertion should not occur because there will be adequate time for recovery from any short term muscle fatigue before the next period of lifting starts. The recovery time estimates are based on dynamic work recovery times required after different durations of work (cf, Eastman Kodak, 1986; Rohmert, 1973b).

1. Continuous Work Duration of One Hour or Less

These workloads can be maintained for a continuous duration of one hour or less followed by a light work allowance of at least 120% of work time. In other words:

Light Work = $1.2 * \text{Work Time in minutes}$

where WT is work time ≤ 60 minutes

For example, if a worker works for 25 minutes at these work rates, a light work task should follow for at least 30 minutes. This work/recovery pattern can be followed up to a total of 8 hours.

2. Continuous Work Duration of 2 Hours or Less

These workloads can be maintained for a continuous duration of 2 hours or less followed by a rest allowance of at least 30% of the work time. In other words:

$$\text{Light Work} = 0.30 * \text{Work Time in minutes}$$

where $WT < 120$ minutes

For example, if a worker works for 70 minutes at these work rates then he/she should be given a light work task for at least 20 minutes. This work/recovery pattern can be followed up to a total of 8 hours.

3. Continuous Work Duration of 8 Hours or Less

These work loads can be maintained for a continuous work duration of 8 hours or less. No additional fatigue or light work allowance is required other than the fixed mid-morning, mid-afternoon, lunch and the light work allowances given by the company.

4. Guidelines

a. If object weight \leq AL for 8 hours, no additional light work allowance is required.

b. AL for 8 hours $<$ object weight \leq AL for 2 hours

$WT \leq 2$ hours

RT (or Light Work) = $0.30 * WT$

- c. AL for 2 hours < object weight \leq AL for 1 hour
WT \leq 1 hours
RT (or light work) = 0.30 * WT

- d. Weight > AL for 1 hour
Not recommended without administrative controls

- e. The same guidelines apply for MPL including administrative controls.

Examples of problems where repetitive lifting is analyzed are given in the User's Guide and Recommendations sections of this report. In general, lifting frequencies of more than 5/minute, even with very light objects, will be becoming limiting to a significant part of the available industrial workforce, especially if the tasks involve low lifts. Techniques to raise the parts or materials so the lifts can be made closer to waist level will reduce extra effort and allow more people to work efficiently. For continuous lifting tasks, rotation to lighter work frequently during the shift (so the muscles can recover and the total effort level can be reduced) often is enough to reduce the risk of overexertion injuries. Involvement of the workers in setting the rotation schedule is the best way to assure its acceptance and appropriateness.

BIBLIOGRAPHY: PHYSIOLOGICAL COST OF LIFTING - J.W. YATES

- Aquilano, N.J. "A physiological evaluation of time standards for strenuous work as set by stopwatch time study and two predetermined motion time data systems," J. Inc. Eng., 19(9): 425-432, 1968.
- Asfour, S.S., M.M. Ayoub, and A. Mital. "Effects of an endurance and strength training programme on lifting capability of males," Ergonomics, 27(4): 435-442, 1984.
- Asfour, S.S., A.M. Genaidy, and A. Mital. "Physiological guidelines for the design of manual lifting and lowering tasks: the state of the art," Am. Ind. Hyg. Assoc. J., 49(4) 150-160, 1988.
- Asfour, S.S., A.M. Genaidy, T.M. Khalil, and Greco. "Lifting capacity norms based on strength and endurance of workers," in Trends in Ergonomics/ Human Factors II, eds. Eberts and Eberts, Elsevier Science Publishers (North-Holland), pp. 609-615, 1985.
- Asfour, S.S., A.M. Genaidy, T.M. Khalil, and Greco. "A combined approach for determination of lifting capacity" in Trends in Ergonomics/ Human Factors II, eds. Eberts and Eberts, Elsevier Science Publishers (North-Holland), pp. 617-623, 1985.
- Astrand, I. "Degree of strain during building work as related to individual aerobic work capacity," Ergonomics, 10: 293-303, 1967.
- Astrand, P.-O. and K. Rodahl. Textbook of Work Physiology, 3rd Edition, NY: McGraw Hill, 1986.
- Borg, G.A.V. "A category scale with ratio properties for intramodal and interindividual comparisons," Paper presented at the International Congress of Psychology, Leibig, West Germany, 1980.
- Borg, G., P. Hassmen, and M. Lagerstrom. "Perceived exertion related to heart rate and blood lactate during arm and leg exercise," Eur. J. Appl. Physiol., 65: 679-685, 1987.
- Brown, J.R. "Lifting as an Industrial Hazard," Am. Ind. Hyg. Assoc. Journal, 34: 292-297, 1973.
- Carlson, B.R. "Level of Maximum Isometric Strength and Relative Load Isometric Endurance," Ergonomics, 12: 429-435, 1969.

Ciriello, V.M. and S.H. Snook. "A study of size, distance, height, and frequency on manual handling tasks," Human Factors, 25(5): 473-483, 1983.

Doolittle, T. "Aerobic testing for manual handling jobs," in Advances in Industrial Ergonomics and Safety I, ed. A. Mital, Taylor and Francis, pp. 105-112, 1989.

Doolittle, T. "Selection standards for manual handling tasks using dynamic strength tests," in Advances in Industrial Ergonomics and Safety I, ed. A. Mital, Taylor, and Francis, pp. 515-521, 1989.

Eastman Kodak Company Human Factors and Ergonomics Groups, Ergonomic Design for People at Work, Volumes 1 and 2, NY: Van Nostrand Reinhold, 1983 (Vol. 1) and 1986 (Vol. 2).

Fernandez, J.E. and M.M. Ayoub. "The psychophysical approach: the valid measure of lifting capacity," in Trends in Ergonomics/Human Factors V, ed. F. Aghazadeh, Elsevier Science Publishers, (North-Holland), pp. 837-845, 1988.

Fernandez, J.E. and M.M. Ayoub. "Maximum acceptable weight lifted over extended periods," in Trends in Ergonomics/Human Factors IV, ed. S.S. Asfour, Elsevier Science Publishers, (North-Holland), pp. 917-923, 1987.

Frederik, W.L. "Human energy in manual lifting," Modern Materials Handling, March, 1959.

Gallagher, S., W.S. Marras, and T.G. Bobick. "Lifting in stooped and kneeling postures: effects on lifting capacity, metabolic costs, and electrography or eight trunk muscles," Int. J. Ind. Ergonomics, 3: 65-76, 1988.

Gamberale, F. "Perceived exertion, heart rate, oxygen uptake and blood lactate in different work operations," Ergonomics, 15(5): 545-554, 1972.

Garg, A. A Metabolic Rate Prediction Model for Manual Materials Handling Jobs, Ph.D. Dissertation, University of Michigan, 1976.

Garg, A. "Physiological responses to one-handed lift in the horizontal plane by female workers," Am. Ind. Hyg. Assoc. J., 44(3): 190-200, 1983.

Garg, A. "A psychophysical, physiological and biomechanical evaluation of NIOSH guidelines for manual handling," in Trends in Ergonomics/Human Factors IV, ed. S.S. Asfour, Elsevier Science Publishers (North-Holland), pp. 925-931, 1987.

Garg, A. and J. Banaag. "Maximum acceptable weights, heart rates, and RPEs for one hour's repetitive asymmetric lifting," Ergonomics, 31(1): 77-96, 1988.

Garg, A. and J. Banaag. "Psychophysical and physiological responses to asymmetric lifting," in Trends in Ergonomics/Human Factors V, ed. F. Aghazadeh, Elsevier Science Publishers (North-Holland), pp. 871-877, 1988.

Garg, A., D.B. Chaffin, and G.D. Herrin. "Prediction of metabolic rates for manual materials handling jobs," Am. Ind. Hyg. Assoc. J., 39: 661-674, 1978.

Garg, A., G. Hagglund, and K. Mericle. "A physiological evaluation of time standards for warehouse operations as set by traditional work measurement techniques," IIE Transactions, Sept. pp. 235-245, 1986.

Garg, A. and G.D. Herrin. "Stoop or squat: A biomechanical and metabolic evaluation," AIIE Trans., 11(4): 293-302, 1979.

Garg, A. and U. Saxena. "Effects of lifting frequency and technique on physical fatigue and special reference to psychophysical methodology and metabolic rate," Am. Ind. Hyg. Assoc. J., 40(10): 894-903, 1979.

Garg, A. and U. Saxena. "Maximum frequency acceptable to female workers for one-handed lifts in the horizontal plane," Ergonomics, 25(9): 839-853, 1982.

Garg, A. and U. Saxena. "Physiological stresses in warehouse operations with special reference to lifting technique and gender: a case study," Am. Ind. Hyg. Assoc. J., 46(2) 53-59, 1985.

Genaidy, A.M., S.S. Asfour, T.M. Khailil, and S.M. Waly. "Physiologic issues in manual materials handling," in Trends in Ergonomics/Human Factors II, eds. Eberts and Eberts, Elsevier Science Publishers (North-Holland), pp. 571-576, 1985.

Genaidy, A.M. and S.S. Asfour. "Review and evaluation of physiological cost prediction models for manual materials handling," Human Factors, 29(4) 465-476, 1987.

Genaidy, A.M. and S.S. Asfour. "Effects of frequency and load of load on endurance time," Ergonomics, 32(1): 51-57, 1989.

Genaidy, A.M., A. Mital, and K.M. Bafna. "An endurance training programme for frequent manual carrying tasks," Ergonomics, 32(2): 149-155, 1989.

Hake, M. and E.D. Michael, Jr. "The physiological cost of box lifting," J. Human Ergol., 6: 167-178, 1977.

Hamilton, B.J. and R.B. Chase. "A work physiology study of the relative effects of pace and weight in a carton handling task," AIIE Trans., 1(2): 106-111, 1969.

Hayward, V. and L. McCreary. "Comparison of the relative endurance and critical occluding Tension Level of Men and Women," Research Quarterly, 49: 301-307, 1978.

Intaranont, K., M.M. Ayoub, W.M. Bobo, and J.L. Smith. "Physical lifting capacity: the anaerobic threshold approach," in Trends in Ergonomics/ Human Factors III, ed. W. Karwowski, Elsevier Science Publishers (North-Holland), pp. 835-846, 1986.

Jorgensen, K. and E. Poulsen. "Physiological problems in repetitive lifting with special reference to tolerance limits to the maximum lifting frequency," Ergonomics, 17(1): 31-39, 1974.

Kamon, E.E. "Physiological basis for the design of work and rest," in Handbook of Ind. Eng., ed. G. Salvendy, (Wiley: New York), pp. 6.4.1-6.4.17, 1982.

Karwowski, W. and J.W. Yates. "The effect of time in the psychophysical study of the maximum acceptable amounts of liquid lifted by females," Proceed. of the Human Factor Society, 28th Annual Meeting, pp. 586-590, 1984.

Karwowski, W. and J.W. Yates. "Reliability of the psychophysical approach to manual lifting of liquids by females," Ergonomics, 29(2): 237-248, 1986.

Karwowski, W. and M.M. Ayoub. "Effect of frequency on the maximum acceptable weight of lift," in Trends in Ergonomics/Human Factors I, ed. A. Mital, Elsevier Science Publishers (North-Holland), pp. 167-172, 1984.

Khalil, T.M., A.M. Genaidy, S.S. Asfour, and T. Vinciguerra. "Physiological limits of lifting," Am. Ind. Hyg. Assoc. J., 46(4): 220-224, 1985.

Kumar, S. "The physiological cost of three different methods of lifting in the sagittal and lateral planes," Ergonomics, 27(4): 425-433, 1984.

- Kumar, S. "The effects of the reach and level of lifting/lowering tasks on the metabolic cost in symmetric and asymmetric planes," Int. J. Ind. Ergonomics, 2: 273-284, 1988.
- Legg, S.J. and C.M. Pateman. "A physiological study of the repetitive lifting capabilities of healthy young males," Ergonomics, 27(3): 259-272, 1984.
- Lind, A.R. and G.W. McNichol. "Cardiovascular Responses to Holding and Carrying Weights by Hand or Shoulder Harness," Journal of Applied Physiology, 25(3): 261-267, 1968.
- Ljungberg, A.S., F. Gamberale, and A. Kilbom. "Horizontal lifting - physiological and psychophysical responses," Ergonomics, 25(8): 741-757, 1982.
- London, M. and A. Bhattacharya. "The relation between frequency of industrial lifting and the fatigue produced," J. Human Ergol., 14: 3-13, 1985.
- Louhevaara, V., P. Teraslinna, P. Piirila, S. Salmio, and J. Ilmarinen. "Physiological responses during and after intermittent sorting of postal parcels," Ergonomics, 31(8): 1165-1175, 1988.
- Maas, S., M.L.J. Kok, H.G. Westra, and H.C.G. Kemper. "The validity of the use of heart rate in estimating oxygen consumption in static and in combined static/dynamic exercise," Ergonomics, 32(2): 141-148, 1989.
- Miller, J.C., D.E. Farlow, and M.L. Seltzer. "Physiological analysis of repetitive lifting," Aviat. Space. Environ. Med., 48(10): 984-988, 1977.
- Mital, A., S.S. Asfour, and M.M. Ayoub. "Physiological approach in manual lifting: work rate recommendations and a comparison with the psychophysical approach," J. Human Ergol., 11: 143-156, 1982.
- Mital, A. "The psychophysical approach in manual lifting - a verification study," Human Factors, 25(5): 485-491, 1983.
- Mital, A. "Maximum frequencies acceptable to males for one-handed horizontal lifting in the sagittal plane," Human Factors, 25(5): 563-571, 1983.
- Mital, A. "Maximum weights of lift acceptable to male and female industrial workers for extended work shifts," Ergonomics, 27(11): 1115-1126, 1984.

Mital, A. "Comprehensive maximum acceptable weight of lift database for regular 8-hour work shifts," Ergonomics, 27(11): 1127-1138, 1984.

Mital, A. and R.L. Shell. "A comprehensive metabolic energy model for determining rest allowances for physical tasks," J. Methods-Time Meas., 11(2): 2-8, 1984.

Mital, A. "A comparison between psychophysical and physiological approaches across low and high frequency ranges," J. Human Ergol., 14: 59-64, 1985.

Mital, A. "Models for predicting maximum acceptable weight of lift and heart rate and oxygen uptake at that weight," J. Occup. Accidents, 7: 75-82, 1985.

Mital, A. and H.F. Fard. "Psychophysical and physiological responses to lifting symmetrical and asymmetrical load symmetrically and asymmetrically," Ergonomics, 29(10): 1263-1272, 1986.

Mital, A., H.F. Fard, H. Khaledi, and C. Channeveeraiah. "Are manual lifting weight limits based on the physiological approach realistic and practical," Trends in Ergonomics/Human Factors IV, ed. S.S. Asfour, Elsevier Science Publishers (North-Holland), pp. 973-977, 1987

Mital, A. "Patterns of differences between the maximum weights of lift acceptable to experienced and inexperienced materials handlers," Ergonomics, 30(8): 1137-1147, 1987.

Morrissey, S.J. "Influences of task posture on physiological task responses," Int. J. Ind. Ergonomics, 1: 209-217, 1987.

Nicholson, L.M. and S.J. Legg. "A psychophysical study of the effects of load and frequency upon selection of workload in repetitive lifting," Ergonomics, 29(7): 903-911, 1986.

Nicholson, L.M. and S.J. Legg. "The effect of load and frequency upon selection of workload in repetitive lifting using the psychophysical methodology," Proc. 1984 Int. Conf. Occup. Ergonomics, pp. 328-331, 1984.

Petrofsky, J.S. and A.R. Lind. "Metabolic, cardiovascular, and respiratory factors in the development of fatigue in lifting tasks," J. Appl. Physiol., 45(1): 64-68, 1978.

Petrofsky, J.S. and A.R. Lind. "Comparison of metabolic and ventilatory responses of men to various lifting tasks and bicycle ergometry," J. Appl. Physiol., 45(1): 60-63, 1978.

Rodgers, S.H. "Metabolic Indices in Manual Materials Handling Tasks," in Safety in Manual Materials Handling, edited by C.G. Drury, DHEW/NIOSH Pub. #78-185; Cincinnati: DHEW/NIOSH, pp. 52-56, 1978.

Rodgers, S.H. "Recovery Times Needs for Repetitive Work," NY: Thieme Medical Publishers Seminars in Occupational Medicine, 2(1): 19-24, 1987.

Rodgers, S.H. "Job Evaluation in Worker Fitness Determination," in Worker Fitness and Risk Evaluations, edited by Jay Himmelstein, MD and Glenn Pransky, MD, Occupational Medicine: State of the Art Reviews, 3(2) April - June, 1988, Philadelphia: Hanley and Belfus, Inc., pp. 219-239, 1988

Rohmert, W. "Ermittlung von erholungspausen fur statische arbeit des menschen," Int. Z. Angew. Physiol., 18: 123, 1960.

Rohmert, W. "Problems in Determining Rest Allowances. Part I: Use of modern methods to evaluate stress and strain in static muscular work," Applied Ergonomics, 4: 91-95, 1973a.

Rohmert, W. "Problems in Determining Rest Allowances. Part II: Determining rest allowance in different human tasks," Applied Ergonomics, 4(2): 158-162, 1973b.

Ronnhom, N., M.J. Karvonen, and V.O. Lapinleimu. "Mechanical efficiency of rhythmic and paced work of lifting," J. Appl. Physiol., 17(5): 768-770, 1962.

Samanta, A. and B.B. Chatterjee. "A physiological study of manual lifting of loads in Indians," Ergonomics, 24(7): 557-764, 1981.

Scherrer, J. and H. Monod. "Le Travail Musculaire Local et le Fatigue Chez L'Homme," Joier de Physiologie, (Paris) 52: 419-501, 1960.

Sharp, M.A., E. Harman, J.A. Vogel, J.J. Knapik, and S.J. Legg. "Maximal aerobic capacity with three standard exercise testing modes," Eur. J. Appl. Physiol., 57: 753-760, 1988.

Taboun, S.M. and S.P. Dutta. "Effect of task variables and their interactions in intermittent carrying tasks," in Trends in Ergonomics/Human Factors IV, ed. S.S. Asfour, Elsevier Science Publishers (North-Holland), pp. 995-1002, 1987.

Williams, C.A., J.S. Petrofsky, and A.R. Lind. "Physiological responses of women during lifting exercises," Eur. J. Appl. Physiol. 50: 133-144, 1982.

Yates, J.W. and W. Karwowski. "Maximum acceptable lifting loads during seated and standing work postures," Appl. Ergonomics, 18(3): 239-243, 1987.

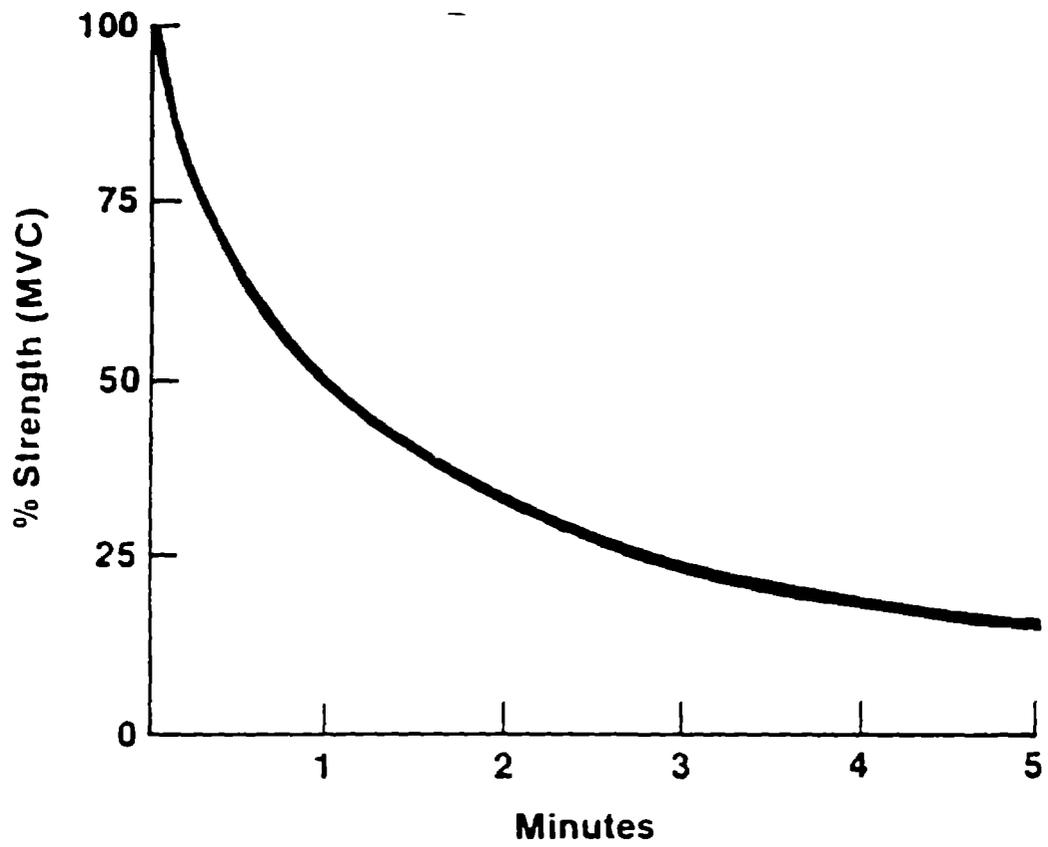


Figure 1: Intensity/Duration Relationship for Static Muscle Work (after Rohmert, 1973a; Scherrer and Monod, 1960).

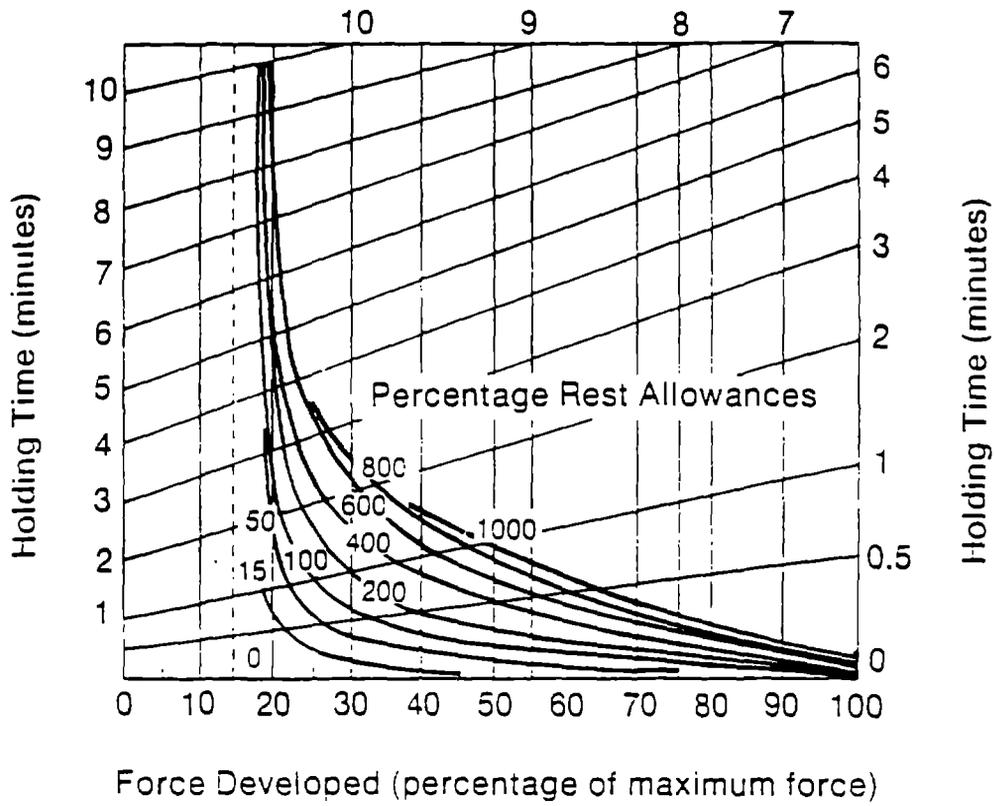


Figure 2: Rest Allowances for Static Muscle Work (after Rohmert, 1973a).

—	6	
—	7	very, very light
—	8	
—	9	
—	10	
—	11	fairly light
—	12	
—	13	somewhat hard
—	14	
—	15	hard
—	16	
—	17	very hard
—	18	
—	19	very, very hard
—	20	

—	0	Nothing at all
—	0.5	Very, very weak (just noticeable)
—	1	Very weak
—	2	Weak (light)
—	3	Moderate
—	4	Somewhat strong
—	5	Strong
—	6	
—	7	Very strong
—	8	
—	9	
—	10	Very, very strong (almost maximum)
	•	Maximal

a. Rating of Perceived Exertion (RPE)

b. Large Muscle Group Ratio Scale

Figure 3: Psychophysical Effort Rating Scales (G.A.V. Borg, 1980).

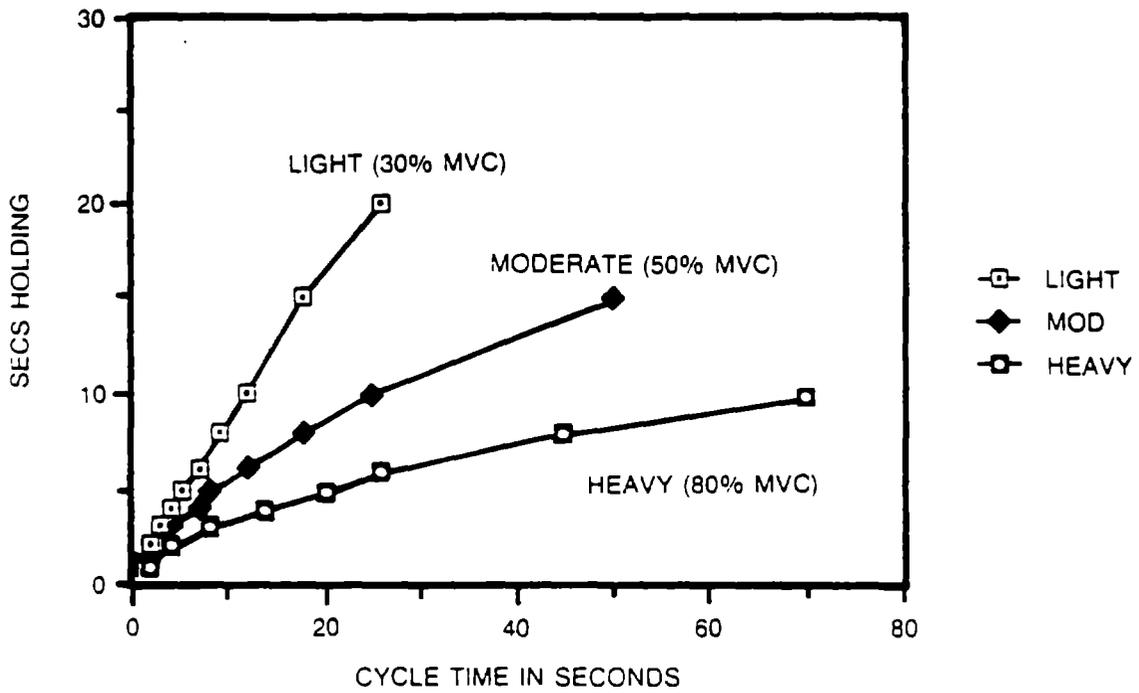


Figure 4: Work and Recovery Guidelines for Muscle Work as a Function of Effort Intensity, Duration, and Frequency (Rohmert, 1973a; Rodgers, 1987).

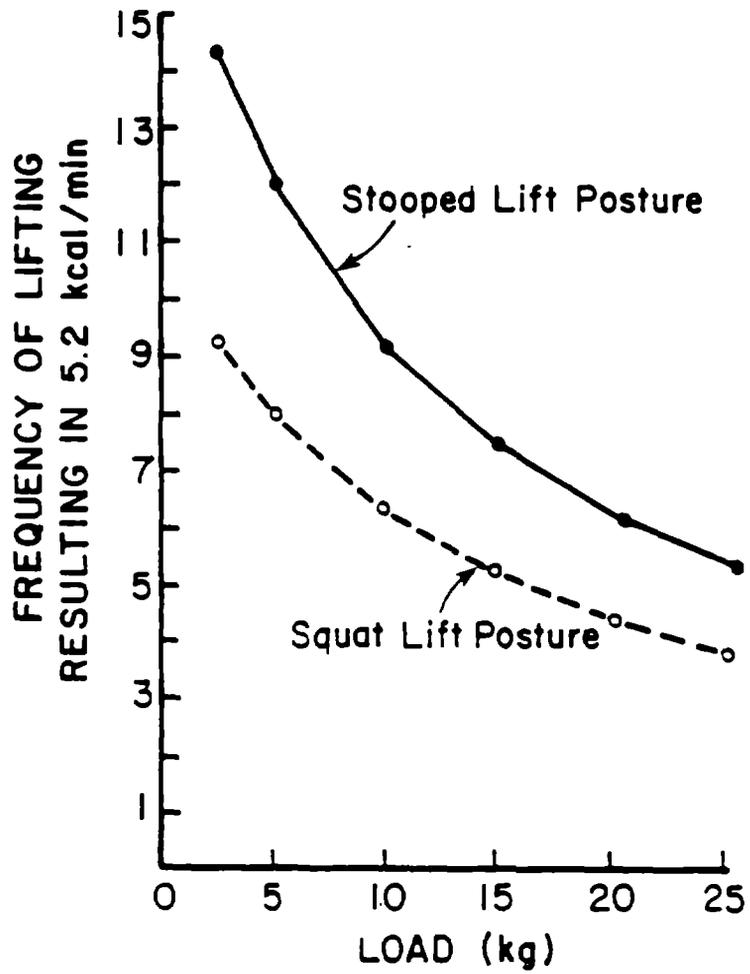


Figure 5: Estimated Maximum Frequency of Lift with Two Postures (Adapted from Garg and Herrin, 1979).

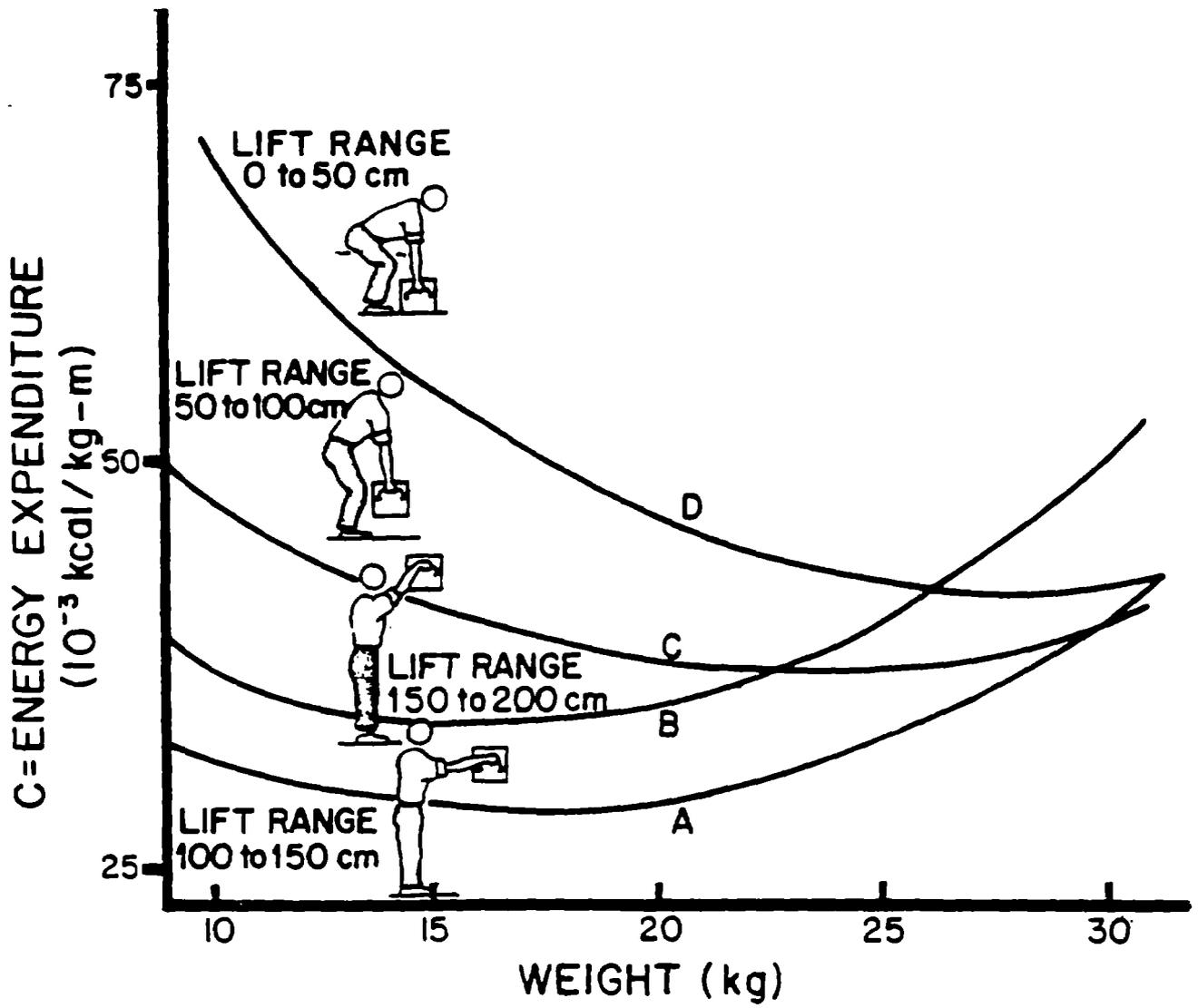


Figure 6: Energy Efficiency with Weight and Range of Lifting (Frederik, 1959).

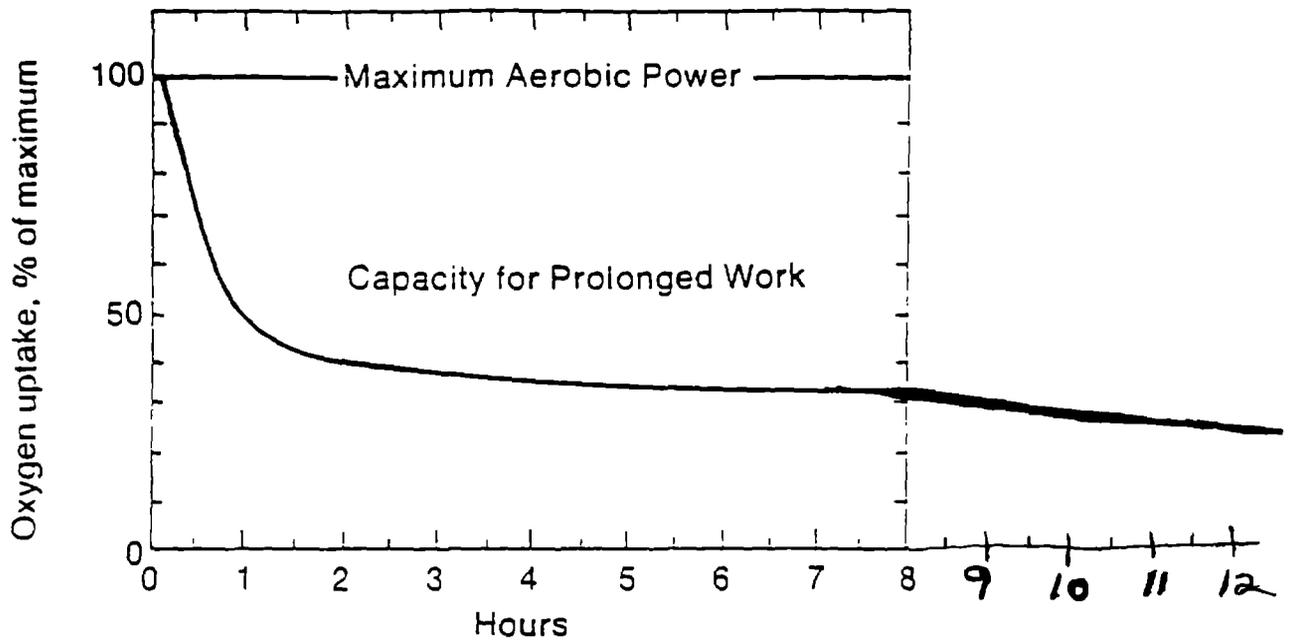


Figure 7: Effect of Work Duration on Percent of Maximum Aerobic Capacity Available for Work (after Astrand and Rodahl, 1970).