CHAPTER 4

BASIS FOR GUIDE: PHYSIOLOGICAL APPROACH

This chapter is concerned with the design of repetitive lifting tasks which a person can perform without excessive fatigue. Oxygen consumption, metabolic energy expenditure rate and heart rate are the physiological measurements which have been suggested most often for determining the maximum work intensity that can be continuously performed without accumulating excessive physical fatigue.

It is convenient to consider these responses first as they are measured in the laboratory and then to place our understanding of them in the practical conditions of everyday industrial work.

There are two kinds of muscular activity. First, dynamic exercise, which forms the bulk of everyday activity, can be defined as exercise in which muscles shorten, causing movement of the bones around joints of the skeleton. Exercise such as walking, jogging, bicycling, etc. comprise almost "pure" dynamic exercise. The second type of exercise is isometric, when the muscles do not shorten and there is no movement around the joints; carrying or holding packages, suitcases, etc. are common examples. The physiological responses to these two kinds of exercise are quite different; while dynamic exercise provides a greater expenditure of energy in daily work, isometric exercise (or static effort) readily induces muscular fatigue. Daily activity is made up of both types of exercise and the physiological responses to each ought to be properly understood.

In the description of physiological responses to exercise given in this chapter, the individuals are presumed healthy. Illness or disease of many kinds can substantially modify those responses.

DYNAMIC EXERCISE

Physiologists measure this kind of exercise as the amount of oxygen that is used by the muscles. When muscles become active, their increased metabolism demands an increase in the delivery of oxygen and foodstuffs if the activity is to continue. These circumstances call for an increased respiratory function and a greater amount of blood flow to the muscles. However, these respiratory and cardiovascular responses are linearly related to the amount of oxygen used used by the muscles. In turn, the amount of oxygen used (aerobic activity; $\dot{V}O_2$)is linearly related to the amount of external work done by the muscles. Hence we can judge the severity of the exercise by the $\dot{V}O_2$. The skeletal muscles, however, have also the ability to contract even in the absence of oxygen; that anaerobic capacity is limited and is called on only when the aerobic metabolism is insufficient to allow the exercise to continue. When the limit of the anaerobic metabolism is reached, the muscles are fatigued and are no longer able to do effective work.

There is an upper limit to aerobic metabolism, often called the aerobic capacity (or in physiological jargon, the $\dot{V}O_2$ max) which varies considerably from person to person, influenced by a number of factors which are described below. Usually, the muscles' anaerobic metabolism is called into play when the exercise demands 50% or more of the VO_2 max. As the severity of the exercise increases above that level, the greater is the proportion of anaerobic metabolism for the muscular activity and, because the amount of anaerobic metabolism is finite, the duration of exercise before fatigue occurs varies inversely with increasing severity of the activity. Obviously, it is important to know what the $\dot{V}O_2$ max is for an individual or a group of individuals and also to avoid prolonged work at levels greater than 50% $\dot{V}O_2$ max if fatigue is to be avoided (In fact, lower percentages of $\dot{V}O_2$ max have been considered limiting, in some studies, as is discussed below). Factors which influence $\dot{V}O_2$ include:

1. <u>Level of $\dot{V}O_2$ max ("fitness")</u>

It is well established that when men and women engage in a regimen of relatively severe exercise on a controlled repetitive basis, they are able to improve their physical performance. Their aerobic work capacity may increase by amounts reported to be between 5 and 25%; the increase appears to depend on the frequency, duration and severity of the training regimen and also on the degree of "fitness" of the individuals concerned (cf. Astrand and Rodahl, 1970).

The level of activity of the bulk of the population is labelled as "sedentary". In the last few decades surveys have been completed on the proportion of time spent in different activities in a variety of occupations; in a number of these surveys, information has also been collected on activities during non-working hours. In light industries, much of the work done involves low levels of energy expenditure. Except in "heavy" industries such as mining, steel working, etc., the work seldom reaches or exceeds 50% $\dot{V}O_2$ max and then only intermittently.

In these heavy industries, the work level yields an average daily oxygen requirement of about 1 l O_2/min. (metabolic energy equivalent = 5 Kcal/min). Periodically, tasks occur at much higher levels, of 2 l O_2/min (10 Kcal/min) or even as high as 3 l O_2/min (15 Kcal/min). These tasks are short, lasting only for several minutes, and to provide an average daily level of 1.0 l O_2/min, are offset by rest periods along with periods of work at low levels of oxygen usage. Even in "heavy" industries, however, the increasing use of automation tends to reduce the energy expenditure of the work. However, workers in such jobs can be regarded as "active" (or trained) in some degree and they have a greater aerobic capacity than their "sendentary" counterparts in most industries.

2. Age and Sex

The age and sex of an individual have a profound effect on the $\dot{V}O_2$ max. The decline of $\dot{V}O_2$ max with age for both sexes, can be expressed as a linear function (cf. Astrand and Rodahl, 1977; Hodgson and Buskirk, 1978). At age 60 years, an individual will have, on average, a reduction of about 30 to 40% of the $\dot{V}O_2$ max he had at 20 years; that is, there is a loss of about 10% in aerobic capacity each decade. The $\dot{V}O_2$ max at any given age for women averages about 70% of that for men.

3. Body Weight and Body Fat

The $\dot{V}O_2$ 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. The difference between men and women may well be due to sex differences in fat content of the body.

When the $\dot{V}O_2$ max is expressed in terms of unit body weight, the influence of age is not diminished but the variance of the results is much reduced. Treatment of the results in this way also reduces the influence of sex for a given age. When the amount of body weight that is fat is measured, the VO_2 max can be expressed as oxygen uptake per unit of "lean" body weight. That procedure further reduces the variance of the results for men and women at given ages. It diminishes but does not completely abolish the sex difference in $\dot{V}O_2$ max and does not influence the proportional loss of VO_2 max with age.

4. Type of Exercise

The type of exercise used in the assessment of $\dot{V}O_2$ max influences the results. The dominant feature influencing the measurement is the mass of the muscles involved in the exercise. Thereby, running uphill provides values which are marginally greater (5 to 8%) than running on the horizontal or bicycling. Bicycling itself is reported to yield a slightly higher $\dot{V}O_2$ max at 60 rpm than at higher or lower values of rpm. Arm cranking or bicycling with both legs while simultaneously cranking with both arms does not result in a $\dot{V}O_2$ max greater than that found in running uphill; there appears to be an optimum mass of muscles which provides a $\dot{V}O_2$ max.

This matter gains importance when industrial work is considered. It has been shown that the energy cost of lifting boxes of the same weight and at the same frequency is substantially greater when the legs are bent to assist lifting than when the trunk only (cantilever) is bent (Brown, 1971; Garg, 1976). The $\dot{V}O_2$ max of lifting boxes by the cantilever method is much lower than for bicycling (Petrofsky and Lind, 1978). With boxes of 15 kg or more, the $\dot{V}O_2$ max of lifting with the bent-leg method is the same as in bicycling but when the boxes weighed 8 kg or less, the $\dot{V}O_2$ max is lower than the response to bicycling (Lind and Williams, 1979).

Depending on the nature and severity of the task, selection of workers based on their $\dot{V}O_2$ max is clearly desirable. But in many industrial circumstances, it is impractical to provide this kind of selection procedure for individuals.

ISOMETRIC EXERCISE

The methods for assessing physiological responses to isometric exercise are different from those described for dynamic exercise. At most tensions, sustained contractions readily induce local muscular fatigue, from which recovery is slow. For a given group of muscles, the maximum voluntary contraction (MVC) is first measured on a dynamometer. The bulk of experiments then report the endurance time to fatigue when specific sub-maximum tensions are held. There emerges a clear pattern of relationship between the sustained tension and the endurance time (when that tension can no longer be maintained). At 100% MVC the endurance is about 3 to 4 seconds. At 70, 50 and 30% MVC, the endurance is of the order of 35, 90, and 250 sec, respectively. When the tension falls to less than about 15% MVC, the contraction can be maintained for a long time, and results in little fatigue.

The most commonly reported studies involve hand-grip contractions, for which the MVC for men is about 50 kg, while for women it is 35 kg. There is, however, a wide individual variation in both the MVC and the endurance of sub-maximal tensions. Several factors influence both the MVC and the endurance time. Age results in a reduction of strength, but not as dramatically as it affects $\dot{V}O_2$ max in dynamic exercise. Muscle temperature does not affect the MVC but, as the muscle temperature increases, there is a reduction in endurance time. At relatively low tensions (e.g., 30% MVC) this can amount to some 20 sec for each °C difference in muscle temperature; the muscle temperature can readily vary by 5 or 6°C as a result of the influence of the environment, clothing, subcutaneous fat or previous exercise. At high tensions (e.g., 70% MVC) the difference due to temperature is not so marked.

Women have greater endurance than men at all relative tensions below 50-60% MVC. But when these results are considered in absolute terms, the reverse is true because the men are so much stronger than women. As an extreme example, at their average MVC, 36 kg, the endurance of women is only 3 sec whereas the same tension represents only 70% MVC for men who hold that tension for an average of 36 sec, or 12 times longer. At the other end of the tension/endurance curve, a tension of 7.5 kg represents 15% MVC for men and can be held for an average time in excess of 30 min (the absolute time is not known). In contrast, 7.5 kg represents 21% MVC for women and the average endurance time is about 10 minutes.

The type of muscle examined is doubtless an important determinant of endurance, but there is insufficient data to provide realistic comparisons with hand-grip contraction. The muscle mass will undoubtedly affect the oxygen uptake but has little effect on the cardiovascular responses, which provide the most dramatic differences in physiologic changes when compared to those in dynamic exercise. In rhythmic exercise there is a large increase in heart rate but little increase in blood pressure, whereas the increase in heart rate is modest with a large increase in blood pressure during isometric exercise.

The physiological responses to isometric exercise are superimposed on those due to rhythmic exercise when the two kinds of activity are carried out simultaneously. But insufficient information is available about intermittent exercise to characterize precisely that the circumstances that induce fatigue. Current evidence indicates a duration of contractions:rest ratio of 2:1 will induce fatigue at high tensions such as 60% MVC whereas a ratio of 3:1 is necessary to induce fatigue at low tensions (25% MVC).

PHYSIOLOGICAL RESPONSES TO LIFTING WEIGHTS

1. Strength of Lifting

Claims concerning the physiological or anthropometric correlates to lifting strength are varied. Whitney (1958) made it clear that in most lifting actions, the body weight, which acts as a counterbalance, must have a proportional relationship (associated, of course, with the center of gravity of the body) to the lifting strength. He showed that the most important factor which affected the isometric strength in a lifting action was the distance of the feet from the object to be lifted and that other features of the lifting procedure such as the "derrick" or "knee" action, or the type of grasp used, had only small effects on the strength exerted. Poulsen (1970) came to the conclusion that the maximum load that can be lifted correlated well with the maximum isometric strength of the back muscles; it must be noted, however, that the isometric strength of the back muscles was measured with a dynamometer that did not directly duplicate the lifting task. Recent proposals concerning "safe" weights to be lifted in a wide range of positions have been put forward (e.g., Davis and Stubbs, 1977), which are based on intra-abdominal pressures generated in the act of lifting.

2. Repetitive Lifting

In a series of studies on healthy young males and females who were trained to lift boxes, Lind and coworkers observed the following:

A. Aerobic capacity. The $\dot{V}O_2$ max for men who lifted by the cantilever (bent back) method from the floor to a bench 60 cm high (24 inches) was,

1) substantially lower when lifting boxes than on the bicycle ergometer (15% lower when lifting a box weighing 36.4 kg, or 80 lb).

2) directly related to the weight of box, from 1 kg to 36.4 kg.

3) determined, by subjective impression, by the rate at which the trunk and head could be moved for boxes weighing up to 6.8 kg (15 lb) but by fatigue in the forearm muscles when the box weighted 36.4 kg (80 lb). (Lind et al., 1979; Petrofsky and Lind, 1978).

The $\dot{V}O_2$ max of women lifting with the bent-legs method from the floor to a bench 60 cm high (24 inches) showed,

1) no differences in $\dot{V}O_2$ max for boxes weighing 15.9 kg (35 lb) and 22.7 kg (50 lb) and were not statistically different from that measured on the bicycle ergometer. The difference in pattern of response with that of the male subjects is attributable to the different method of lifting.

2) the $\dot{V}O_2$ max increased with the weight of box, from 2 kg (4.4 lb) to 22.7 kg (50 lb) (Lind et al., 1979, Williams et al.. 1980).

B. Level of aerobic capacity associated with fatigue. When men lifted boxes from the floor to a bench 60 cm high (24 inches) for one hour,

1) the evidence from oxygen uptake, heart rate and arterial lactate support the view that fatigue was generated when the work rate exceeded 50% of the $\dot{V}O_2$ max for the given weight of box (i.e., at levels as low as 35% of the $\dot{V}O_2$ max established on the bicycle ergometer for these subjects).

2) there was a reduction on hand-grip isometric endurance (measured after the hour's lifting) linearly related to the weight of the box; electromyographic evidence showed more fatigue generated in the forearm than in the back muscles during lifting. (Lind et al., 1977; Petrofsky and Lind, 1978a).

When women lifted boxes by the bent leg method from the floor to a bench 50 cm high (24 inches),

1) the evidence from oxygen uptake, heart rate, and forearm electromyograms showed that fatigue occurred at approximately 50% of the $\dot{V}O_2$ max measured for the weight of box being lifted (i.e., at levels corresponding to some 40% $\dot{V}O_2$ max for bicycle ergometry at box weights up to 6.8 kg (15 lb).

2) there was a reduction of hand-grip endurance after the hour's lifting which was linearly related to the weight of box. That reduction was not as great as in the data from men. (Lind et al., 1979; Williams et al., 1980).

B. Relationship of $\dot{V}O_2$ to weight of box and frequency of lifting. For all the data available, irrespective of the origin of the lift and its vertical travel, there is

1) a linear increase in $\dot{V}O_2$ with the rate of lifting boxes of the same weight.

2) a linear increase in $\dot{V}O_2$ with the weight of box at the same rate of lifting.

3) a greater $\dot{V}O_2$, when the weight of box and the rate of lifting are constant, when the lifting is performed by the bent-leg method when compared to the cantilever method. (Aquilano, 1968; Hamilton, 1969; Brown, 1971; Snook, 1971; Lind et al., 1977; Miller, et al., 1977; Lind and Petrofsky, 1978a; Lind, et al., 1979; and Williams, et al., 1980).

C. Relationship of $\dot{V}O_2$ with point of origin and height of travel of lifting.

1) There are comparable data on $\dot{V}O_2$ from experiments in which the boxes are lifted from the floor to a height of 50 to 90 cm (20 to 35 inches) when the weight of box and the rate of lifting are constant. The variation in average VO_2 can be attributed to different sizes of box or the method of lifting.

2) The energy cost of lifting boxes from "table" height, 50 to 90 cm (20 to 35 inches) to a height of 100 to 120 cm (40 to 47 inches) is substantially lower than lifting from the floor when the weight of box and the rate of lifting are kept constant.

3) When boxes are lifted down from 60 cm (24 inches to the floor, the VO_2 is lower than when lifting upwards over the same distance.

4) Lifting and turning to place the weight at 90° to the point of origin results in the same regression equations for lifting in the sagittal plane. (Aquilano, 1968; Hamilton, 1969; Miller, et al., 1977; Petrofsky and Lind, 1978a; Snook (1978; and Lind, et al., 1979).

The results from laboratory experiments suggest that lifting exercises in industry will seldom reach or exceed the average male worker's 50% $\dot{V}O_2$ max, which is taken to be the physiological limit beyond which muscular fatigue (and its physiological sequelae) will inevitably occur. Indeed, it seems that there will be few practical situations where the average energy cost of lifting in industry is likely to exceed 35% $\dot{V}O_2$ max, a level of work which is considered by most research workers to be compatible with daily levels of work in "heavy" industries irrespective of age, sex, and other factors which are known or suspected to limit the permissible daily energy expenditure in industry.

One factor that remains to be satisfactorily defined and categorized as a limiting factor in lifting is the static isometric component and its associated physiological responses.

DETERMINATION OF WORK CAPACITY LIMITS BASED UPON ENERGY EXPENDITURE

1. Population Capacity Estimates

Adjusting for age, sex, and body weight variation in the working population Chaffin, (1972) predicted the variation in aerobic capacities illustrated in Figure 4.1. The lower 95 percent prediction intervals are also plotted.

Unfortunately, a large scale evaluation of the aerobic capacities of the American working population has not been undertaken so that values presented in this figure are only rough estimates. Cross-sectional population distributions summarized by Cumming (1967) conform to these data. A study by Rodahl and Issekutz (1962) of American policemen, however, indicates that persons having relatively sedentary jobs would have lower aerobic capacities than expected from Figure 4.1. As a result Chaffin estimated that

> "probably 80 percent or more of American men are <u>not</u> physically fit, as judged by their aerobic capacities being below a reasonable value of 16 Kcal/min."

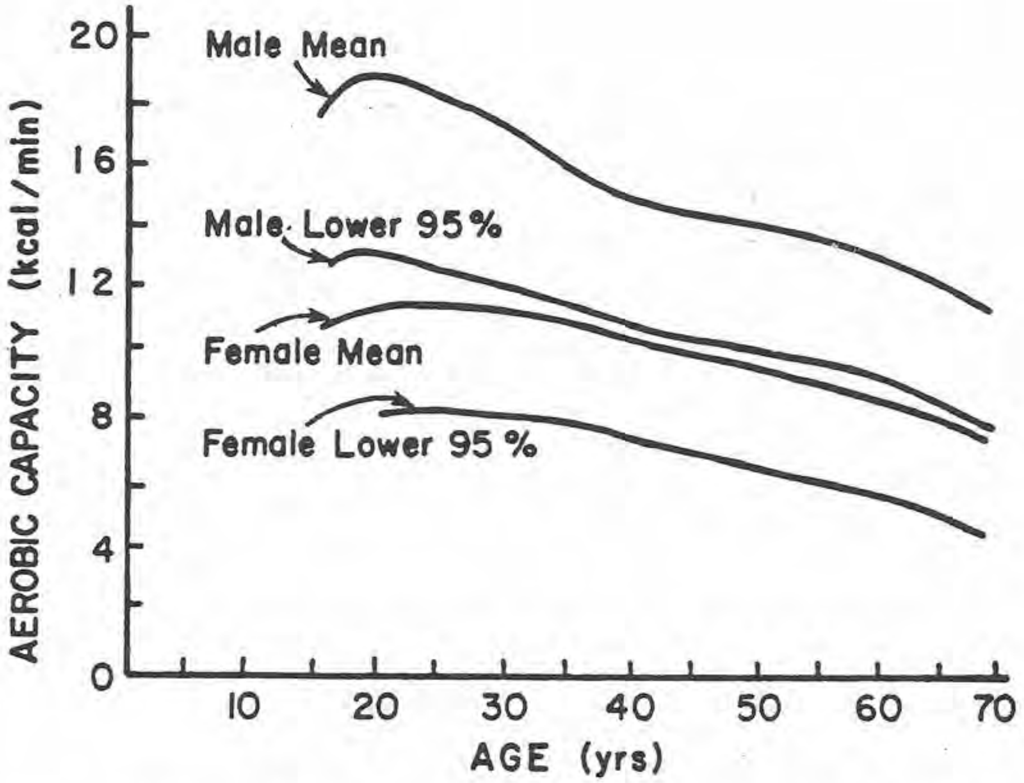


Figure 4.1: Estimated Population Aerobic Capacities for U.S. Men and Women (Chaffin, 1972).

Because the aerobic capacities in the working population vary so greatly, persons being considered for jobs requiring high metabolic demands should be specifically tested. Often aerobic capacity testing is done in industry on those persons who have a history of cardiovascular problems. In this sense it is used to determine the effectiveness of various cardiac rehabilitation programs, rather than being a tool of preventive medicine. Only through routine aerobic capacity testing in industry can objective decisions be made about what job is "too difficult for certain susceptible groups of people and for specific individuals. For the present, the recommendations provided later in this Guide are based on an assumed aerobic capacity of 15 Kcal/min. for men (cf. Robinson, 1939) and 10.5 (70% of men) for women (cf. Astrand, 1960). These limits may be too high, however, for a de-conditioned, aging workforce. Aerobic capacity testing of a broad, cross-section of the U.S. workforce is needed.

2. Eight Hour Work Duration

In terms of endurance, a controversy exists in the literature over appropriate allowances for extended continuous work.

Christensen (1955) proposed that if work is performed with an energy expenditure rate below 50 percent of a person's aerobic capacity, excessive fatigue will not occur. Astrand (1960) tested subjects with a large variation in aerobic capacities (from 11.2 to 26.0 Kcal/min.) and found that when subjects were performing at 50 percent of their aerobic capacities for eight hours, their heart rates increased to a level of 120 to 135 beats per minute. She observed that, if the aerobic capacities had not been measured (and energy expenditure rates adjusted accordingly) the heart rate in the older subjects (with limited aerobic capacities), if required to perform at the same energy expenditure rates as the younger subjects, would have incurred a heart rate increase of 30 beats/minute in the first hour of work. Thus the older subjects would have rapidly approached their predicted maximum heart rates of about 165 beats per minute.

Studies by Lehmann (1953) and Bink (1962, 1964) indicated that a work load of 5.2 Kcal/minute is the maximum energy expenditure rate that should be expected for an eight hour workday. Lehman assumed a mean age of males of 35 years, with 2500 Kcal to be available during an 8 hour day.

Legwork at levels above 5.0 Kcal/minute in well-trained individuals has been found to cause increased levels of blood lactate (Ekblom, et al., 1968). This is further evidence to indicate that the metabolic demand for oxygen within the muscles is not completely fulfilled when the task is at higher levels than 33 percent of the aerobic capacity of the person, even with highly dynamic work. Additional support for using a 33 percent value rather than the higher 50 percent of aerobic capacity is suggested by Snook and Irvine (1969). They found that when healthy industrial men were allowed to choose the amount of repeated lifting acceptable for eight hours, they chose a level that produced a heart rate averaging 112 beats per minute, which would be equivalent to about 5.0 Kcal/minute of energy expenditure.

A more recent industrial study by Rodgers (1976) supported a lower (33 percent) capacity in concluding:

> "We have observed that most people will select a level of effort that keeps them within the 33% of maximum capacity guideline and will also integrate other factors such as:
>
> - the biomechanical aspects of materials to be handled--grasping characteristics, size, etc.
> - environmental characteristics of the workplace--heat, hours of work, chemical agents, pacing, etc.
> - the individual's physical fitness level

- the individual's skill level--training and experience on the job
- the individual's activities outside of work--second job, housework, etc."

In industrial work there is the additional problem of static muscular effort (posture maintenance and holding of worklaods) which reduces blood flow. This would indicate that aerobic capacities for this type of work would in general be lower compared to the dynamic capacities assumed in the above studies (Lind, et al., 1979; Williams, et al., 1980).

For the purposes of this Guide, the lower (33 percent of aerobic capacity) will be assumed for 8 hour work duration.

3. Working Time Prediction

With reference to a normal, healthy, 35-year-old working man, three limitations in physical work capacity as a function of working time were proposed by Bink (1962) and Bonjer (1962):

1) An upper energy work limit of 16 Kcal/minute for four minutes (i.e., aerobic capacity)
2) an eight-hour continuous work limit of 5.2 Kcal/minute, which is 33 percent of (1).
3) a 24-hour performance limit of 2.85 Kcal/minute (based on dietary considerations, (V.V.V. 1958).

The resulting logarithmic relationship of working time to work capacity is illustrated in Figure 4.2. The use of such a logarithmic relationship of the working time and the average work capacity has also been discussed by Bonjer (1971) and Moores (1970).

An example application of the working time prediction concept is illustrated with a coal mining job consisting of the following productive activities (Garry, 1952).

Activity	% of Time	Average Metabolic Rate (Kcal/min.)	Weighted Metabolic Rate (Kcal/min.)
Loading	42%	6.3	2.64
Standing	7%	1.8	0.12
Walking	23%	6.7	1.54
Hewing	4%	6.7	0.27
Timbering	24%	5.7	1.37

Predicted Average Metabolic Rate = 5.94 Kcal/min.

Assuming that a physically fit 35-year-old man (16 Kcal capacity) should be capable of working this job, then it is predicted (from Figure 4.2) that the working time will need to be reduced from a 480 minute day to a 340 minute day, with 140 minutes of rest.

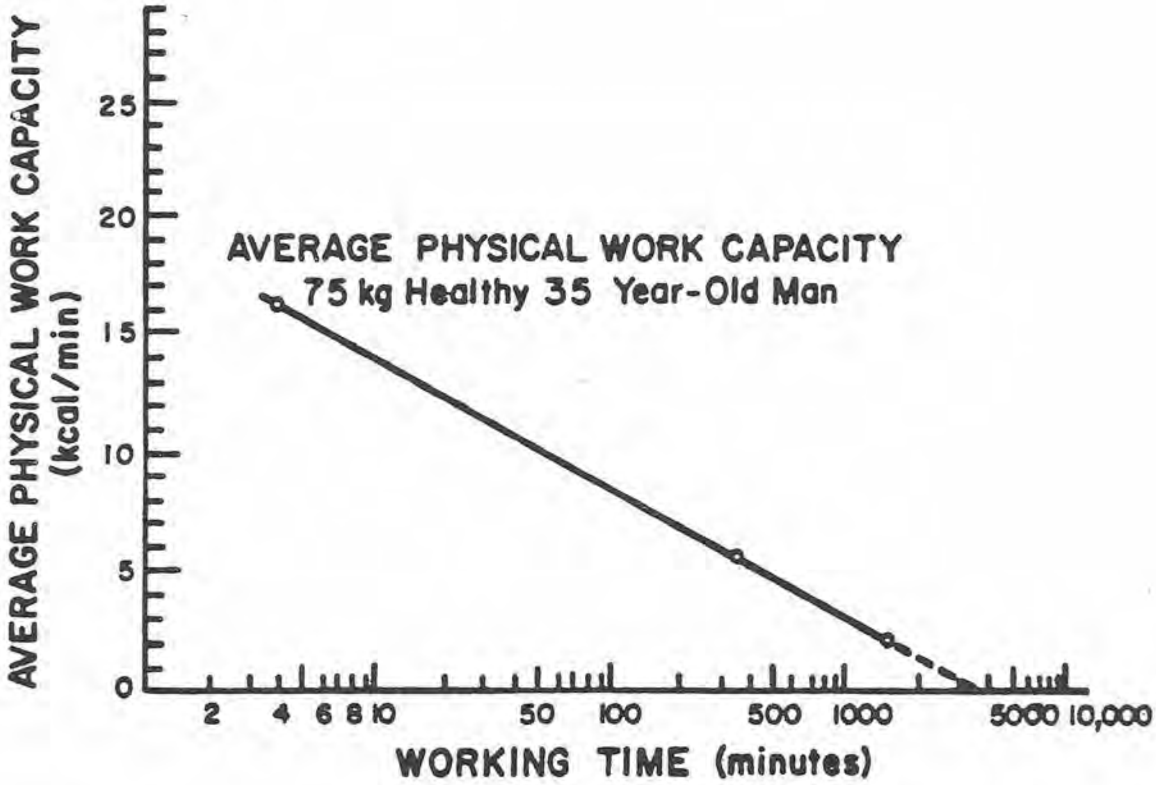


Figure 4.2: Physical Work Capacity and Working Time (Bink, 1962 and Bonjer, 1962).

4. Estimating Task Energy Requirements

Given the ability to assess an individual's metabolic work capacity, adjusted for work duration, the question remains: "How can this be related to a job?" At present, the three commonly used methods for determining the metabolic demands of a particular job are:

1) measurement of oxygen consumption on incumbent workers
2) estimating using tabulated survey values
3) estimating using mathematical models.

On-the-job measurement of oxygen utilization is the most straight-forward method for determining the metabolic energy requirements of a particular person on a particular job. However, on-the-job measurement of oxygen utilization is sometimes difficult due to interference of measuring equipment with the normal work methods. Handling methods, work operations, weight and size of working material and the particular workers may be continually changing (Aberg, et al., 1968), and individual oxygen uptake measurements made today may not be valid later.

On the other hand, extensive tables of metabolic energy expenditure estimates for more than 1000 different activities are available in the literature. Table 4.1 illustrates the average energy costs for a small set of selected activities (Durnin and Passmore, 1967). Such studies provide estimates of the metabolic energy expended by the "average" person who is performing complex manual activities under different working conditions such as unloading coal cars, handling boxes, stapling, loading corrugated cartons (Davis, et al., 1969), working in a hot environment, construction work, etc.

Table values, however, provide only a rough approximation of the metabolic cost of a given job. Such values are specific to particular work situations employed at the time of measurement and do not (for the most part) reflect the variable effects of important personal and task parameters such as body weight, postures, object weight, object size, travel distance, etc. Without more detailed task descriptions it is difficult to interpolate or extrapolate such values.

A third group of studies relate metabolic energy expended by a person to the physical measures of the activity. Primarily through regression and analysis of variance models, empirical relationships between metabolic energy expenditure rates and one or more of the physical parameters of the job have been modelled (Frederik, 1959); Cotes and Meade, 1960; Grimby and Soderholm, 1962; Garg, 1976; Aquilano, 1968; Aberg, et al., 1968; Hamilton and Chase, 1969; Soule and Goldman, 1969; Givoni and Goldman, 1971; Kamon and Belding, 1971; Snook, 1971; Chaffin, 1972; Van Der Walt and Wyndham, 1973; Garg, et al., 1978). In general, it is noted that minor changes in the physical parameters that are commonly used to describe the manual activity result in significant changes in metabolic energy expenditure predictions as will be illustrated in the following section.

5. Variables Affecting Metabolic Rate

In order to develop a predictive model of metabolic rate for lifting a number of variables must be considered. Table 4.2

Table 4.1: Average energy cost while performing selected activities. Values apply for 70-kg (154-pound) man. For most activities adjustment for cost is proportional to body weight. (Durnin and Passmore, 1967)

Body Position and Activity	Total Energy Cost Typical	Kcal/min Range
Heavy activity at fast to maximum pace		10.0-20.0
Jogging, level, 4.5 mph	7.5	
Lifting, 20 kg, 10 cycles per min.		
floor to waist	8.2	
floor to shoulder	10.8	
Reclining, at rest	1.3	
Running, level, 7.5 mph	12.7	
Shovelling, 18 lb. load 1 yd. with 1-yd. lift, 10 times per min.	8.0	
Sitting, at ease		
light hand work (writing, typing)	1.7	1.6-1.8
moderate hand and arm work (drafting, light drill press, light assembly, tailoring)		
light arm and leg work (driving car on open road, machine sewing)	2.8	2.5-3.2
heavy hand and arm work (nailing, shaping stones, filing)	3.5	3.0-4.0
moderate arm and leg work (local driving of truck or bus)	3.6	3.0-4.0
Standing, at ease	1.9	
moderate arm and trunk work (nailing, filing, ironing)	3.7	3.0-4.0
heavy arm and trunk work (hand sewing, chiselling)	6.0	4.0-8.0
Walking, casual (foreman, lecturing)	3.0	2.5-3.5
moderate arm work (sweeping, stockroom work)	4.5	4.0-5.0
carrying heavy loads or with heavy arm movements (carrying suitcases, scything, hand-mowing lawn)	7.0	6.0-8.0
transferring 35 lb. sheet materials 2 yds. at trunk level, 3 times per min.	3.7	
pushing wheelbarrow on level with 220 lb. load	5.5	5.0-6.0
level, 2 mph	3.2	
3 mph	4.0	
4 mph	5.9	

shows the major tasks and personal factors known to affect metabolic energy expenditure rates. A brief description of the effects of each factor follows.

Table 4.2: Major factors affecting metabolic energy expenditure rate.

Worker Variables	Task Variables
1. Gender	4. Load
2. Body Weight	5. Frequency of loading of body
3. Lifting Techniques	6. Vertical travel distance
	7. Vertical origin of lift
	8. Temperature and humidity

The effects of age and body weight have been discussed in the section on dynamic exercise (p. 41).

Other factors affecting the metabolic rate include:

1. Body Posture (or Technique). The body posture used to lift a load may affect the metabolic cost of the job considerably. The following are some of the reasons:

    1. Different body postures affect the loading of different muscle groups and different muscle groups have different metabolic efficiencies.

    2. Body posture affects the muscle moment arm and length of the muscle. Metabolic efficiency is related to muscle tension which is a function of length of the muscle and speed of shortening (Hill, 1938).

3. Squat lifting requires more work to lift the body itself than stoop lifting and thus involves a higher metabolic cost.

Figures 4.3 and 4.4 illustrate the importance of lift technique on metabolic rate. Brown (1971) demonstrated that free style lifting is least fatiguing compared to stooping or squatting as shown in Figure 4.3. Garg and Saxena (1979) found similar differences, expecially with frequent low level lifting as shown in Figure 4.4. (It is important to note that the variables plotted are quite different in these two figures).

2. Weight of the Load. In repetitive lifting, mechanical work per minute can be written as:

   Mechanical Work = Load x Frequency x Distance of Vertical Lift

   Therefore, the heavier the load to be lifted, the greater the mechanical work performed and subsequently the greater energy expenditure. Frederik, 1959; Snook, 1965; Aquilano, 1968; Hamilton, 1969; Brown, 1971; Lind, et al., 1977; and Garg, et al., 1978, have each reported that an increase in load to be lifted results in an increase in metabolic energy expenditure rate. Most studies agree that a linear relation between object weight and metabolic rate is reasonable for most lifting tasks.

3. Frequency of Lifting. Frequency is defined as the number of lifts per minute. The mechanical work done by the musculoskeletal system is also directly proportional to frequency (as noted above). If all other factors such as load, range and distance of vertical lift, speed of lift, technique, etc., are held constant, the metabolic energy expenditure rate should be directly proportional to the pace of lifting.

   The effect of pace on energy expenditure has been studied by Anuilane, 1968; Hamilton, 1969; Chaffin, 1972; Snook, 1965; Garg, 1976; and Lind, et al., 1977. Figures 4.5 and 4.6 illustrate relationships between weight, lifting frequency and metabolic rate observed by Hamilton (1969 and Aquilano (1968). Thus the relationship between work pace and metabolic energy expenditure appears to be linear.

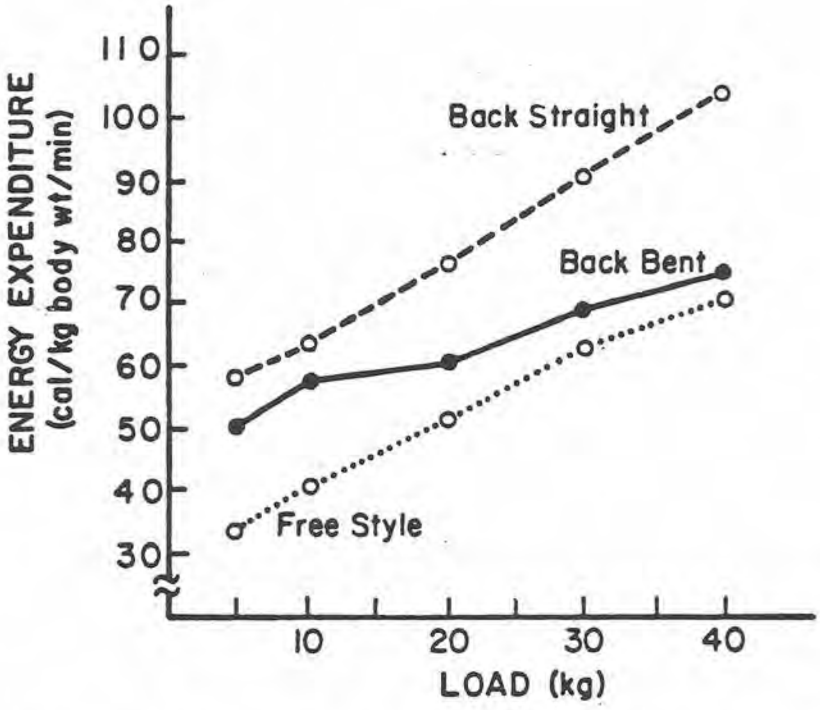


Figure 4.3: Metabolic Rate for Different Postures (Brown, 1971).

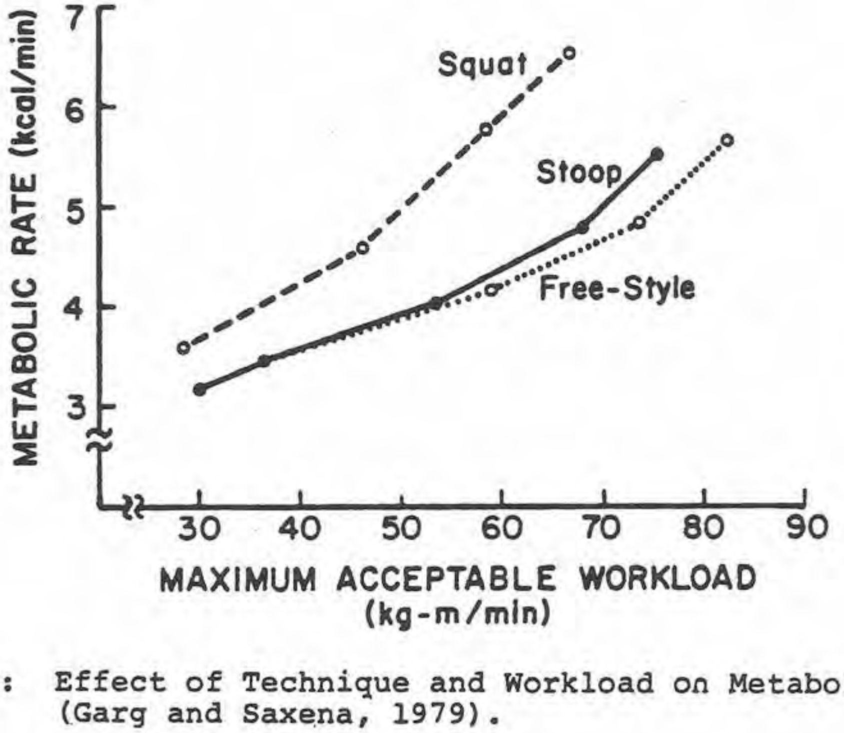


Figure 4.4: Effect of Technique and Workload on Metabolic Rate (Garg and Saxena, 1979).

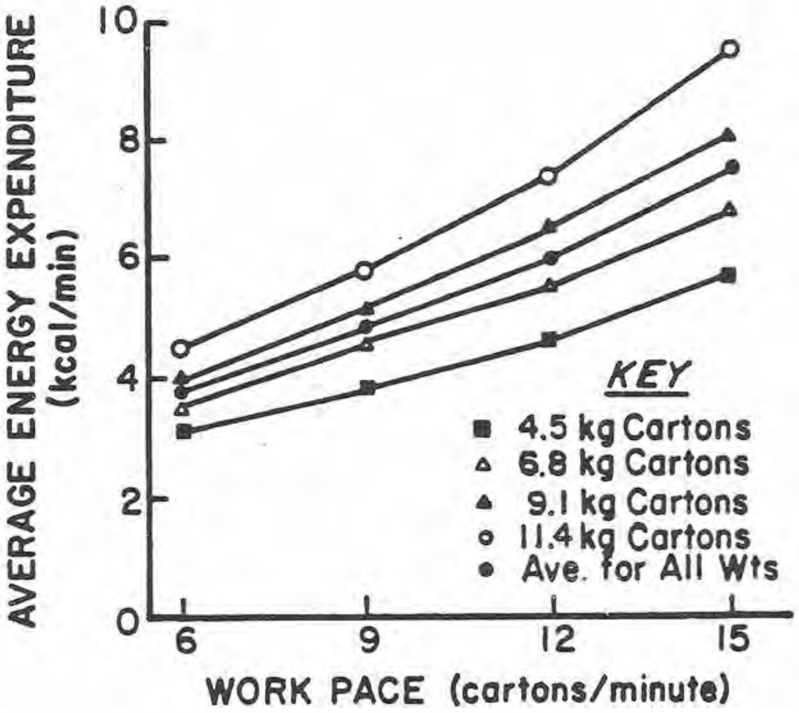
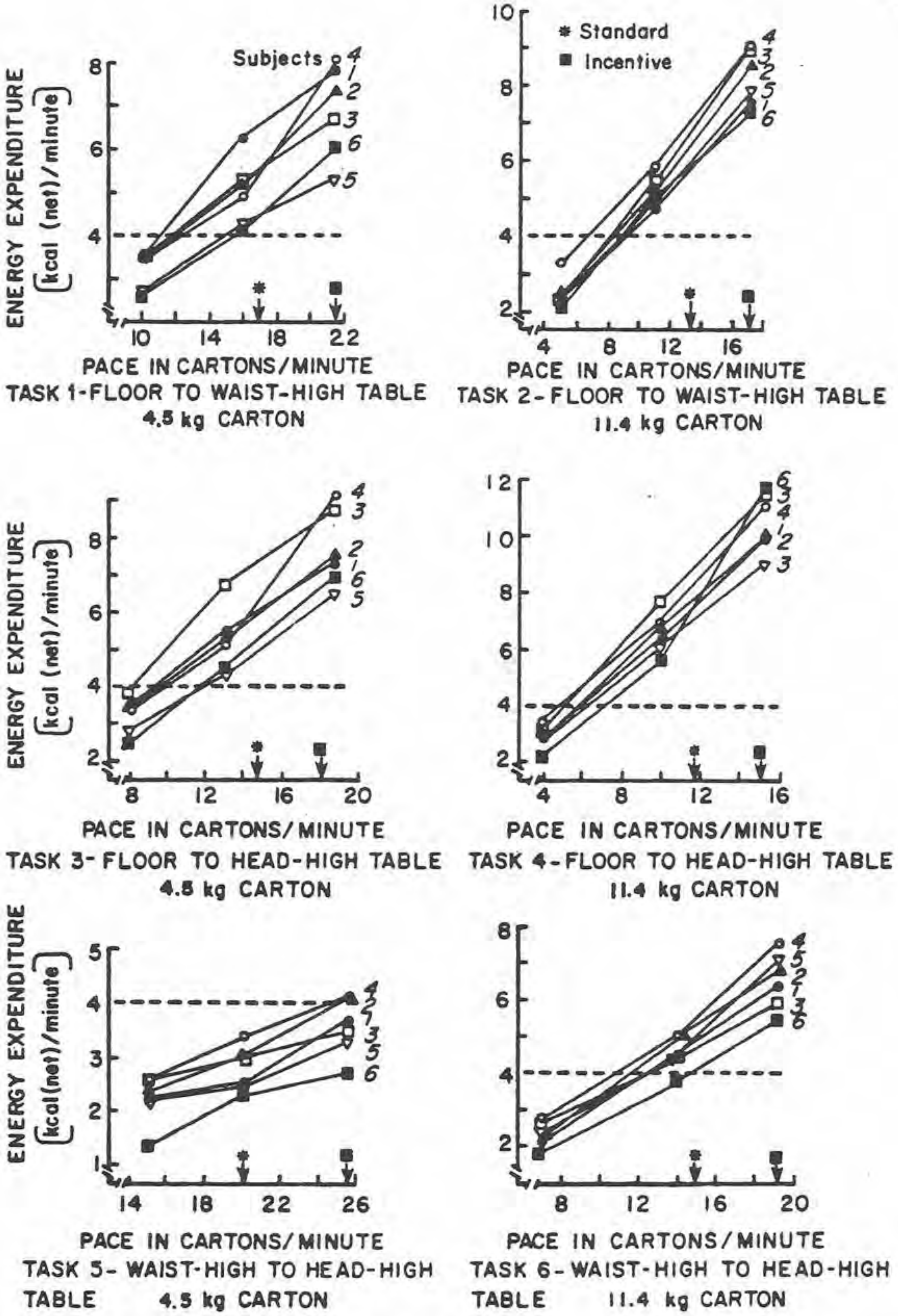


Figure 4.5: Energy Expenditure versus Work Pace (Hamilton, 1969).

4. Vertical Travel Distance of Lift. Since mechanical work is also directly proportional to vertical travel, metabolic energy expenditure should increase with an increase in vertical distance of lift. The results of Aquilano (1968) shown in Figure 4.6 also illustrate this point. When an 11 kg load was lifted from the floor to waist height (92 cm) and head height (168 cm) at a pace of 11 and 10 lifts per minute respectively, the corresponding energy expenditures were 5.21 and 6.58 Kcal/min. The exact relation between metabolic rate and vertical travel distance in this case depends on body posture. Tasks which require raising and lowering the body as well as the load affect efficiency and the total weight moved, consequently the metabolic cost of lifting.



TASK 1-FLOOR TO WAIST-HIGH TABLE
4.5 kg CARTON

TASK 2-FLOOR TO WAIST-HIGH TABLE
11.4 kg CARTON

TASK 3-FLOOR TO HEAD-HIGH TABLE
4.5 kg CARTON

TASK 4-FLOOR TO HEAD-HIGH TABLE
11.4 kg CARTON

TASK 5-WAIST-HIGH TO HEAD-HIGH TABLE 4.5 kg CARTON

TASK 6-WAIST-HIGH TO HEAD-HIGH TABLE 11.4 kg CARTON

Figure 4.6: Effect of Pace on Metabolic Rate (Aquilano, 1968).

5. Vertical Location. Not only is the net vertical distance of the lift important but also the absolute vertical heights of the beginning and end point of the lift. Lifting the same net vertical distance from two different vertical heights, may result in assuming different body postures and varying amounts of movement of the center of gravity of the body. For example, consider the following two tasks (from Garg, 1976):

   Task A - Lifting 4.5 kg from a vertical height of 91 cm to a vertical height of 168 cm at a pace of 25 lifts per minute.

   Task B - Lifting 4.5 kg from the floor to a vertical height of 91 cm at a pace of 21 lifts per minute.

   In these two cases, the total mechanical work is practically the same (i.e., 86.6 and 86 kg-m). The average male energy requirements for the two tasks were 3.56 and 6.77 Kcal/minute respectively (Aquilano, 1968), even though the Task A was performed at a higher pace as shown in Figure 4.6 (Tasks 5 and 1 respectively). Here again, vertical body travel is a critical factor in estimating metabolic rate. Frederick (1959) suggested that the best area for manual lifting is between 100 and 150 cm from floor level for a standing man of average height. The physiological efficiencies (expressed in Kcal/unit of work) for four different vertical ranges of lift as given by Frederik (1959) are illustrated in Figure 4.7.

6. Temperature and Humidity. As previously mentioned, metabolic energy expenditure encompasses two forms of energy. One is mechanical energy, which is the basis of the motor performance capability of man, and the other is heat. The proportion of total energy which is converted to mechanical energy varies from zero in static work to about 30 percent for walking (Grandjean, 1969). This Guide assumes an ambient environment of 70-80°F and 40-50% humidity. Possible controls for heat stress are discussed in Chapter 7.

MODELING TASK AND PERSONAL VARIABLES

Each of the task and personal variables described in the previous section were combined into one predictive model for lifting in a study of Garg, et al., (1978). According to this model the metabolic rate for any task ($\dot{E}_T$) consists of two parts--the metabolic rate necessary to maintain posture $\dot{E}_P$ and the energy required to lift (ΔE) in the following form:

$$\dot{E}_T = \dot{E}_P + F\ (\Delta E)$$

where F is the frequency of lifting. The net metabolic cost of each lift (ΔE) is composed of two parts, the energy necessary to move the body and the energy necessary to move the load. Depending on the posture and vertical location:

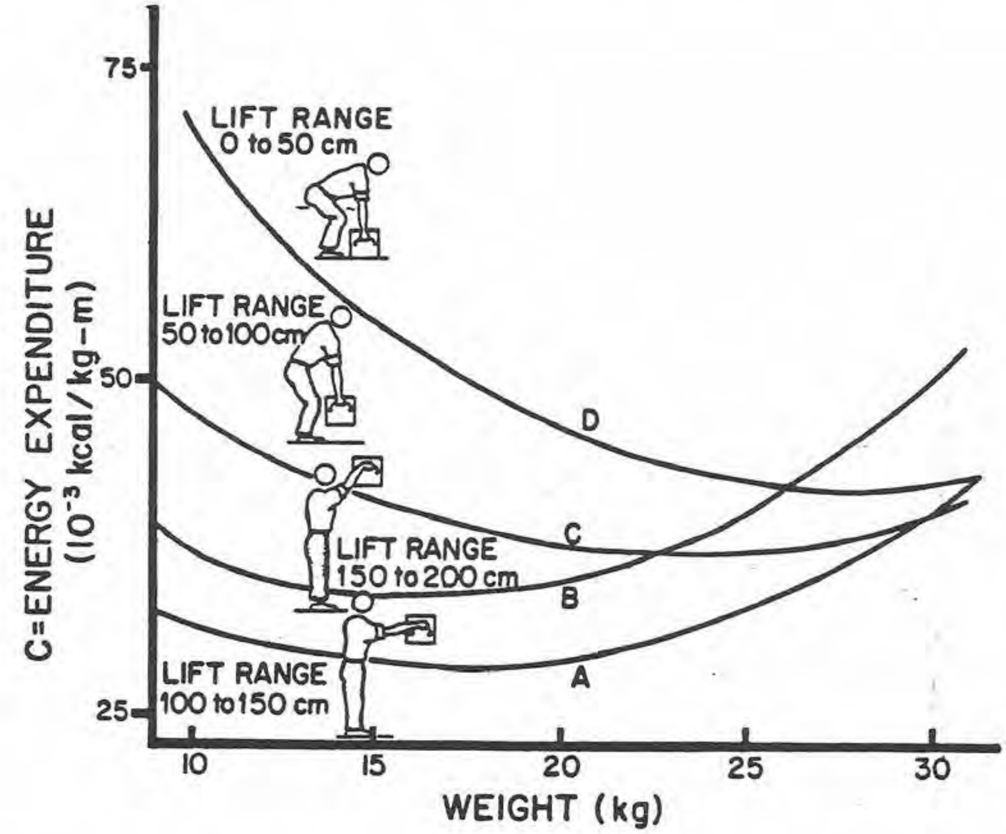


Figure 4.7 Energy Efficiency with Weight and Range of Lifting (Frederik, 1959).

For Arm Lifting (Kcal/lift):

$$\Delta E = 10^{-2}).062\ BW\ (F_V - .81) + (3.1L - .52\ S \times L)(V_2 - V_1))$$

$$\text{for } .81 \leq V_1 < V_2$$

For Stoop Lifting (Kcal/lift):

$$\Delta E = 10^{-2}\ (0.325\ BW\ (0.81 - V_1) + (1.41L + 0.76\ S \times L)$$

$$(V_2 - V_1)) \text{ for } V_1 < V_2 < 0.81$$

For Squat Lifting (Kcal/lift):

$$\Delta E = 10^{2}\ (0.514\ BW\ (0.81 - V_1) + (2.19L + 0.62\ S \times L)$$

$$(V_1 < V_2 < 0.81$$

where:

BW = Body weight (kg)

V_1 = Vertical height from floor (m); starting point for lift and end point for lower

V_2 = Vertical height from floor (m); end point for lift and starting point for lower

L = Weight of the load (kg)

S = Gender (1 for males; 0 for females)

$\dot{E}_P$ = .924 VW if standing erect

= .028 if standing in bent position (Aberg, 1968)

Application of the model to predict metabolic rates on 48 different industrial jobs showed a simple correlation of .95 with a standard error of 10.2% (Garg, et al., 1978). Simplifying the above equations based on an average male body weight (BW = 77 kg), lifting from the floor ($V_1 = 0$) to bench height ($V_2 = .81$) and assuming a desired average metabolic rate ($\dot{E}_T$) of 5.2 Kcal/min. the relationships between load, frequency, and body posture can be estimated, in untrained subjects, illustrated as in Figure 4.8. This figure demonstrates the cost associated with moving the body from a squat versus stoop posture. This may be one of the reasons why workers often employ the stoop posture (minimizing energy expenditure) for a fixed work output.

The relationship between load and frequency is illustrated in Figure 4.9. This study (Snook, 1971) demonstrated the effect of work load (load x frequency x distance of lift) on metabolic rate for different loads based on 30 male workers. For a fixed work capacity criterion (such as 5.0 Kcal/min) it is apparent that a greater amount of work can be accomplished if heavier loads are lifted at slower paces.

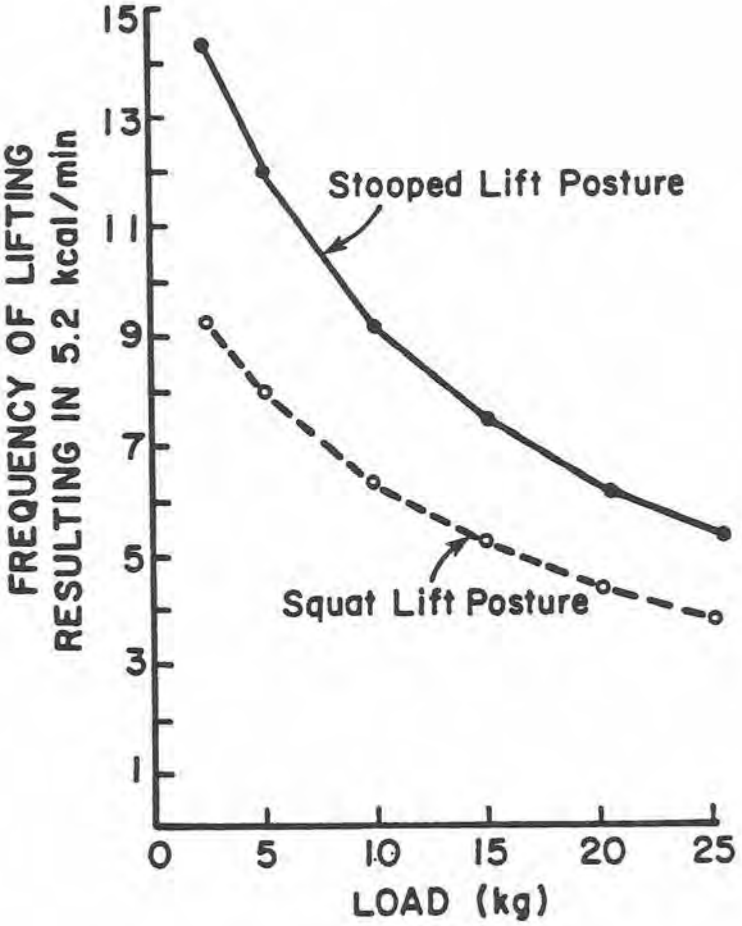


Figure 4.8: Estimated Maximum Frequency of Lift with Two Postures (Adapted from Garg and Herrin, 1979).

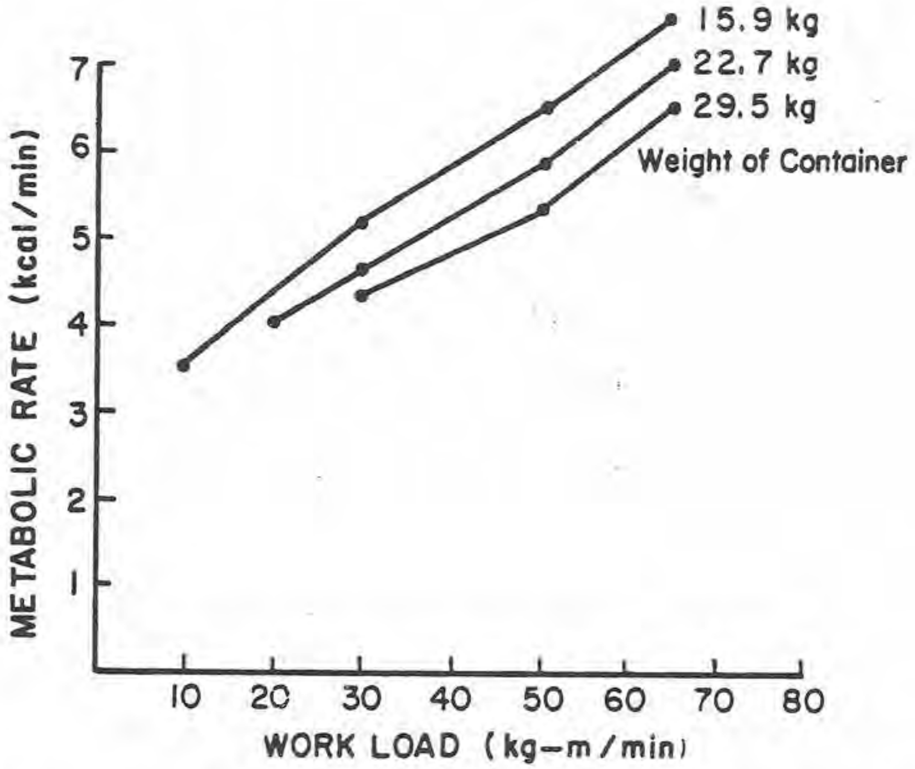


Figure 4.9: Effect of Workload on Metabolic Rate (Snook, 1971).

PHYSIOLOGICAL DESIGN CRITERIA

Based on the preceding discussion of the metabolic costs associated with repetitive work it is recommended that:

1. For occasional lifting (for one hour or less) metabolic energy expenditure rates should not exceed 9 Kcal/min for physically fit males or 6.5 Kcal/min for physically fit females (see Figure 4.10). This is based on industrial population aerobic capacity estimates discussed earlier in this chapter adjusted for working time. (It does not, however, take into account, Lind's observations that the $\dot{V}O_2$ max Kcal/min values for men and 10.5 Kcal/min values for women).
2. Likewise, continuous (8 hour) limits should not exceed 33% of aerobic capacity or 5.0 Kcal/min and 3.5 Kcal/min respectively. These guideline limits do not reflect the increased metabolic rates which would be associated with overweight or deconditioned workforces.
3. Personal attributes of age, gender, body weight, etc. are insufficient to accurately predict work capacity for any particular individual, although such data are sufficient for making predictions of group averages.

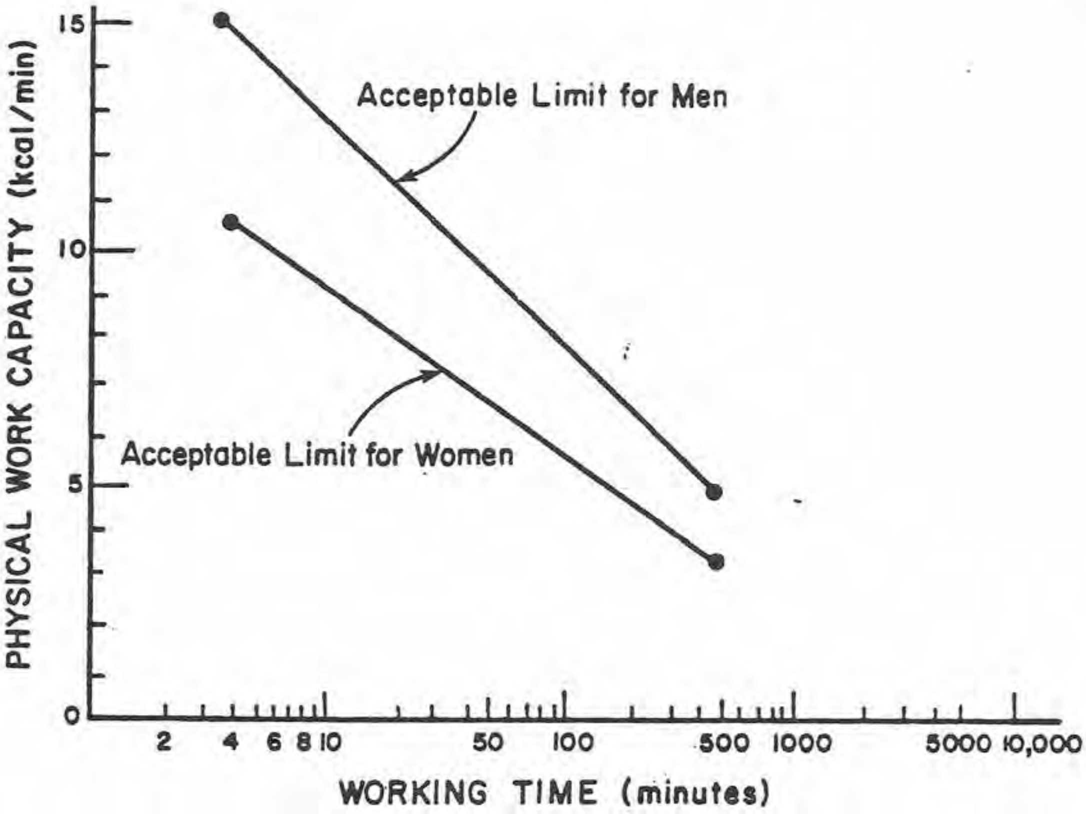


Figure 4.10: Recommend Maximum Capacities for Continuous Work.

4. The primary task variables which influence metabolic rate during lifting are

   A) load handled, L

   B) vertical location at beginning of lift, V (and consequently posture)

   C) vertical travel distance, D

   D) frequency of lift, F.

The guideline recommendations summarized in Chapter 8 combine the above criteria with the biomechanical criteria of the preceding chapter and the psychophysical criteria of the next chapter. Estimates of the metabolic rates for the various working conditions described in Chapter 8 are provided in Appendix A. These estimates are based on the model of Garg, et al., (1978) assuming an average male body weight of 77 kg for the upper limit and average female body weight of 62 kg for the lower limit.

CHAPTER 5

BASIS FOR GUIDE: PSYCHOPHYSICAL APPROACH

A minimal requirement for performing any manual materials handling task is sufficient strength to exert the required force. Strength in this context is defined as the maximum voluntary force a person is willing to exert in a single attempt. Endurance (capacity) is the force a person is willing to repeatedly exert for an extended period of time without "feeling fatigued".

In this chapter, human strength will be expressed in psychophysical terms. Unlike the biological concepts of fatigue and tissue tolerance; psychophysics is concerned with human acceptance of pain or discomfort during an exertion under normal conditions.

PSYCHOPHYSICS

Psychophysics is a very old branch of psychology that is concerned with the relationship between human sensations and their physical stimuli; very rarely is this a one-to-one relationship. According to modern psychophysical theory (Stevens, 1960), the strength of a sensation (S) is directly related to the intensity of its physical stimulus (I) by means of a power function: $S = kI^n$. The constant (k) is a function of the particular units of measurement that are used. When plotted on log-log coordinates, a power function is represented by a straight line, with the exponent (n) being equal to the slope of the line. Exponents have been experimentally determined for many types of stimuli, for example, 3.5 for electric shock, 1.3 for taste (salt), and 0.6 for loudness (binaural). Of interest here is the perception of muscular effort and force, both of which have been found to obey the power law, and both with an exponent of approximately 1.6 (Borg, 1962; Eisler, 1962). Stevens and Cain (1970) found that the exponent for duration of hand grip is about half the exponent for force of hand grip.

Psychophysics has been applied to practical problems in many areas. For example, the scales of effective temperature, loudness, and brightness were developed with psychophysical methodology (Houghton and Yagloglou, 1923; Stevens, 1956, 1960). Psychophysics has also been used by Borg (1962, 1973) in developing ratings of perceived exertion (RPE); by the U.S. Air Force in studies of lifting (Emanuel, et al., 1956; Switzer, 1962); by the U.S. Army in studies of treadmill walking (Evans, 1961, 1962); and in the development of effort scales (Caldwell and Smith, 1967; Caldwell and Grossman, 1973).

STATIC STRENGTH

The usefulness of any test of human performance is inherently limited by the reliability and repeatability of the measurement technique. Strength is no exception. It is susceptible to many influences which can affect the outcome of the measurement. Following a review of the literature by Kroemer and Howard (1970), it was recognized that there was little uniformity in either the techniques used in assessing strength or in the statistical methods used to report the results of studies. Due to the lack of consensus on methodology, an ad hoc committee of experts first held a series of meetings in 1972 for the purpose of proposing a strength testing standard (Caldwell, et al., 1974). The recommendations of this group were later adopted as an "Ergonomics Guide for the Assessment of Human Static Strength" by the American Industrial Hygiene Association (Chaffin, 1975). This guide describes the use of static tests for the measurement of human strength.

Static strength is defined as:

> "...the maximal force muscles can exert isometrically in a single voluntary effort." (Roebuck, Kroemer, and Thompson, 1975).

There are several advantages in using this technique of strength assessment.

1. The technique is relatively simple. The subject is asked to assume a particular body posture and to exert a force against a stable resistance. As a result, the position of the subject's joints are under the control of the experimenter and only one measurement is required, namely the magnitude of the exertion. On the other hand, dynamic strength tests involve body motion. The positions of the subject's joints are no longer controlled and, therefore, should be continuously monitored. Furthermore, the velocity and acceleration of various body members need to be measured. Instead of recording and analyzing a single result, many data points must be considered in the dynamic analysis of strength (Kroemer and Howard, 1970; Caldwell, et al., 1974).

2. Subjects are at minimal risk of injuring themselves during this type of test since the exertion is isometric and completely voluntary. They are requested to slowly increase their exertions, and to stop if any abnormal discomfort is felt.

3. The measurement is repeatable with a high degree of reliability, (test-retest coefficient of variations on the order of 14 percent are reported by Chaffin, et al., 1977).

Although repeated strength tests on a particular muscle group are highly reliable, the strengths of different muscles, even within subjects, are only weakly correlated (Thordsen, et al., 1972; Laubach, et al., 1972). In these studies, 51 subjects were asked to perform maximal isometric exertions in 44 different tests. Of the 768 simple correlations among the 44 measures taken, only 13 had correlation coefficients of .71 or higher (i.e., could explain at least 50 percent of the variance). This finding indicates that when it is necessary to determine a person's ability to perform a particular job element, it is often more accurate to simulate the job's activity in a strength test, rather than trying to predict job strength from standardized tests.

A number of studies by Asmussen and Heeboll-Nielsen (1961), Backlund and Nordgren (1968), Chaffin (1974), Kroemer (1969), Laubach and McConville (1969), Snook, Irvine and Bass (1970), Snook and Ciriello (1974), Troup and Chapman (1969), Nordgren (1972) report strength capabilities of various populations. Laubach (1976) summarized each of these studies in a review of the literature. He concluded that average female strength ranges between 35 and 84 percent of average male strength, depending on the nature of the test and specific muscles involved. Averaging the results of all nine studies, women were found to demonstrate only about 64 percent of the strength men demonstrate. Mean values however do not reflect the variability of strength within each gender. When this is accounted for, the problem becomes more complex as discussed below.

Recently, Keyserling, et al., (1978) summarized the isometric strength of 1,239 workers in rubber, aluminum, steel and electronic component industries as shown in Table 5.1. Attempts to predict these six isometric strengths based on individual worker height (S), body weight (W), age (A), and gender (G) revealed that anthropologic measures are not good predictors of strength. Calculated coefficients of determination (R^2) indicate that these variables rarely explain more than one-third of the population variance as shown in Table 5.2.

Gender, however, is an important factor in predicting strength, with females being weaker than males. (Note the negative regression coefficients involving gender.) Also, taller, heavier workers are stronger (positive regression coefficients for the S x W interaction) than their counterparts and body weight is detrimental to strength with increasing age.

An important point with this table is that unexplained variability between (among) and within (test-retest) particular individuals was quite large (ranging from an average standard deviation of 6.4 kg for high far lifting to 29.0 kg for leg strength). Consequently, it would be imprudent to use these anthropologic variables alone to predict how any particular individual would fare on a particular strength demanding task.

Table 5.1: Maximal voluntary isometric strength (kilograms)

			MALES						RETEST		FEMALES				
				POPULATION %TILE							POPULATION %TILE				
TEST	ASSUMED DISTRIBUTION	SAMPLE SIZE	COEFF. OF VARIATION	10	25	50	75	90	SAMPLE SIZE	COEFF. OF VARIATION	10	25	50	75	90
1. Arm Lift	Normal	1052	.07	23	31	39	48	56	·187	.08	9	15	22	28	34
2. Torso Lift	Log Normal	1052	.09	26	34	45	60	77	187	.10	13	17	24	33	44
3. Leg Lift	Normal	638	---	49	69	91	114	134	133	--	5	27	40	53	64
4. High Far Lift	Log Normal	309	.09	16	19	23	28	34	35	12	9	11	13	16	19
5. Floor Lift	Normal	309	.08	59	74	91	108	123	35	.08	32	44	56	69	80
6. High Near Lift	Normal	309	.08	35	44	55	66	76	35	1	16	2	29	36	42

(1) ARM LIFT
90°

(2) TORSO LIFT
V=38 cm H=38 cm

(3) LEG LIFT
V=38 cm H=0 cm

(4) HIGH FAR LIFT
V=152 cm H=51 cm

(5) FLOOR LIFT
V=15 cm H=25 cm

(6) HIGH NEAR LIFT
V=152 cm H=25 cm

Table 5.2: Prediction equations using anthropometry (Keyserling, et al., 1978)

STRENGTH	REGRESSION EQUATION	R^2	STD. ERROR
Arm Lift	Y = 23.8 - 13.2G + .00162SxW - .00303WxA	.294	11.5
Torso Lift	Y = 11.4 - 14.7G + .00309SxW + .00263SxA - .00844WxA	.204	19.4
Leg Lift	Y = 61.5 - 41.2G + .00422SxW - .0109WxA	.379	29.0
High Far Lift	Y 6.23 + .00117SxW 000571SxWxG	.302	6.44
Floor Lift	50.9 - 69.8G + [illegible]52SxW - .0000302SxWxA + 00877SxAxG	.246	23.1
High Near Lift	[illegible] .510S - [illegible]19W - 8 2G - .0000189SxWxA	.307	14.5

S [illegible] m.
W [illegible] kg
A = age [illegible] years
G = gender (0=male, 1=female)

A similar study by Kamon and Goldfuss (1978) of 457 male and 137 female industrial workers produced comparable results as illustrated in Figure 5.1. The back extension measures reported here are not directly comparable to the results of Keyserling, et al., (1978) due to methodological differences. The elbow flexion data are comparable to Tables 5.1 and 5.2. In both studies, unexplained differences between individuals were foughly 1/3 of the mean values.

STATIC STRENGTH MODELS

Very few predictive models of human strength are available in the literature. Most models are regression models which are very poor in terms of interpolation and extrapolation from experimental data. The primary reason for the lack of models is the complexity of the human body.

A computerized, 3-dimensional isometric strength model is reported by Garg and Chaffin (1975). This model is based on a mechanical analog of the human body. This analog treats the body segments as a set of links with masses distributed as dictated from many past population surveys depicted spatially in Figure 5.2.

Essentially, this model develops resultant torque estimates at each joint center for specified external forces acting on the body. These are then compared to the inputted reactive volitional torques that can be achieved at each joint (i.e., to the muscle

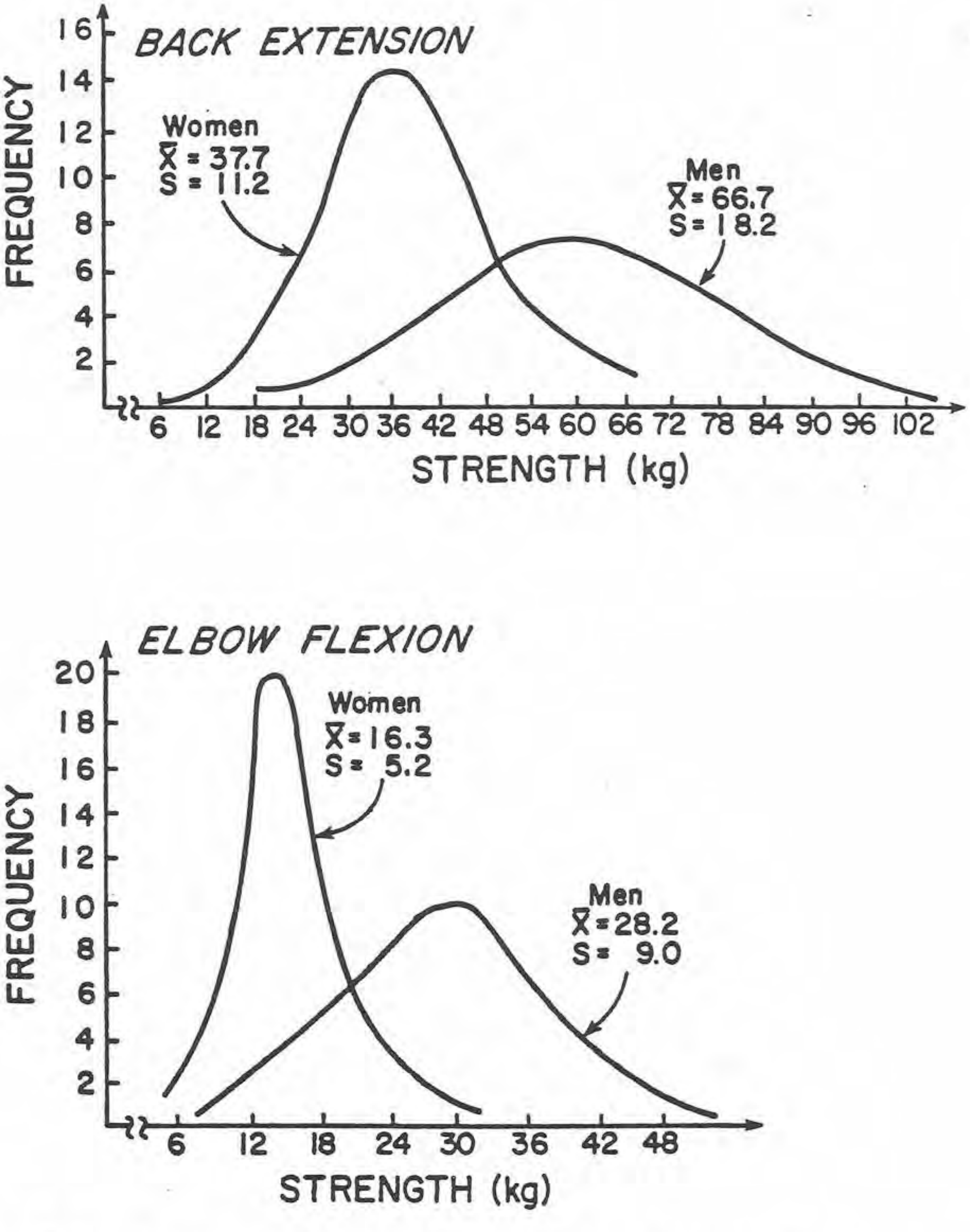


Figure 5.1: Strength Differences between Male and Female Industrial Workers (Kamon and Goldfuss, 1978).

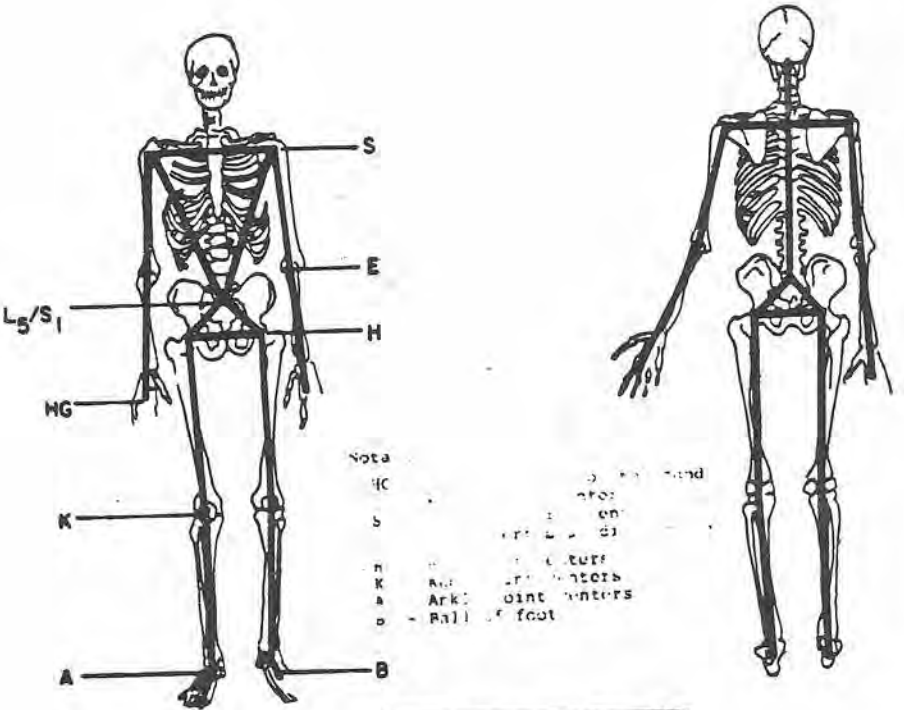


Figure 5.2: Linkage representation (Garg and Chaffin, 1975)

group strengths). Figure 5.3 depicts the body angles used to describe the posture of a person for modeling. For each angle there are at least two opposing muscle strengths that must be inputted to the model to act as the limiting reactive voluntary torques at each joint. These inputted muscle strengths need to either be measured, or population distribution strengths can be assumed. The model then allows the manipulation of the external forces and postures of interest to determine the maximum hand forces that can be produced by a designated population without having a joint resultant torque exceed a given joint reactive torque strength. Thus, the model can be thought of as depicting the static muscular capability of a person in any posture and load combination described.

Two other human limitations are recognized by the model for strength prediction. One is the body balance capability. As an example it is possible when standing that the external forces on the body can cause the line of gravity of the total person/load system center of gravity to be outside the area bounded by the feet, and hence the person will fall over if a rapid postural correction is not made. This loss of static equilibrium is assessed for any posture and force combination inputted to the model,

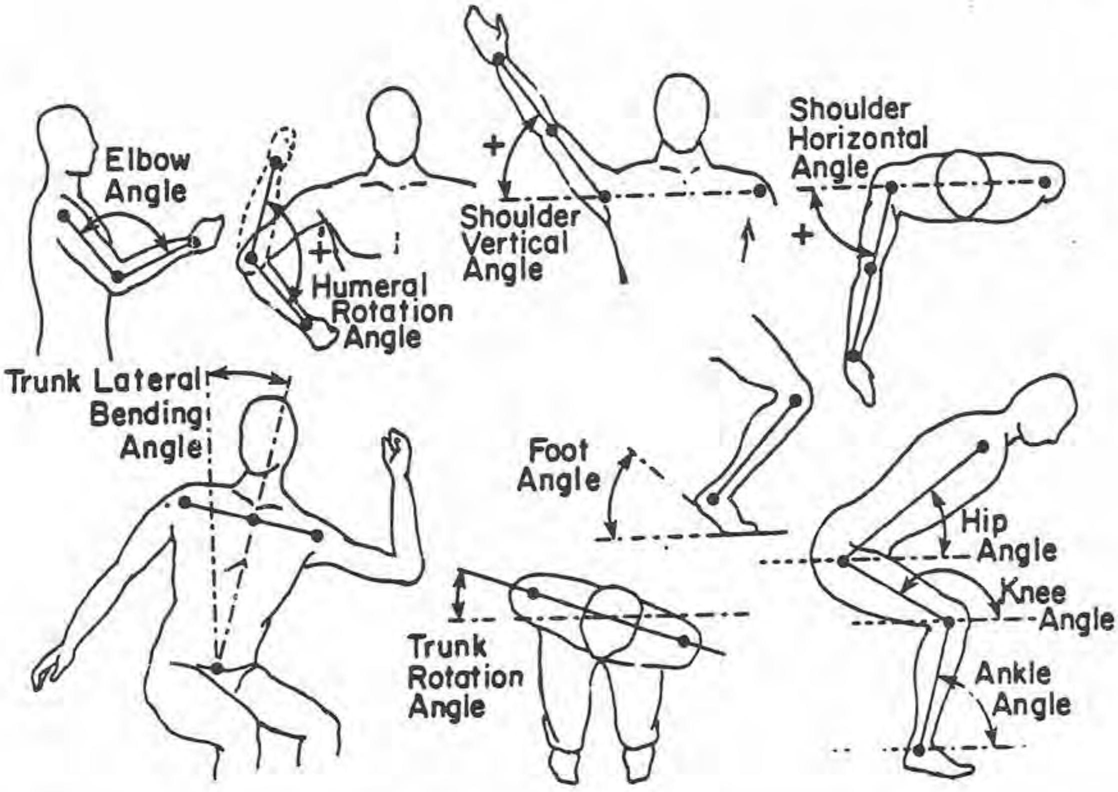


Figure 5.3: Body Angles Used to Depict Posture (Garg and Chaffin, 1975).

and hence the user can easily determine when balance is critical to task performance.

The final constraint in the model is based on evidence that lumbar compression forces may limit a person's volitional capability as discussed in Chapter 3. Thus, an assessment similar to the Morris, Lucas and Bresler Model of low-back compression has been included in the strength model, with acceptable compression limits being selected by the user.

Figure 5.4 illustrates the strength capabilities of a strong 2.5 percentile male (97.5% of males have a lower strength capability) predicted with a two-dimensional form of the model (Chaffin, 1974). Similar force contours could be defined for other population percentiles and anthropometric characteristics (i.e., age, gender, body weight, stature, etc.). These are summarized at the end of this chapter.

In summary, this model produces three key pieces of information. First, it allows the rank ordering of the gross strength requirements of the various tasks involved in a job. Second, it identifies

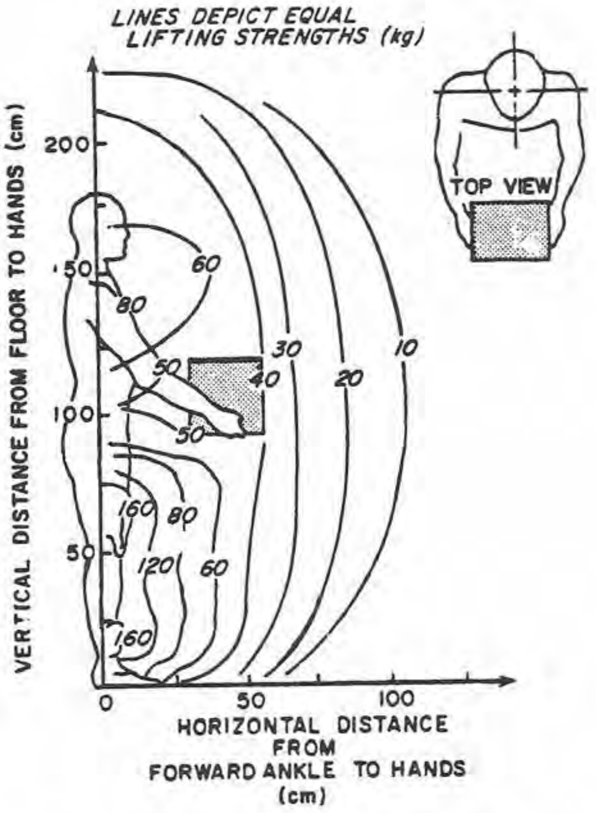


Figure 5.4: Predicted Lifting Strength of Large/Strong Male (Chaffin, 1974).

the muscle groups which limit performance on each task. Finally, it predicts the percentage of the male and female populations that could be expected to perform each job activity. The model has several assumptions which limit its usefulness:

1. The model selects the "best" posture in terms of maximal strength. Thus, it does not reflect additional stresses a person may receive due to poor posture selection.

2. Body weights and link lengths are based on 50th percentile anthropometry for men and women. Therefore, model predictions may be inaccurate for unusually large or small populations.

3. Lifting, may require certain amounts of dynamic strength depending upon acceleration, deceleration and speed of movement. This biomechanical model is based only on static strength capabilities. The relationship between static and dynamic strength is not well understood. Therefore, if the model is used to simulate a highly dynamic task, (e.g., one with jerking actions) the

predictions may overestimate capability (and underestimate stress on the low back, for example).

For additional information on this biomechanical strength prediction model, refer to Garg and Chaffin (1975). For an example application of the approach to industrial job analysis, refer to Chaffin, Herrin, Keyserling, and Garg (1977). This model was applied to the various situations described in the recommendations chapter. The comparative results are presented in the Appendix.

DYNAMIC STRENGTH

Another method for measuring the capacity of an individual to lift has been referred to in the literature as psychophysical strength. This is actually a misnomer since isometric strength (as discussed in the preceding section) is also psychophysical. Dynamic strength is a more appropriate name for this type of measurement even though time dependent forces and accelerations are seldom measured.

The measurement of dynamic strength using the "psychophysical approach" has been extensively used by several researchers (e.g., Snook, 1976, 1978; Snook and Irvine, 1968, 1969; Snook and Ciriello, 1974; Ayoub, et al., 1973, 1976, 1978; Strindberg and Peterson, 1972; Switzer, 1962; and Emanuel, et al., 1956) for determining different load handling capacities of individuals or groups of individuals.

Essentially, the subject is given control of one of the task variables, usually the weight of the object being handled. All other variables such as frequency, size, height, distance, etc., are controlled. The subject then monitors his own feelings of exertion or fatigue, and adjusts the weight of the object accordingly. The work tasks are made as realistic as possible with subjects tested in repetitive dynamic lifting tasks for several hours.

In each of these studies, subjects lifted industrial tote boxes with handles. The subject varied the weight of the box by adding or subtracting lead shot. In an attempt to minimize visual cues, each box contained a false bottom. The subject was aware of the false bottom, but never knew how much lead shot it contained. The amount of weight in the false bottom was randomly varied.

Subjects were instructed to work on an incentive basis, working as hard as they could without straining themselves, or without becoming unusually tired, weakened, overheated or out of breath. Several days of training sessions were usually required to allow subjects to gain experience at monitoring their own feelings, and adjusting the object weight.

The results of the seven manual handling studies conducted by Liberty Mutual Insurance Co. were recently summarized by Snook

(1978). The maximum acceptable weights for lifting tasks are given in Table 5.3 for male industrial workers, and in Table 5.4 for female industrial workers. For example, 18 kg is the maximum acceptable weight for 75% of the male workers lifting a rather large object (75 cm width) through a 76 cm distance from the floor to knuckle height once every minute. The equivalent value acceptable to 75% of female workers is 13 kg.* These values are based upon a freely chosen lifting posture where workers are not instructed to lift by any particular technique. An earlier experiment indicated that workers would not lift as much weight when required to maintain a straight back and bent knees. The maximum acceptable weights of lift are based upon objects with handles located in the middle of the width dimension.

Ayoub, et al., (1978) conducted a similar study to determine and model the lifting capacity of male and female industrial workers. Seventy-three male and 73 female subjects were used. Six different height levels and four frequencies (2,4,6, and 8 lifts/minute) were employed. The height levels were: (1) floor to knuckle; (2) floor to shoulder; (3) floor to reach; (4) knuckle to shoulder; (5) knuckle to reach; and (6) shoulder to reach as illustrated in Figure 5.5. The results of the study are summarized in Table 5.5.

A number of other studies are reported in the literature (e.g., Emanuel, 1956; Switzer, 1962; Whitney, 1958; etc.). Much of this earlier literature involves experiments with college students or air force personnel and will not be presented in detail.

DYNAMIC STRENGTH MODELS

Several researchers have used the psychophysical approach to develop lifting capacity prediction models (McConville and Hertzberg, 1968; McDaniel, 1972; Dryden, 1973; Knipfer, 1974; Ayoub and McDaniel, 1973; Ayoub, et al., 1973, Ayoub, et al, 1976a, Ayoub, et al., 1976b; Ayoub, et al., 1978; and Mital, et al., 1978).

Table 5.6 summarizes their models for lifting activities based on the psychophysical approach. These models lead to some interesting conclusions. According to the model developed by McConville and Hertzberg (1968), a person cannot lift a box which is 60 inches wide. Models developed by Poulsen (1970), McDaniel (1972), Dryden (1973), Knipfer (1974), Ayoub and McDaniel (1973), Ayoub, et al., (1973), Ayoub, et al., (1976a), Ayoub, et al., (1976b), Ayoub, et al., (1978), and Mital, et al., (1978) have one thing in common: lifting capacity is a function of isometric back strength. In these models, the independent variables do not include task variables. It should also be noted that most of these models do not include interactive effects.

*It should be noted here that "width" for the Snook data means distance of the load away from the body measured in the horizontal axis (See fig. 8.3).

Table 5.3: Maximum acceptable weight of lift for males (kg) (Snook, 1978)

Width (a)	Distance (b)	Percent (c)	Floor to knuckle ht.						Knuckle to shoulder ht.						Shoulder to arm ht.					
			One lift every						One lift every						One lift every					
			5	9	14	1	5	8	5	9	14	1	5	8	5	9	14	1	5	8
				s		min		h		s		min		h		s		min		h
		75	10	14	15	18	25	29	12	16	18	17	21	24	9	12	14	16	20	23
	76	50	13	17	19	22	30	36	14	19	21	21	27	30	11	15	18	20	25	28
		25	16	20	23	26	36	42	17	22	25	26	32	36	13	18	21	24	29	33
		75	11	14	16	19	26	31	13	17	19	20	24	27	10	14	15	18	22	25
75	51	50	14	18	20	23	31	37	15	20	23	24	30	34	12	17	10	22	28	31
		25	16	21	24	27	37	44	18	24	27	29	36	40	14	20	23	27	33	37
		75	13	17	19	21	29	34	15	20	22	23	28	32	11	16	18	21	26	30
	25	50	16	21	23	26	35	42	18	24	27	28	35	40	14	20	22	26	33	37
		25	19	25	28	31	42	50	21	28	32	34	42	47	17	24	27	31	39	44
		75	12	15	17	21	28	34	12	16	18	17	21	24	9	12	14	16	20	23
	76	50	15	19	21	26	35	42	14	19	21	21	27	30	11	15	18	20	25	28
		25	17	23	26	31	42	50	17	22	25	26	32	36	13	18	21	24	29	33
		75	12	16	18	22	30	35	13	17	19	20	24	27	10	14	15	18	22	25
49	51	50	15	20	22	27	37	43	15	20	23	24	30	34	12	17	19	22	28	31
		25	18	24	27	32	44	52	18	24	27	20	36	40	14	20	23	27	33	37
		75	14	18	21	24	33	39	15	20	22	23	28	32	11	16	18	21	26	30
	25	50	18	23	26	30	41	49	18	24	27	28	35	40	14	20	22	26	33	37
		25	21	28	31	36	49	59	21	28	32	34	42	47	17	24	27	31	39	44
		75	13	17	20	23	31	37	13	17	19	18	23	26	9	13	15	17	21	24
	76	50	17	22	25	29	39	46	15	20	23	23	29	32	11	16	19	21	27	30
		25	20	27	30	34	47	55	18	23	26	28	34	39	14	19	23	26	32	36
		75	14	18	20	24	32	38	15	18	20	21	26	29	10	15	16	19	24	27
36	51	50	17	23	26	30	40	48	16	21	24	26	32	36	13	18	20	24	30	34
		25	21	28	31	36	49	57	19	25	28	31	39	44	15	22	25	29	36	40
		75	16	21	24	27	37	43	16	21	24	24	30	34	12	17	19	23	28	32
	25	50	20	27	30	34	46	54	19	25	28	31	38	13	15	22	24	28	35	40
		25	25	32	36	40	55	65	22	29	33	37	45	51	18	26	29	34	42	48

(a) Width of object (cm) Note: horizontal hand location is at least (15 + width/2)
(b) Vertical distance of lift (cm)
(c) Percent of industrial population exceeding table value

Table 5.4: Maximum acceptable weight of lift for females (kg) (Snook, 1978)

Width (a)	Distance (b	Percent (c)	Floor to knuckle ht.						Knuckle to shoulder ht						Shoulder to arm ht.					
			One lift every						One lift every						One lift every					
			5	9	14	1	5	8	5	9	14	1	5	8	5	9	14	1	5	8
				s			min	h		s			min	h		s			min	h
		75	8	10	11	13	17	20	8	11	11	11	14	15	5	9	9	10	12	14
	76	50	9	12	13	14	20	23	9	12	12	13	16	18	6	9	10	11	13	15
		25	10	13	15	16	22	26	10	13	13	14	18	20	6	10	11	12	15	17
		75	8	10	12	13	18	21	9	12	12	12	15	17	6	10	11	11	14	15
75	51	50	9	12	14	15	20	24	10	13	13	14	18	20	6	11	12	12	15	17
		25	10	14	15	17	23	27	11	14	14	16	20	22	7	12	13	13	17	19
		75	9	12	14	15	20	24	11	14	14	15	18	20	7	11	13	13	16	18
	25	50	11	14	16	17	23	27	12	15	15	17	21	23	8	13	14	14	18	20
		25	12	16	18	19	26	31	13	17	17	19	23	26	8	14	15	16	20	22
		75	9	11	13	15	20	24	8	11	11	11	14	15	5	9	9	10	12	14
	76	50	10	13	15	17	23	27	9	12	12	13	16	18	6	9	10	11	13	15
		25	11	15	17	19	26	31	10	13	13	14	18	20	6	10	11	12	15	17
		75	9	12	13	15	21	25	9	12	12	12	15	17	6	10	11	11	14	15
49	51	50	10	13	15	17	24	28	10	13	13	14	18	20	6	11	12	12	15	17
		25	12	15	17	20	27	32	11	14	14	16	20	22	7	12	13	13	17	19
		75	10	14	15	17	23	28	11	14	14	15	18	20	7	11	13	13	16	18
	25	50	12	16	18	20	27	32	12	15	15	17	21	23	8	13	14	14	18	20
		25	14	18	20	22	30	36	13	17	17	19	23	26	8	14	15	16	20	22
		75	10	13	14	16	22	26	9	12	12	12	14	17	6	9	10	11	13	15
	76	50	11	15	17	19	25	30	10	13	13	14	17	19	6	10	11	12	15	16
		25	13	17	19	21	28	34	11	14	14	15	19	21	7	11	12	13	16	18
		75	10	13	15	17	23	27	9	12	12	13	17	19	6	10	11	12	15	17
36	51	50	12	16	17	19	26	31	10	14	14	15	19	21	7	11	13	13	16	18
		25	14	18	20	22	30	35	11	15	15	17	21	24	8	12	14	14	18	20
		75	12	16	18	19	26	31	11	15	15	16	19	22	8	12	14	14	17	20
	25	50	14	18	20	22	30	35	12	16	16	18	22	25	8	14	15	16	19	22
		25	16	21	23	25	33	40	13	18	18	20	25	29	9	15	16	17	21	24

(a) Width of object (cm) Note: horizontal hand location is at least (15 + width/2).
(b) Vertical distance of lift (cm)
(c) Percent of industrial population exceeding table value

Table 5.5: Mean and standard deviation of maximum weights (kg) of lift acceptable to male and female industrial workers (corrected for one lift/min.).

Height of Lift	Sex	Mean	Standard Deviation
Floor to knuckle	Male	28.0	7.66
	Female	16.9	3.06
Floor to shoulder	Male	23.3	5.50
	Female	14.1	2.97
Floor to reach	Male	22.3	5.09
	Female	12.8	2.46
Knuckle to shoulder	Male	26.1	6.67
	Female	14.5	2.98
Knuckle to reach	Male	24.3	4.86
	Female	11.9	2.21
Shoulder to reach	Male	19.8	4.75
	Female	11.7	1.90

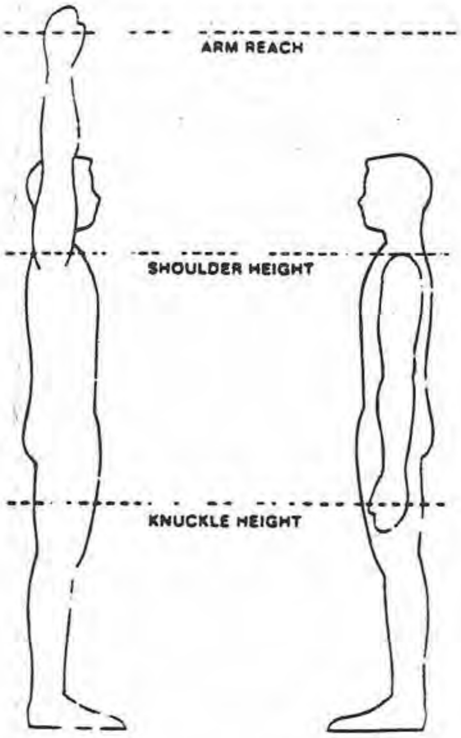


Figure 5.5: Classification of Lifting Height

Table 5.6: Summary of dynamic strength regression models

Researchers	Dependent Variables	Height Level	Male	Female	Both	Model
McConville & Hertzberg, 1968	Load of lift	Floor to knuckle	X			Predicted lift = 0-X;
Poulsen, 1970	Maximum weight of lift	Floor to table			X	Predicted lift = 1.4 (Max. Isometric Back st.) - 0.5*Body Wt.;
		Table to head			X	Predicted lift = 0.5 (Sum of the right and left max. isometric arm push);
McDaniel, 1972	Load of lift	Floor to knuckle	X			Predicted lift = -172.3599+0.022*Height^2 -2.728*Static End^2 +-.0209*RPI*Arm St. +0.0534*RPI*Back St.-2.5134 (FI/Dynamic End.);
	Load of lift	Floor to knuckle		X		Predicted lift = -24.0268+0.1936*RPI^2 +0.00607*Arm St.* Leg St.;
	Load lift	Floor to knuckle			X	Predicted lift = 11.934-1.12*Back St +0.158(RPI^2+0.0046* Back St.^{2}-8.807*Static End.^{2}-0.095*Sex* FI +0.06*Height*RPI+0.[illegible] *RPI*Leg St.
Dryden 1973	Load of lift	Knuckle to shoulder	X			Predicted lift = 0.82766*Chest Circumference+0.55885*Dynamic End;
	Load of lift	Knuckle to shoulder		X		Predicted lift = 3.8092*RPI-1.473*Height *FI/1000-0.31199*RPI*Stat. End.+1.228*Percent Fat* FI/1000;
	Load of lift	Knuckle to shoulder			X	Predicted lift = 25.1212+0.37912*Sex* Dynamic Eng.;
Knipfer, 1974	Load of lift	Shoulder to reach	X			Predicted lift = 4.983+0.197*Back St. -0.0177*Shoulder St. +0.429*Age.
	Load of lift	Shoulder to reach		X		Predicted lift = 15.071+0.343*Weight +0.839*Dynamic End.+ 0.355*Foream Circumference;
	Load of lift	Shoulder to reach			X	Predicted lift = 5.225*Sex+0.00494*Shoulder St.+0.1944*Horizontal Push St.;

Table 5.6: (cont.)

Researchers	Dependent Variables	Height Level	Male	Female	Both	Model
Knipfer, 1974 (continued)	Load of lift	Floor to knuckle; knuckle to shoulder, shoulder to reach			X	Predicted lift = 13.19226+13.85436*Sex +0.25741*Dynamic End.;
Ayoub et al., 1978 and	Load of lift+body wt.	Floor to knuckle			X	Predicted lift = -63.776-30.793*Sex+ 23.922*Weight Code- 0.509*Age+1.235*Shoulder Ht.+0.087*Back St.+4.902 Abdominal Depth;
Mital et al., 1978	Load of lift+body wt.	Floor to shoulder			X	Predicted lift = -129.615-20.278*Sex+12.51* Weight Code-0.488*Age +1.429*Shoulder Ht. +0.124*Back St.+6.294* Abdominal Depth;
	Load of lift+body wt.	Floor to reach			X	Predicted lift = -42.372-22.184*Sex+16.983* Weight Code-0.711*Age+ 0.835*Shoulder Ht.+0.125* Back St.+6.022*Abdominal Depth;
	Load of lift+body wt.	Knuckle to shoulder			X	Predicted lift = 60.312-22.1[illegible]*Sex+11.612* Weight Code-0.4[illegible]*Age+ 0.877*Shoulder Ht.+0.165* Back St.+6.267*Abdominal Depth;
	Load of lift+body wt.	Knuckle to reach			X	Predicted lift = -102.799-21.387*Sex+ 17.537*Weight Code-0.318* Age+1.317*Shoulder Ht. 0.094*Back St.+5.315* Abdominal Depth;
	Load of lift+body wt.	Shoulder to reach			X	Predicted lift = -40.415-20.511*Sex+20.[illegible]37* Weight Code-0.508*Age+ 0.942*Shoulder Ht.+0.117* Back St.+[illegible].704*Abdominal Depth

All U.S. units of measure

X - width of the box in inches

RPI = Body Ht./$\sqrt[3]{\text{Body wt}}$

$FI = \frac{100 \text{ x duration of the step exercise (seconds)}}{2\text{x pulse recovery sum}}$

Models developed by Poulsen (1970), McDaniel (1972), Dryden (1973), Knipfer (1974), Ayoub and McDaniel (1973), Ayoub, et al., (1973), Ayoub, et al., (1976a), Ayoub, et al., (1976b), and McConville and Hertzberg (1968) have their obvious limitations. They are applicable to only one or two height levels for lifting in the sagittal plane and are developed by collecting data at only one frequency of lift. Some of these limitations have been overcome in the models developed by Ayoub, et al., (1978) and Mital, et al., (1978), but still the models are for lifting in the sagittal plane.

Some disagreement between the results of these studies can be observed. According to McDaniel (1972) and Dryden (1973), males and females should not be used together in the same model to predict the acceptable weight of lift. Their conclusion was different from the one drawn by Knipfer (1974). According to his results, the combined model predicts the lifting capacity as well as the individual models. According to Ayoub, et al., (1978) and Mital, et al, (1978) the combined models predicted lifting capacity better than individual models.

PSYCHOPHYSICAL DESIGN CRITERIA

Table 5.7 combines the most recent studies of Snook (1978) and Ayoub, et al., (1978) in predicting average lifting capacity of 75 percent of industrial women and 25 percent of industrial men.

These quartiles were selected to represent the inherent variability within the industrial population. Based on the epidemiological evidence presented in Chapter 2, the majority of low back injuries were shown to occur on jobs that were not acceptable to more than 75 percent of the population (Snook, 1978). Therefore, if the workforce was predominantly women, this percentile specification should be protective. For an all male workforce this limit would be overly restrictive. Further, were individuals tested for strength capability, an even greater capacity could be expected. The choice of a 25th percentile male is arbitrary, but assumed reasonable based on the reliability of available testing methods.

The values presented in Table 5.7 were arrived at by adjusting Snook's data (1978) for box size and frequency and then combining it with the lifting capacity data generated by Ayoub, et al., (1978). A linear box size (horizontal location of the hands in the sagittal plane) and frequency effect were assumed for interpolation and extrapolation. These values were further adjusted to show a linear frequency effect.

For the floor to shoulder height, floor to reach height, and knuckle to reach height levels, the lifting capacity values recommended by Ayoub, et al., (1978) were used for frequency adjustment since no other data exist for these height levels. The standard deviation assumed in Table 5.7 is the larger of the values generated by

Table 5.7: Maximum recommended weights based on dynamic strength (Kg.)

			Female		Male .	
Height of Lift	Horz. (cm)	Freq. (lift/min)	25%ile	50%ile	50%ile	75%ile
Floor to knuckle	30	1	18	20	30	36
		2	17	18	28	34
		4	14	16	24	28
		6	12	14	22	28
		8	11	13	21	26
		12	9	11	18	21
	38	1	15	17	27	32
		2	11	13	26	31
		4	10	13	24	30
		6	10	12	22	25
		8	10	12	20	24
		12	9	10	15	18
	46	1	13	16	24	29
		2	11	13	23	27
		4	11	12	21	26
		6	11	12	20	23
		8	10	11	18	23
		12	8	10	14	17
Floor to shoulder	30	2	11	13	23	27
		4	12	13	22	25
		6	11	13	20	24
		8	11	13	19	23
	38	2	12	14	24	26
		4	11	13	23	27
		6	9	13	22	25
		8	10	12	21	25
	46	2	11	13	23	26
		4	11	13	22	25
		6	10	12	21	24
		8	9	11	20	25
Floor to reach	30	2	11	12	21	24
		4	10	12	20	24
		6	11	11	19	21
		8	10	11	18	20
	38	2	11	13	24	29
		4	11	12	21	25
		6	10	11	18	21
		8	10	11	15	17
	46	2	10	12	18	22
		4	9	11	18	20
		6	9	11	17	20
		8	9	10	17	20

Table 5.7: (cont.)

Height of Lift	Horz. (cm)	Freq. (lift/min)	Female 25%ile	Female 50%ile	Male 50%ile	Male 75%
Knuckle to shoulder	30	1	13	14	24	29
		2	12	14	23	27
		4	12	13	22	26
		6	11	13	20	24
		8	9	12	18	22
		12	9	10	15	18
	38	1	12	13	27	31
		2	11	13	26	30
		4	12	13	24	28
		6	11	13	22	27
		8	9	11	20	24
		12	8	9	14	17
	46	1	11	13	21	25
		2	11	13	20	25
		4	10	12	19	24
		6	9	11	18	24
		8	9	10	17	21
		12	8	9	14	17
Knuckle to reach	30	2	10	13	21	26
		4	10	12	20	22
		6	10	12	18	21
		8	9	11	17	19
	38	2	11	12	24	27
		4	11	12	22	24
		6	10	11	20	22
		8	10	11	18	21
	46	2	13	14	24	28
		4	11	13	22	24
		6	11	12	20	21
		8	9	11	18	20
Shoulder to reach	30	1	11	12	23	27
		2	10	12	22	24
		4	10	11	21	25
		6	9	10	19	22
		8	7	8	15	18
		12	6	6	11	14
	38	1	10	11	20	24
		2	9	11	19	22
		4	9	10	18	22
		6	8	9	17	22
		8	6	8	15	18
		12	5	6	11	13
	46	1	11	12	20	24
		2	10	11	18	22
		4	9	10	18	21
		6	9	10	17	21
		8	8	9	15	18
		12	5	6	11	13

Ayoub, et al., (1978) and Snook (1978). The horizontal location of the hands is assumed to be 1/2 the horizontal box size plus 15 centimeters for body clearance.

A similar illustration of the effects of object size (horizontal and vertical location of the load) on the isometric strength capabilities of these two population percentiles is presented in Figures 5.6 and 5.7. These figures are based on the biomechanical model of Chaffin, et al., (1978) discussed earlier in this chapter. They apply for occasional lifts (less than 1 lift per 5 minutes).

Depending on the specific task (weight handled, vertical and horizontal hand location, vertical lift distance, and frequency of lifting) different guidelines would be suggested based on isometric versus dynamic strength. Both are required for safe lifting. The guideline presented in Chapter 8 is evaluated in terms of both isometric and dynamic strength capacities in the Appendix.

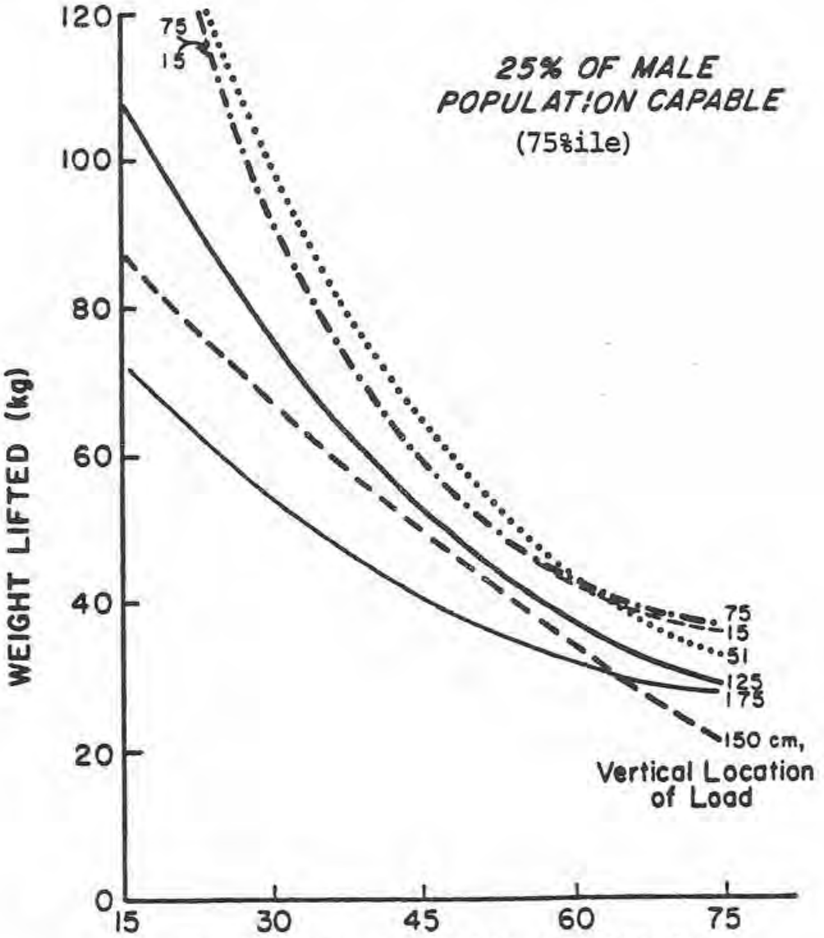


Figure 5.6: Maximum Recommended Weights Based on Male Isometric Strength

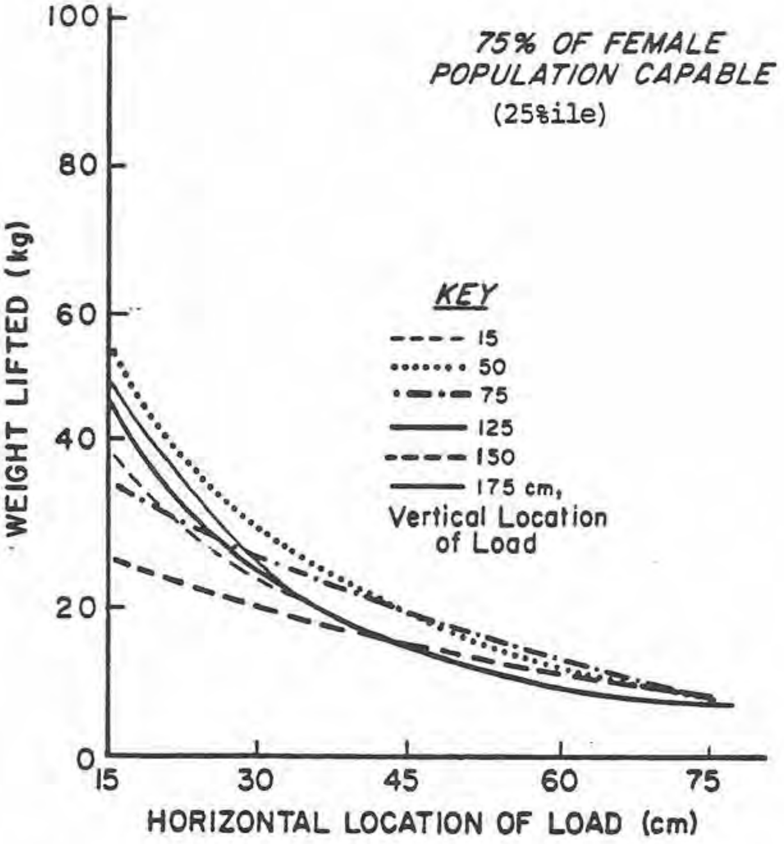


Figure 5.7: Maximum Recommended Weights Based on Female Isometric Strength

It is also interesting to note that the psychophysical criteria discussed in this chapter lead to slightly different conclusions than the physiological criteria in Chapter 4. Figure 5.8 shows the trade-off between weight lifted and frequency of lift observed by Snook (1978) using the psychophysical approach compared with the continuous work capacities predictions of Lind, et al., (1977) using the physiological approach. Based on lifting from the floor to knuckle height, Snook observed that workers were willing to work above 35% of their aerobic capacity($\dot{V}_{O_2}$ max) when lifting more frequently than 6 times per minute, but well below that level with infrequent lifts.

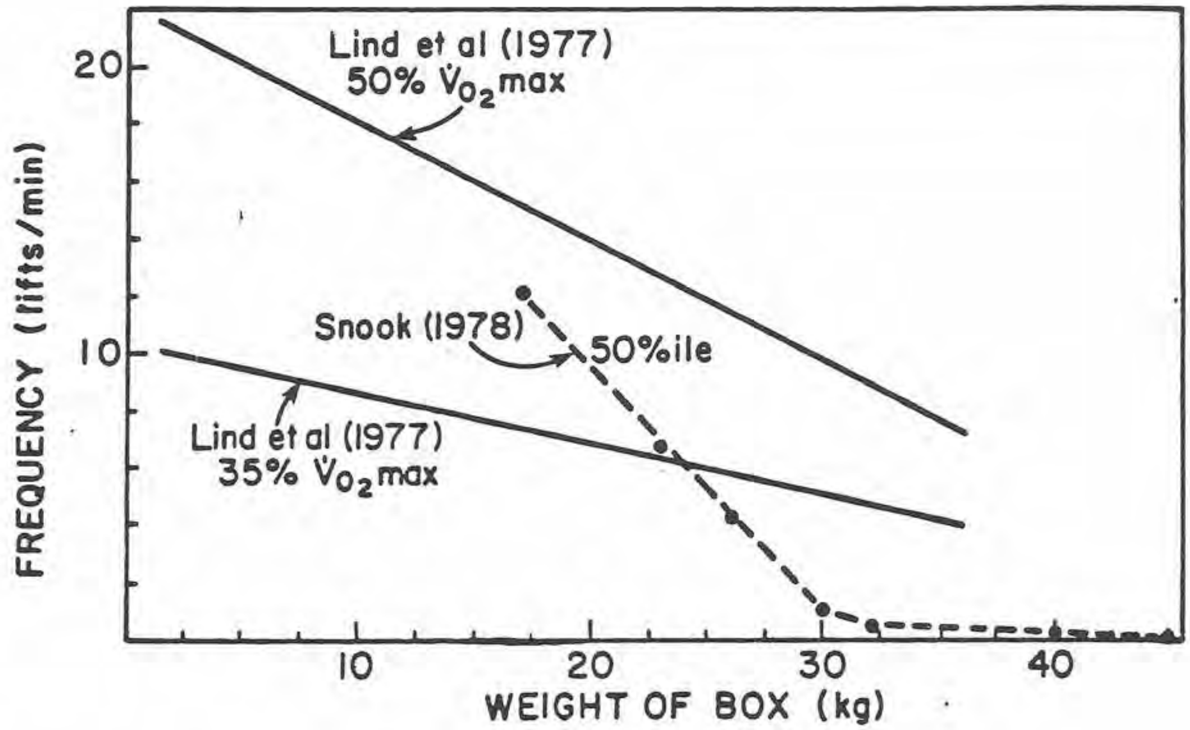


Figure 5.8: Comparison of Physiological and Psychophysical Criteria.

Two major points can be drawn from this illustration. First, for low frequency lifting, capacities are limited by strength rather than endurance criteria. Second, endurance is a function of work duration. For continuous 8 hour lifting, the metabolic criteria of Chapter 4 need to be applied to avoid fatigue. For occasional high frequency lifting the psychophysical limits developed in this Chapter are more appropriate.

CHAPTER 6

ADMINISTRATIVE CONTROLS

As discussed in Chapters 3-5, a large variation in lifting capacity exists in the working population. One must be conscious of the fact that with any ergonomic criterion (e.g., strength, aerobic capacity, etc.) it is often true that the standard deviation of any general population sampled will be between 30 and 40 percent of the mean of the population attribute measured.

Such a large variation in the population's tolerance to physical stress supports the need for administrative controls to assure that both,

1. a worker who is either weak or unfit is not exposed to the demands of lifting heavy loads, or,
2. a strong, fit worker is suitably trained to avoid certain lifting posture and activities which are believed to increase the hazard level.

This chapter develops guidelines for selection and training of such workers who are to be placed on jobs requiring the lifting of materials.

SELECTION OF WORKERS

Present selection procedures vary widely. A large number of smaller manufacturing, distribution and service industries have neither medical nor nursing staffs, and no formal selection system exists. The principal method has been self-selection by the worker based on their initial tolerance for the demands of the job. In larger industries, new employees are often asked to complete a questionnaire on health and medical history; and are submitted to routine tests of visual, auditory and pulmonary function, of blood pressure, mobility, etc., often with the addition of a chest X-ray. A physician will only see those whose replies and test results reveal abnormality or doubt on the part of the test administrator. In a few large industries, every recruit is examined by a physician but this usually depends on the existence of recognized physical or environmental hazards.

The clinical examination is widely regarded as the first essential step in a good selection procedure for physical labor (Magnussen and Coulter, 1921; Becker, 1961; Moreton, et al., 1958; McGill, 1968; Rowe, 1971) and it is generally agreed that the primary aim is to identify those who have had previous episodes of back or sciatic pain. This is based on the finding that the probability of episodes of back pain increases by a factor of 3 or 4 after the first reported attack (Dillane, et al., 1966). However, other than the scars of surgery, there are few reliable and objective signs of previous back problems, and the medical history is often of skeptical value for this purpose (Rowe, 1971).

After some type of evaluation, assuming no gross abnormalities have come to light, new employees are certified as fit for general work, still subject to training. It is comparatively rare, unfortunately, that the orientation and training period is under medical supervision. It is proposed that with such supervision during the first few days on the job, many postural stress related problems could be prevented. Clearly, for any physical work which is unfamiliar, a period of adaptation and conditioning is needed. Tolerance for postural stress, and for kinetic stress arising from rapid trunk movements, is likely to increase over a period of days or weeks. Similarly, the magnitude and frequency of the loads which can be handled without discomfort may increase with physiological adaptation and the acquisition of skill. However, the processes of adaptation to postural induced kinetic stresses may lag (scientific evidence is limited in this regard).

It is recognized that selection must be concerned with both the initial screening and placement of employees and their acclimitization to the physical stresses of the job. Further, very few companies are now capable of such aggressive management. Fortunately, some are developing and evaluating formal selection/placement/conditioning and training programs. It is clear that these efforts must be encouraged.

Criteria for Physical Assessments

There are many different methods by which a concerned physician may evaluate a person's capability to handle heavy loads safely in a future job. Some of these methods may have merit. Others are of questionable value. In providing any such assessment it is important that certain medical, social, economic, and legal criteria must be met. In choosing between alternative methods, it is suggested that the following criteria be applied:

1. Is it safe to administer?
2. Does it give reliable, quantitative values?
3. Is it related to specific job requirements?
4. Is it practical?
5. Does it predict risk of future injury or illness?

Is the test safe to administer? Perhaps one of the most widely used procedures in the past for evaluating a person's physical capability, the low-back X-ray, provides an example of these criteria. As will be discussed later in this section, the evidence which supports the use of such X-rays for routine pre-employment and placement screening is usually insufficient to warrant the procedure, especially when the radiation hazard is considered.

Tests of a person's physical strength and endurance have also become popular in many industries, primarily because they can meet some of the other criteria. It is imperative that such tests be carefully evaluated to assure that they are safe. For instance, a test which sets a specific goal for the worker, (i.e., the person must lift an object of specified weight to obtain a job), is a situation which may produce overexertion injury in an overly motivated subject. On the other hand, if there is no specific goal stated or direct feedback given as to how great the exertion is during the test, as recommended by the AIHA Ergonomics Committee (Caldwell, et al., 1974), isometric strength testing has proven to be safe in several studies (Chaffin, 1974; Chaffin, et al., 1978; Laubach, 1976). It is recommended, however, that any such tests be included as part of a medical examination only after the person's medical history has been screened for any past history of musculoskeletal or coronary problems, and a general physical examination has been performed.

Does the test give reliable, quantitative values? Though clinical impression is important in assessing a person's physical capability, specific tests with quantitative scoring should be performed. Stereotypes based on age, gender, and body weight have all been shown to be only weakly correlated with physical capability to exert high forces (Chaffin, et al., 1978; Bernauer, et al., 1975; Laubach, 1976, and Kamon, et al., 1978).

A test of physical capability, like any other diagnostic test, should produce repeatable results. A common measure of such is the coefficient-of-variation of the repeated tests, which is the standard deviation of the repeated values divided by their mean value. This is expressed as a percentage, and thus, represents the percent error in the test due to measurement procedures. It should be possible in physical capability tests to achieve a coefficient-of-variation of less than 15% (Chaffin, et al., 1977), with well-controlled laboratory tests often achieving 5%.

Is the test related to specific job requirements? It has been disclosed by several studies that one physical attribute of a person does not correlate well with another. For instance, grip strength is a poor predictor of other strengths (Laubach, 1976). Considering anthropometric and specific strength values together, one can achieve a better prediction of the strength scores achieved by people performing physical acts common to industry but a high unexplained variance (about 27%) remains even when five or six attributes are combined (Chaffin, et al., 1977).

The exact nature of the physical task required of a person dictates which physical attributes are important. In one task, functional reach overhead may be important. In another, lifting, pushing, or pulling force capabilities are essential. To designate which one is most relevant to selection, it is necessary to evaluate carefully the job physical requirements as outlined later in Chapter 8. In this same regard, it is a legal requirement that such tests be job related to assure that they do not discriminate against women, minorities, aged workers, or the physically disabled (Miner, et al., 1978).

Is the test practical? To be used, a selection procedure must be practical. What is necessary in one industry may not be needed in another. Smaller industries may be able to construct a set of carefully controlled tests of a person's physical capability while the person is learning the job during the first couple of days or weeks on the job. Larger industries may need more standardized tests under more clinical settings to assess large numbers of job applicants. These should meet the following practical conditions:

1. Require minimum hardware expense.
2. Have hardware capable of simulating different job conditions.
3. Require minimum time to administer.
4. Require minimum instruction and learning time.

Does the test predict risk of future injury or illness? This criterion is probably the most difficult one to meet. It requires continual evaluation of new selection methods using epidemiological studies in industry. Injury and illness data supporting any selection and placement procedure are necessary. Once a procedure is chosen, careful evaluation of its potential effect on injury and illness data should be instigated to assure that it meets the desired goal of reducing health and safety problems. Such an evaluation must consider the degree of matching of a worker's physical capabilities (as measured by the proposed test) with the job physical demands. After a period of time, injury frequency and severity rates can then be compared for both those that are well matched and for those that are not well matched.

Radiological Screening

There has been considerable zeal amongst a number of occupational medical advisors for routine lumbar spinal radiography as a prerequisite for employment in heavy manual work (Stewart, 1947; Colcher and Hursh, 1952; Becker, 1955; 1961; Kosiak, et al., 1966; McGill, 1968; Bimlett, 1972; Moreton, 1974). Elsewhere the enthusiasm waned and it is considered by many to be unwarrantable

(Wilkins, et al., 1957; Redfield, 1971; Harley, 1972; Montgomery, 1976) if not condemned out of hand (Houston, 1977). At a conference on this topic in 1973, sponsored by the American College of Radiology, the American Academy of Orthopaedic Surgeons and the Industrial Medical Association, low back X-rays without prior clinical examination were deplored. It was agreed that no worker should be rejected solely on the basis of radiological appearance and that the conference recognized that low back X-rays had yet to be proved as having reliable predictive value. In a recent American Occupational Medical Association (AOMA) association affairs committee report (1979), it was concluded that "lumbar spine X-ray examinations should not be used as a routine screening procedure for back problems, but rather as a special diagnostic procedure available to the physician on appropriate indications for study."

LaRocca and Macnab (1969), Rowe (1969), Troup, et al., (1974) and Magora and Schwartz (1976) have found no statistically significant differences in the incidence of ra-iological abnormalities between workers with known history of back or sciatic pain and those without. One study by Redfield (1971) reported a lower incidence of back pain in a group of workers who had been identified as radiologically of 'high-risk' than in a group with normal radiological appearance. For the majority of industrial purposes, however, pre-employment radiological screening cannot be justified on statistical grounds and due attention must be paid to the hazards of radiation.

The criteria upon which radiological screening is deemed necessary thus depend on the definition of an abnormally high risk of back injury. To take an extreme example from the armed forces: pilots may have to be ejected from fighter aircraft in an emergency, and this carries a high risk of spinal fractures - some of which damage the spinal cord. Experimental work has shown that the presence of some radiological abnormalities (for example, Schmorl's nodes, which can safely be ignored in most clinical situations) may adversely affect the capacity of the spine to withstand the acceleration on ejection (Kazarian, 1978). Such risks can reasonably be defined as unacceptable and radiological screening is well justified. Moreover exceptionally high radiographic standards are needed to achieve the definition required (for example, an enema may be needed before being X-rayed if the image is not to be obscured by flatus).

As far as industry is concerned, there may be jobs entailing a high risk of back injury due to MMH, but it is not possible to define a criterion for the need for radiological screening. Cases must be assessed on their own merits and with due regard to current radiological opinion and radiographic practice. When low-back X-rays are considered justifiable, the informed consent of the individual is essential. (It should be noted that gonadal protection cannot be adequately achieved in women for this purpose and thus a higher risk for them must be considered).

Even where low-back X-rays are deemed acceptable, there remains the problem of interpretation. An Ad Hoc Committee on Low Back X-rays

(1964) proposed some radiological criteria for job-placement based on a consensus of opinion (since there were no reliable data on the predictive rating for the observed abnormalities). Such data are still nonexistent. It is impossible to quote a value for the increased probability of back trouble for each abnormality. One partial exception is the case of scralisation studied extensively by Tilley (1970). He studied lost work-time due to back pain in 7,236 workers who had pre-employment X-rays: 1013 (14%) had sacralisation and as a group their average lostwork-time of 3.4 days/year did not differ from the normal. When the group was subdivided, some types of sacralisation were associated with less than the average lost work-time (e.g., bilateral sacralisation and fusion - 2.4 days/year) and others with aboveaverage (e.g., pseudarthrosis one side and fusion the other - 4.6 days/year). Even in this case there is hardly an adequate basis for advising anyone not to take a given job based solely on this positive sign.

Spondylolisthesis is more generally assumed to be a 'high-risk' abnormality, particularly in the younger worker (Parvi and Virolainen, 1975). However, in none of the many published series in which its incidence is recorded has there been any attempt to differentiate by cause [i.e., spondylolytic, dysplastic, degenerative, etc., (Wiltse, et al., 1976); by vertebral level, despite the widely varying prognostic implications [clinically, those at $L_4/_5$ are more likely to have neurological dysfunction than those at L_5/S_1 (Jackson, et al., 1977); or, in the case of spondylolysis, in terms of its structural stability (Hirabayashi, et al., 1972; Troup, 1976].

A third aspect of the interpretation of lumbar spinal radiographs concerns the size and shape of the spinal canal and intervertebral foramina. Computer-assisted tomography is a technically elegant way of assessing these dimensions. There is evidence that those with sciatic pain or symptoms due to stenosis have narrower canals and foramina than the normal population (Porter, et al., 1980). The phenomenon is not one of general narrowness in all dimensions because there is evidence that the different measurements (midsagittal diameter, interpedicular distance, pedicular length or foraminal AP, and interfacetal distance) are independent variables (Troup, et al., 1974). The predictive significance of these measurements to back or sciatic pain is not yet known, though Troup, et al., (1974) found an inverse relationship between previous sciatic pain and AP foraminal diameter.

In summary, with present knowledge of the prognostic significance of radiological abnormality, employment advice should be given with caution, and then only by an experienced physician or surgeon after a thorough interview and examination, and with full knowledge of the postural, kinetic and handling stresses of the MMH job concerned.

Strength Testing

Many industries have jobs that require occasional lifting, wherein for a few seconds a high amount of force is required. Common examples are loading stock into a machine, picking-up a tote pan full of parts, lifting a broken machine component during maintenance, or replacing the dies in a press. The activities are often not frequent enough, or they can be paced by the worker so that endurance, in the cardio-pulmonary sense, is not the limiting factor. Rather, one is concerned with the brute force required to successfully and safely accomplish the task.

Recent studies have indicated that such force requirements increase both the frequency and severity of musculoskeletal problems, and particularly low-back pain incidents in industries of various types (Hult, 1954; Chaffin, et al., 1977; Miner, et al., 1978). These studies and others have substantiated the need to more carefully select and place employees on jobs requiring high forces. What follows is a description of the development of isometric strength tests for this purpose. It is presented as a better example application of the preceding criteria.

The first step in developing a selection program is to determine whether such is applicable. This determination often occurs in two phases. First, the medical and/or safety functions should perform a statistical analysis of musculoskeletal problems in the organization and determine if these problems are particularly prevalent and/or severe. As reported in Chapter 1, a recent analysis of compensation injuries in the state of Arkansas disclosed that approximately one-third of all injuries and illnesses reported in all industries were musculoskeletal strains and sprains (Bureau of Labor Statistics, 1976). Some industries, however, report a prevalence of over 60%. Once it is decided that the prevalence and/or severity data are excessive, then a second phase of analysis is initiated. This involves a further statistical analysis of the injury data to determine if certain jobs (known to require high exertions) have higher injury frequency rates and severity rates than the more sedentary jobs in the plant.

At this point, a job analysis as outlined in Chapter 8 should be initiated to determine actual job requirements. These data should be gathered in the systematic way described in Chapter 8 and made part of the job description record.

Without a specific physical description of the job it is not possible to develop a valid selection/placement procedure. Variations in work postures will result in specific stresses on the musculoskeletal system. A test of one type of strength selected for its administrative simplicity may not predict the type of strength required on the job if the test does not also reflect the most strenuous postures required on the job. Given that the job strength requirements are documented for those jobs having high musculoskeletal problems, then valid tests of employees can be developed.

Isometric strength tests are preferred due to the safety criterion. In an isometric test the subject is required to slowly increase the force exerted until they reach a level which "feels" safe. No specific feedback or challenges are given during the testing. This procedure has been proposed in an AIHA Ergonomic Guide as being a safe and reliable procedure (Chaffin, 1975). It has been used in a number of industrial studies (see Chapter 5) testing over 3000 individuals and no injuries have been reported with the above procedure.

As to whether such testing is a valid indicator of potential risk of future injury, two longitudinal studies have been performed. Collectively, these have involved nearly 1,000 workers in both a light and heavy products industries (Chaffin, 1974; Chaffin, et al., 1978). These studies have revealed that both frequency and severity rates of musculoskeletal problems were about three times greater for those workers who were placed on jobs that required physical exertions above that demonstrated by them in the isometric strength tests, when compared with workers placed on jobs having exertion requirements well below their demonstrated capabilities.

The practicality of strengh testing depends on the sophistication of the medical and personnel functions. An isometric strength testing apparatus can be purchased for between one and four-thousand dollars, depending upon the sophistication and reliability required. A space in the medical department must be provided which is private. A nurse or medical technician needs to be trained to perform the tests following the directions proposed in the AIHA Ergonomics Guide (Chaffin, 1974). Instructions and administration will normally require between 14 and 30 minutes depending on the number of tests.

Perhaps more important than the time and capital outlay for the testing apparatus, however, is the need to have the jobs evaluated in a way that dictates which types of strength tests are applicable. This requires a close coordination of the medical function and the work practice or industrial engineering functions. The latter groups must perform a rigorous evaluation of the high incidence jobs and document the actual strength requirements, even on "occasional lifting tasks". In so doing, they must also assure that the tasks so documented cannot be easily modified to reduce the physical demands. In other words, the tasks must be truly inherent to the processes, and as such, require excessive capitol expenditure to redesign.

Aerobic Capacity Testing

The physical endurance of the worker becomes critical when the job requires much high frequency, whole-body activity. When this is the case, it is important that the individual involved can sustain the required level of activity for an extended period of time without fatigue. To achieve this the individual must be able to intake enough oxygen and transport it through the blood stream at a rate sufficient to meet the oxygen demands of the active muscles.

As was noted in Chapter 4, when oxygen is not available to the muscles, lactic acid is produced, contractile abilities rapidly decrease and eventually the muscles can no longer generate significant force. Aerobic capacity testing is one means for assessing this dimension of individual physical fitness (as proposed by the American Heart Association (1972) and the American Industrial Hygiene Association (Kamon and Ayoub, 1976)).

A person's aerobic capacity corresponds to the maximal oxygen uptake rate, which is accompanied by the maximal attainable heart rate, for that individual. One can determine a person's aerobic capacity by monitoring the oxygen uptake and heart rate while increasing the work load in a controlled manner. Common devices for this are motor driven treadmills, stationary bicycles and benches which are used for stepping. The maximal oxygen uptake is determined by noting the value at which the oxygen uptake stops climbing as the work load increases. Since the conversion factors between oxygen uptake level and metabolic rate have been established, one can convert the maximal oxygen uptake to the maximal aerobic metabolism rate (also commonly called the maximal aerobic power or aerobic capacity).

Maximal aerobic capacity testing, as described above, is quite stressful. Often the test is run until the person cannot continue due to exhaustion. Since this condition may present a serious medical risk, sub-maximal testing is often employed instead.

Sub-maximal aerobic capacity testing consists of measuring oxygen uptake and heart rate at two to three work loads ranging between 50% and 75% of the worker's expected aerobic capacity and extrapolating. A population based estimate of expected maximum heart rate (based on the worker's age, sex and physical fitness) is then used to estimate the maximal oxygen uptake. This extrapolated value is then converted to an estimate of aerobic capacity. Since an individual's maximal heart rate may vary as much as ± 20 beats per minute from tabulated population values, a 10 to 15% error can accrue for the estimated maximal oxygen uptake (Kamon and Ayoub, 1976). Thus sub-maximal testing is not as accurate as maximal testing.

Aerobic capacity testing needs to be undertaken with caution, especially if it involves submitting the individual to a workload corresponding to his or her maximal aerobic power. Obviously, maximal testing should only be done under the most careful attention of a physician. Sub-maximal testing is not as risky but still should only be undertaken with healthy individuals who have been ascertained by a physician to have no cardiovascular impairments or indications of infectious diseases including the common cold.

Metabolic requirements for jobs can be estimated using the methods described in Chapter 4. These requirements can then be compared to the individual's aerobic capacity after adjustment for work period duration to determine the relative stressfulness of the job.

Aerobic capacity testing is most appropriate for jobs that involve relatively continuous, dynamic work. For activities such as lifting, holding and carrying a significant amount of static work is also performed. Thus, the above testing methods and comparisons may not be very accurate. Preliminary studies indicate that more research is needed before good evaluation techniques for the metabolic cost of mixed static and dynamic tasks will be available. At present, applying capacity estimates based on dynamic testing to jobs with both static and dynamic tasks will not necessarily be protective.

In terms of practicality, numerous variations in aerobic capacity testing procedure exist. The primary differences are in the sophistication of hardware required and the time needed to complete the test (Kamon and Ayoub, 1976). As would be expected, the major trade-off is between accuracy and cost. Procedures can take anywhere from fifteen minutes to approximately an hour and involve nothing more than a simple step device or require relatively elaborate heart rate monitoring and gas analyzers.

SELECTION OF WORKERS - SUMMARY

The assessment of a worker who performs manual lifting must include specific tests of physical capability. Such tests must meet certain criteria to be accepted as medically, economically, and legally justified. The medical and economic justification for such tests is recognized by all concerned with controlling the excessive costs and human suffering associated with overexertion strain/sprain injury and illness in industry. The legal basis for such tests is not well established, and will not exist until a documented history of success or failure is developed in the courts for different types of tests.

It is hoped that as various tests are developed by medical departments, the criteria stated in the first part of this section will be of assistance. Strength testing and aerobic capacity testing have been implemented as part of medical examinations in a number of large industries as experimental medical procedures. Further studies are needed to validate and refine the necessary procedures.

TRAINING OF WORKERS

Training for safety in MMH has been in practice in several European countries since the Second World War. A pioneer in this field T. McClurg Anderson (The Institute of Kinetics, Glasgow) advanced the concept of "human kinetics" in the avoidance of unnecessary stress. It was widely adopted by a number of government departments and industries in the United Kingdom and forms the basis for industrial training courses run by the Royal Society for the Prevention of Accidents. Comparable modified courses are held for recruits in many industries and instructors' courses are run by organizations such as the British Safety Council. The Back Pain Association has recently published an instructors' manual, "Lifting in Industry." In France, the Institut Nationale de Recherche et de Securitie publishes "Gestes et postures de securitie dans le travail"; and similar courses are offered throughout Europe and Scandinavia.

The importance of training in manual materials handling in reducing hazard is generally accepted. The lacking ingredient is largely a definition of what the training should be and how this early experience can be given to a new worker without harm. The value of any training program is open to question as there appear to have been no controlled studies showing a consequent drop in the MMH accident rate or the back injury rate. Yet so long as it is a legal duty for employers to provide such training or for as long as the employer is liable to a claim of negligence for failing to train workers in safe methods of MMH, the practice is likely to continue despite the lack of evidence to support it. Meanwhile, it may be worth considering what improvements can be made to existing training techniques.

Training Aims

The aims of training for safety in MMH should be:

1. to make the trainees aware of the dangers of careless and unskilled MMH;
2. to show them how to avoid unnecessary stress and
3. to teach them individually to be aware of what they can handle safely.

Instructors must be well versed in the sciences basic to MMH and in Safety Engineering, and be practically experienced and skilled in all types of manual handling. The content of the courses should be suited to the educational background of the trainees. It is important not to underestimate people's practical intelligence and understanding.

The course should cover the following aspects:

1. The risks to health of unskilled MMH: This should be rooted in local experience and the MMH accident pattern of the organization concerned;

2. The basic physics of MMH: Every MMH worker should possess at least a subjective understanding which can be acquired using simple models (levers, beam-balances, pulleys, etc.) to illustrate:

   a. the principles of levers;
   b. the difference between the force needed to resist gravitational force on a load and the work needed to raise it;
   c. the work needed to move a load horizontally;
   d. the work needed to change the direction of motion;
   e. momentum and kinetic energy;
   f. Newton's 3rd Law of Motion.

3. The effects of MMH on the body: The basic functional anatomy of the spine and the muscles and joints of the trunk and limbs is easily taught to trainees in terms of their practical experience, and with reference to basic physics. It is easy to demonstrate muscular activity while muscles are being stretched or lengthened isometrically; how the rib cage is constrained by pushing and carrying; how the shoulder, abdominal and back muscles contribute to lifting. The increase in intrathoracic and intra-abdominal pressures during MMH is not difficult to understand because of the familiarity of breath-holding when making an effort.

4. Individual awareness of the body's strengths and weaknesses: The first practical lesson in MMH which all trainees must learn is how much they can handle comfortably; and where, in relation to their bodies, their strengths and weaknesses lie.

5. How to avoid the unexpected: There is a need to recognize the physical factors which might contribute to an accident, and eliminate them. For example:

   a. is the load free to move and not stuck?
   b. is it a weight that is comfortable to handle alone or should help be sought?
   c. are lifting aids available?
   d. has the load proper handles to grasp or can they be provided?
   e. is protective clothing indicated?
   f. is the area for MMH clear of obstruction?
   g. is the floor clean, dry and non-slip?
   h. is the area for setting the loads down clear?

6. Handling Skill: The actual handling tasks chosen for teaching purposes should cover a range of materials but the emphasis should be on the actual materials handled by the organization concerned. There are a number of points of general application which should be taught. Skill depends on:

   a. preparation to avoid being caught unaware,
   b. being able to recognize what can be handled comfortably without help,
   c. keeping the center of mass of the load close to the body when lifting,
   d. not twisting or bending sideways,
   e. using the legs to get close to the load and to make use of the body weight and the kinetic energy of the body and load,
   f. timing for smooth MMH.

7. Handling Aids: Handling aids are available for most material handling tasks. Often, they can be improvised if they do not exist. One problem here is encouraging their use, especially with unpaced or incentive jobs.

It is not enough to teach the theoretical aspects of safety in MMH and demonstrate the practical points by slides or films. Every trainee must be practically involved from the start: in the theoretical teaching of basic physics and functional anatomy; in learning how to recognize the loads that can be handled without undue sense of effort, and where in relation to the body MMH is easiest; and in acquiring the skills of safer and easier MMH. Classes cannot be large or the element of personal involvement is missing.

It is not enough to teach only in a classroom because the lessons must be applied on site. There is another danger in teaching only in a classroom and that is that many of the older (or longer employed) workers and supervisors have not been taught safe MMH techniques. If the instructors are never seen on site, the trainees quickly forget and go back to their old habits.

Many of the instructors of the past (and much of the published teaching material) have tended to rely on a dogmatic style of instruction; and sets of 'rules' for safe lifting are common. The drawback is that literal application of some of these rules has led to quite unsafe lifting practices. For example, to insist on the rule "Lift with the knees" is not well founded. In many people the quadriceps femoris muscle is just not strong enough. Moreover, this could lead to lifting at arm's length in front of the knees, thus creating more stress on the spine than the straight-legged stoop posture. Any rules used as memory aids should at least teach a basic aim or principle. What matters is that the trainee is led to a proper understanding of the problem and not merely expected to remember a set of catch-phrases.