Psychophysical Basis for Manual Lifting Guidelines

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PSYCHOPHYSICAL APPROACH

1. Psychophysics

Psychophysics is the exact science of the functional relations between "body and mind" (Stevens, 1951). In other words, psychophysics is the science of the response of organisms to stimulating configurations. Here the responses may be the sensations, perceptions, attitudes, judgments, preferences, and the like. The organisms may be people and animals. Psychophysics may be said to have been born when scientists began to think about the possibility that they might measure sensation.

Whenever the stimulus increases, the intensity of the sensation grows in accordance with a common basic principle which states: equal stimulus ratios produce equal subjective ratios. In every sense modality, sensation is a power function of stimulus. This is the basic principle that underlies the psychophysical law.

The premise of magnitude estimation is that the perceived intensity of the stimulus (S) is directly related to a constant (k) multiplied by the physical intensity of the stimulus (I) which is raised to the nth power (Stevens 1960):

$$S = kI^n$$

The constant k depends on the units of measurement and is not of interest; but the value of the exponent n serves as a kind of signature that may differ from one sensory continuum to another. As a matter of fact, one of the important features of a sensory continuum lies in the value of its exponent (Stevens, 1975). The exponent n determines the slope of the function when plotted on log-log coordinates, and for lifting weights, n has been determined to be 1.45 (Stevens, 1975).

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).

1.1 Psychophysics in Manual Materials Handling

While the biomechanical approach attempts to estimate worker capacity based on stresses imposed on the musculoskeletal system of the worker, usually, compression on the spine, and the physiological approach attempts to estimate capacity by assessing metabolic energy expenditure, the psychophysical approach attempts to estimate capacity based on subjective evaluation of effort under different job conditions. Subjective evaluation of effort is accomplished through magnitude estimation since both muscular effort and force obey the psychophysical function (Borg, 1962; Eisler, 1962). To apply the principle of psychophysics to people at work, is to utilize the human capability to judge the subjectively perceived strain at work in order to determine voluntarily accepted work stresses.

Snook and et al. (1967) used a subjective criterion to determine the maximum acceptable weight which a subject should lift. In magnitude production, the experimenter states or indicates a series of sensory magnitudes, and the subject adjust a stimulus to produce them. Psychophysics in manual handling deals not with a series of magnitudes, but usually with only one magnitude - the maximum acceptable weight of lift. The technique of letting the subject adjust the weight lifted according to his or her own feelings is actually a variation of the psychophysical method of magnitude production.

When employing psychophysics in manual materials handling, the adjustment method is used. Subjects adjust one task variable (e.g., weight of the load) so that the load is the maximum that the subject can handle without becoming tired, out of breath, over-heated, and without excessive strain or discomfort. The most commonly adjusted task variable is the weight of the load. In some instances, the frequency of lift is adjusted. As stated by Legg and Myles (1981), with good subject cooperation and firm experimental control, the psychophysical method can identify loads that subjects can lift repetitively for an eight-hour work-day without metabolic, cardiovascular or; subjective evidence of fatigue. Although most experimentation relating to manual materials handling activities have investigated lifting tasks, the use of psychophysics is not restricted to lifting tasks. Magnitude estimation is also applicable to lowering, pushing, pulling, holding and carrying activities (Ayoub and Mital, 1988; Snook, 1978).

When using the psychophysical methodology to determine capacity, it is necessary to simulate the industrial task as realistically as possible. If lifting is being studied, the task should be a dynamic lift using the job conditions of interest. The type of subject used in a psychophysical study is very important. If the study is investigating industrial tasks, then industrial workers should be used as subjects. It is also advised to have the same subjects returning for several days or weeks in order to overcome the motivational effects created by the experimental atmosphere which will frequently cause to bias the subjects estimate of their capabilities.

1.2 Application of Fuzzy Set Theory

There are disagreements among the three approaches. Garg and Herrin (1979) have pointed out that there exists a trade-off between biomechanical stress criterion and physiological metabolic energy criterion. Biomechanical stress criterion ignores the effects of frequency of lift, therefore, it tends to minimize the load by using smaller, more frequent lifts (to reduce stresses on the low back), while physiological metabolic energy criterion focuses more on the effects of frequency of lift, and therefore, it tends to permit larger weights at less frequent intervals (to reduce metabolic energy expenditure) (Ayoub and Kim, 1988).

In reviewing the literature in MMH, one finds that for infrequent lifting, the maximum acceptable weights of the load based on the biomechanical stress criteria (including strength) may be less than those based on the psychophysical fatigue criteria. For repetitive lifting the maximum acceptable weights based on psychophysical fatigue criteria are lower at low lifting frequencies and higher at high frequencies than those based on physiological fatigue criteria (Karwowski, 1982). There are differences: (1) between the biomechanically and physiologically determined lifting capacity, (2) between biomechanically and psychophysically determined lifting capacity, and (3) between physiologically and psychophysically determined lifting capacity. This is illustrated in Figure 1.

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INSERT FIGURE 1
Figure 1: Comparison of Biomechanical, Physiological and Psychophysical Fatigue Criteria.
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The utility of magnitude estimation is that the researcher can predict perceived stress of the stimulus from the measurement of its physical stresses. Karwowski (1982) intended to establish that psychophysical lifting stress (perceived stress) can be predicted from the combined assessment of biomechanical and physiological stresses of lifting (physical stress). In order to establish this relationship, the physiological, biomechanical and psychophysical criterion and stresses must be compared. Then a method of combining the measurement of physiological and biomechanical stresses must be identified.

Understanding differences among criterion allow for correctly combining of two quantitatively different stresses. It is assumed that physiological and biomechanical stresses combine synergistically. To reiterate Karwowski's hypothesis, the sensation of this synergistic combination of the physiological and biomechanical stresses (physical stress) is directly reflected in a worker's subjective judgment of the maximum acceptable weight of lift (perceived stress).

According to Karwowski (1982) and Karwowski and Ayoub (1984), comparison between psychophysical stress and combined physiological and biomechanical stresses cannot be achieved by typical mathematical models which are based on statistics. These mathematical models are inappropriate for qualifying differences between "acceptable" and "safe" load limits, which are unclear terms, therefore, fuzzy set theory was used. Fuzzy set theory accounts for a complex system where there is no sharp transition from membership to nonmembership of classes of weights.

Using the fuzzy set measure, Karwowski (1982) was able to develop a model for the interaction between psychophysical, physiological, and biomechanical stresses. The physiological and biomechanical stresses were combined by taking the algebraic product of acceptability measures. The relationship between maximum acceptable weights of lift from the psychophysical model and the maximum acceptable weights of lift from combined stress were assessed.

Karwowski and Ayoub (1984) confirmed this hypothesis by concluding that the psychophysical criterion appeared to be the result of the integration of the physiological and biomechanical stresses. Thus, in cases where predicted psychophysical stress is desired, psychophysical stress can be determined from the measurement of biomechanical and physiological stresses. These findings were supported by Hafez (1984) who reported a fuzzy measure of similarity between psychophysical stress and combined biomechanical, physiological and thermal stresses.

Figure 2 describes the relationship between the biomechanical and physiological membership functions and various load weights and/or spinal compressions. Figure 3 describes psychophysical membership function and the load lifted. Both figures are based on data from Hafez (1984). Two examples are included on these figures to demonstrate that psychophysical stress is the combined effect of biomechanical and physiological stresses. In the first example, assume a load of 20 kg is to be lifted with a frequency of 3 lifts/min in an environmental temperature of 32 WBGT. From Figure 2, the obtained physiological value is 0.83, and the obtained biomechanical value is 0.76. When multiplied together, the biomechanical-physiological membership function product equals the psychophysical value of 0.63. Figure 3 does indeed yield a psychophysical value of 0.63 for a 20 kg load lifted with a frequency of 3 lifts/min in an environmental temperature of 22 WBGT. Similarly, a 30 kg load lifted with a frequency of 3 lifts/min. yields a physiological value of 0.77 and a biomechanical value of 0.83. When multiplied, they result in a psychophysical value of 0.52. This value is concurrent with the psychophysical value obtained from Figure 3.

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Insert Figures 2 and 3

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Of the three design criteria (biomechanical, physiological, and psychophysical criteria), the psychophysical criterion appears to be an appropriate single criterion to use to determine lifting capacity. Both biomechanical and physiological stresses are present in almost all lifting tasks, however, recommendations based on either approach are not necessarily compatible. Lifting is a complex task which cannot be explained completely by either the physiological or biomechanical criterion alone. As described above, the psychophysical criterion is the combination of stresses into a comprehensive whole; perceived stress.

2. Factors Affecting Manual Material Handling Activities

Individual, task, material and container, and environmental variables affect manual material handling ability. Individual components comprise all variables that define or describe the individual's working capability, such as age, gender, body weight, etc. The task component comprise all variables that define or describe the task, such as frequency of lift, weight of lift, posture, range of lift. Material and container characteristics include size, shape of container, and means of coupling as well as the material being handled. The environmental component comprise all variables that define or describe the environment, such as heat stress, light, noise, traction, etc. All of these factors interact in a complex manner to yield the psychophysically perceived stress and hence the maximum acceptable weight of lift.

2.1 The Worker Component

In terms of manual materials handling activities, the physiological cost to the worker should not exceed acceptable limits. The worker should not suffer from excessive fatigue, and physical stresses should not strain or injure the spine or other body parts. The capacity to perform the physical act of lifting varies considerably not only from individual to individual but within any given individual over time and under different job conditions. Furthermore, the limitations of this capacity are complex and interrelated. Understanding the relationship of these characteristics to the resulting risk of injury to the worker is prerequisite to the development of schemes for designing job or placing people in jobs which do not compromise their health and safety.

2.1.1 Sex

Sex is considered an important worker characteristic since sex greatly affects anthropometric, biomechanical and physiological variables (Grasley, et al., 1978). A number of researchers (Chaffin and Moulis, 1969; Astrand and Rodahl, 1970; Herrin, et al., 1974b; Brown, 1975; Garg, 1976; Chaffin et al., 1977; Graseley, et al., 1978) report that definite differences in males and females affect manual materials handling activities, including differences in anthropometry, strength, physical capacity, maximal oxygen uptake, heart rate and injury risk. The ILO (1967) and the U.S. Department of Labor (1970) recommended that women not lift as much as men.

Body dimensions of males and females are proportional to their stature, a female's stature being 93% of a male's stature. This slight difference in stature can cause profound differences in strength (Pheasant, 1982). Generally, females have two-thirds the physical capacity of males. A female's lifting strength is approximately 70% that of a male's lifting strength (Ayoub, et al., 1978; Mital, 1984 a, b; Asmussen and Haeboll-Nielson, 1961; Petrofsky and Lind, 1975; Chaffin, 1974; Snook, 1978a, b; Snook and Ciriello, 1974a; Mital, et al., 1978; Troup and Chapman, 1969b; Pheasant and Grieve, 1981).

As found with strength and muscle power differences, aerobic capacity differences exist between males and females after puberty. Generally, females have 70-75% the aerobic capacity of males (Astrand and Rodahl, 1977).

Biomechanical linkage mechanism differences between males and females account for some sex differences (Chaffin and Moulis, 1969; Tichauer, 1973). It is thought that biomechanical linkage mechanisms cause different intra-abdominal pressure when the same force is applied. Females have approximately 50% more intra-abdominal pressure than males when the same force is applied according to David, 1985. According to Magora, 1970 and Brown (1971 and 1974) this is reflected in the number of complaints reported by females when required to participate in physically demanding tasks.

2.1.2 Age

The effect of age on manual material handling capability is not clearly understood. It is accepted, generally, that a worker's manual materials handling capability declines after the age of 20 years (Aberg, 1961).

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

Fisher and Birren, 1947 and Hettinger, 1961.

In both sexes, there is a peak at eighteen to twenty years of age, followed by a gradual decline in the maximal oxygen uptake. At the age of sixty-five, the mean value is about 70 percent of what it is for a twenty-five-year-old individual (Astrand and Rodahl, 1970).

Muller (1962) was doubtful that maximum oxygen consumption was an appropriate index for continuous-work capacity. He insisted that a decrease in maximum oxygen consumption with increasing age does not indicate that continuous-work capacity also decrease with age.

Snook (1965) and Henschel, and et al. (1964) report no increase in heart rate with increasing age while performing work at a fixed level. Snook (1971) reported that continuous-work capacity does not decrease with increasing age. Ayoub, et al. (1978) reported that age does not have an effect on an individual's determination of maximum acceptable weight of lift. They include age variable in the model for individual lifting capacity. This model was modified later by dropping age and sex variables (Ayoub et al., 1986). However, Karwowski and Ayoub (1984) used age as a factor for the model of the oxygen consumption rate.

Despite controversial data, it is practiced pervasively throughout the world that older workers are awarded the softest jobs since age is considered a potential risk factor.

2.1.3 Body Weight

Body weight is also an important worker variable that affects the person's manual materials handling capability.

Herrin, et al., (1974), Chaffin, et al., (1977), and Ayoub, et al., (1978) reported that, in addition to other variables, such as age, and sex, body weight has an effect on an individual's lifting capacity. However, they state that the individual's body weight effects are probably secondary when compared to the effects of the individual's strength and physical work capacity characteristics.

Metabolic energy expenditure rate increases as body weight increases (Wyndham, et al., 1963; Kamon and Belding, 1971; Garg, 1976). Thus, heavier workers performing the same task as lighter workers will be more stressed physiologically. This could lead to a greater number of cardiovascular problems, and quicker exhaustion for the heavier worker. Although the heavier worker may tire quickly, he is usually stronger than his lighter counterpart and usually has the mass necessary to counter-balance the handling of large objects (Snook and Irvine, 1967; Troup and Chapman, 1969a; Konz, et al., 1973; Larsson, et al., 1979; Laubach and McConville, 1969). Additionally, the heavier worker usually has larger abdominal and pelvic girth than lighter workers which can cause postural problems. Further problems can arise as the distance between the load and the spine increases. Also, Ayoub et al. (1978) found that there appears to be a relationship between body size and ability to lift. For these reasons, body weight can be a limiting factor (Jorgensen, 1970).

The body weight can be considered to add to the MMH capacity as a dependent variable. Two reasons may be suggested for this method. First, the body weight plays an important role in MMH activity. For example, to conduct a carrying activity, the operator must move his body weight as well as the object in order to accomplish the task. For other activities, such as lifting and lowering, the body weight is a significant component of the mass which needs to be moved. Second, the correlation between some of the strength variables and MMH capacities are higher as the body weight is added to the MMH capacities, as opposed to those without adding body weight. This findings were reported by Macintosh (1974), Ayoub, et al. (1978), and Jiang (1985).

Macintosh (1974) stated that additional mass slowed the movement so that the muscle action became more similar to a static contraction. Ayoub, et al. (1978), had lifting capacity plus body weight as dependent variables in six prediction equations for six ranges of lift. These models were further modified by Ayoub, et al. (1986). Jiang (1985) reported that the correlation between MMH capacities and isometric strength or isoinertial strengths with body weight added was higher than the case for without body weight added to the MMH capacities.

2.1.4 Strength and Physical work Capacity

It has been mentioned in the preceding sections that there are a number of factors; such as age, sex, body weight, and training which have an effect on an individual's strength (Astrand and Rodahl, 1970; Herrin, et al., 1974) and physical work capacity (Astrand and Rodahl, 1970; Garg, 1976) which could then have an effect on an individual's lifting capacity. However, Herrin, et al., (1974) and Chaffin, et al., (1977) stated that these attributes are probably secondary when compared to the effects of the individual's strength and physical work capacity on their lifting capacity attributes. The effect of these two factors, strength and PWC, is the least understood.

It is accepted, generally, that the physically fit worker is less prone to injury (Doelan and Wright, 1979). The physically fit worker takes fewer "sick days" due to minor injury, and is more likely to participate in more physically demanding tasks than workers who are not physically fit. According to Scott and Gilsbers (1981) physically fit workers have a high pain tolerance limit. Conversely, lack of physical fitness and previous back injury are causes for concern since this type of worker may have recurrent back pain (Rowe, 1971; Karvonen, et al., 1980b; Troup, et al., 1981; Dillane, et al., 1966; Nordgren, et al., 1980; Lloyd and Troup, 1983).

Researchers have been investigating the topical areas of strength as cited by Kroemer (1976) and physical work capacity (PWC) as cited by Kamon and Ayoub (1976). A few, as cited by Drury and Spitz (1976), have attempted to investigate the relationship between the two phenomena.

Kroemer (1976) has proposed the following definition for strength: "Strength is the capacity to produce torque or work by maximal voluntary contraction." He then defines, respectively, static and dynamic strengths as "static strength is the capacity to produce torque by an isometric maximal voluntary contraction" and "dynamic strength is the capacity to produce work by dynamic maximal voluntary contraction." Maximal voluntary contractions (MVC) refer to how much effort the individual is willing to exert. The capability of an individual to sustain a particular activity (static or dynamic) can be expressed then as a fraction or percentage of the MVC, although MVC generally is used when referring to static forces (Drury and Spitz, 1976).

Astrand and Rodahl (1970) pointed out some interesting facts about strength. For example, the day-to-day variation ranges from ± 10% to ± 20% and the maximal strength capacity is reached between the ages of 20 and 30 years, after which it gradually declines. Kroemer (1976) also states that dynamic exercise can probably be performed for a long period of time if the developed strength does not exceed 10% to 20% of the maximal voluntary static strength.

Asmussen and Heeboll-Nielsen (1962), Chaffin (1974), Chaffin, et al., (1977), Snook and Ciriello (1974), Petrofsky and Lind (1975) indicated that, in general, female strength ranges from 60% to 70% that of males. Chaffin, et al., (1977) cites Laubach (1976) when stating that, for specific strengths, female strengths may range from 35% to 85% of male strength.

Kamon and Ayoub (1976) define Physical Work Capacity (PWC) as the "physiological mechanism that underlies the performance using large muscle groups in rhythmical contractions." They then explain that an individual's ability to continue dynamic muscle action is made possible through the oxidation of various nutrients. The oxidation process requires the transport of oxygen to the muscles by way of the cardiovascular and respiratory systems. The oxygen is transferred from the lungs to the blood. The blood transports the oxygen to the muscles. The oxygen is then extracted from the blood, at the cellular level, while simultaneously permitting the removal of metabolic by-products resulting from previous oxidation processes. The supporting systems (cardiovascular and respiratory) gradually adjust to the activity demand (work load) until an elevated "steady state" level is reached. These elevated functional levels are reflected by an increased frequency of respiration and heart beat. These represent the response of the physiological system to the increased muscle demand for oxygen.

2.1.5 Training

Training has been advocated by many researchers (Brown, 1971, 1974; Davies, 1978). It is assumed that after training, the workers will (1) use the correct method of material handling, (2) recognize and adjust for potential hazards due to worker, task or environmental variables, and (3) show physical capacity improvements. Overall, it appears that training programs do meet the expected outcomes. There is controversy over the length of time that any given training is effective. Selby (1983) suggests that frequent, regular refresher courses be scheduled.

The effects of training on the amount of oxygen that can be consumed per minute during maximal exercise has been studied extensively; there is little doubt that it is increased with training. Astrand (1952), Ekblom, et al., (1968), Fox, et al., (1973), Fox, et al., (1975), Saltin, et al., (1969), Astrand (1967), Astrand and Rodahl (1970), and Tzankoff, et al., (1972) all reported an increase in maximal oxygen uptake with training. The magnitude of increase reported in the literature varied considerably, however, an average improvement of between 5 and 20 percent was documented (Asfour, 1980).

Astrand and Rodahl (1970) were able to show that short duration (10-15 seconds), high intensity efforts, with the appropriate rest periods, could be as effective as high intensity, long duration efforts (10 minutes or longer) if not more effective regarding the improvement of oxygen uptake.

Saltin, et al., (1968), Fox, et al., (1973), and Fox, et al., (1975) reported a slight decrease in maximal heart rate. with training. However, Ekblom, et al., (1968), and Maksud, et al., (1972) reported that no change occurred in maximal heart rate.

Ekblom, et al., (1968), Fox, et al., (1973), Fox, et al., (1975), Frick, et al., (1967), and Frick, et al., (1963) all reported a decreased heart rate during submaximal exercise following training.

Astrand and Rodahl (1970) presented documentation which indicated that minimal training is required to improve muscular strength, but that an improvement in strength performance is a function of specific training.

Shannon (1978) reported that individual who participated in a lifting training program, which consisted of a specific schedule for repeatedly lifting fixed loads, developed improved lifting techniques.

Asfour (1980) reported that training significantly increased the individual's strength, endurance, and lifting capacity.

Karwowski (1982) investigated the effects of training for muscle strength, lifting capacity and cardiovascular endurance. He reported that the overall static strength index, based on the sum of the back strength, shoulder strength, arm strength, composite strength, standing leg strength and sitting leg strength, increased after 10 training sessions by an average of 11.23%. The average value of the maximum amount of weight lifted as the repetition maximum, increased by 20.03% after 5 training sessions, and by 34.66% after the 10 sessions in comparison to the initial amount lifted before the experiment. A comparison with the results of the training on muscular strength reported by Asfour (1980) shows that Asfour's results in arm strength, back strength, standing leg strength are much higher than the results by Karwowski. However, for shoulder strength, Karwowski's result is much higher than the results by Asfour. Karwowski reported that no obvious explanation for the differences in static strength increase between the two studies could not be given. He claimed that the differences in the starting strength of the subjects used for the experiments might be part of the possible explanation of this fact. He also reported that the average increase in the adjusted maximal oxygen uptake of all subjects was 15.60%. He compared his result with previous studies (Rowell, 1962; Ekblom, et al., 1968; Saltin, et al., 1969; Asfour, 1980) and claimed that the comparison showed that the percentage increase in maximal oxygen uptake obtained in his study was very close to most of those reported. Only the study by Asfour (1980) resulted in much greater increase in the maximum oxygen uptake of the subjects.

2.1.6 Attitude

Psychological variables and their effect on manual material handling tasks are not well understood. Lehman, et al., (1939) concluded that workers stop working when the sum of all negative factors, such as fatigue, muscle pain, etc., exceed the sum of all positive factors, such as motivation. This contention was supported by Alles and Feigen (1942) and Smith and Beecher (1959). Bakken (1983), using psychometrics, concluded that attitude greatly affects the maximum acceptable weight lifted. These results, however, have not been validated.

Blow and Jackson (1971) and Herrin, et al., (1974), reported that a personality characteristic such as attitude, might have an effect on an individual's lifting capacity.

Selan (1986) reported that subjects classified as possessing the Type A behavior pattern (aggressive, impatient) would work during the psychophysical lifting task at a higher %PWC than subjects classified as Type B (passive, patient) regardless of the social condition. Type A subjects required significantly less time deciding their MAWL, and made fewer weight adjustments in terms of decreasing box weight, than Type B subjects. He concluded that the behavior pattern, attitude towards physical work, should be used as a predictor of psychophysical lifting capacity.

2.2 The Task Component

2.2.1 Frequency of Lifting

The term "frequency of lift" refers to the number of lifts or treatments the subject performed per period of time (lifts/minute). It is obvious that the higher the frequency of lift the more energy will be expended by the subject and the sooner fatigue will take place.

Frequency can be classified in three gross categories (NIOSH, 1981):

1. Infrequent : either occasional or continuous lifting less than once per 3 minutes.
2. Occasional High Frequency: lifting one or more times per 3 minutes for a period up to 1 hour.
3. Continuous High Frequency: lifting one or more times per 3 minutes continuously for 8 hours.

For infrequent lifting, a person's musculoskeletal strength and potential high stress to the back are the primary limitations to ability. As such, biomechanical variables are predominant in determining hazards.

For occasional high frequency lifting, the cyclic loading on the spine may result in stress which may be the primary limitation. For continuous, high frequency lifting the primary limitations are based on cardiovascular capacity and metabolic endurance. Van Wely (1961) suggested that the physiological efficiency does not depend only on the weight lifted but also on the number of lifts per unit time.

Snook, et al., (1970) reported that the individual's maximum acceptable weight of lift occurred at a frequency of one lift per minute. But when the subjects were permitted to determine a most desirable frequency of lift, they selected four lifts per minute. Unfortunately, little documentation was available on lifting activities occurring at frequencies below one lift per minute. Snook and Irvine (1966) reported that frequencies above 10 lifts/min could not be maintained for any length of times.

Chaffin, et al., (1977) studied the relation of frequency, duration and pace of lifting to back injury potential. They discovered that the more frequent the lifting of maximal loads on a job, the greater the frequency and severity rates of musculoskeletal problems (other than backs) and the greater the severity of contact injuries.

Snook (1978), and Ayoub, et al., (1978), utilized a psychophysical approach to determine the maximum acceptable weight of lift for workers. Their findings indicated a linear decrease in the weight lifted with an increase in the frequency of lift.

The maximum acceptable weight of lift decreases non-linearly as pace, or frequency, increases (Mital, 1984a, b; Snook, 1978a, b; Mital and Manivasagan, 1983a; Asfour, et al., 1984a, b; Ayoub, et al., 1980b, 1983b; Ciriello and Snook, 1983; Foreman, et al., 1984; Garg and Saxena, 1978; Karwowski and Ayoub, 1984a, b; Khalil, et al., 1985; etc.). While this is true, the total acceptable workload increases as pace decreases (Mital, et al., 1978; Mital and Ayoub, 1981a; Mital and Asfour, 1983; Garg and Saxena, 1978; Mital and Okolie, 1982). Thus, the psychophysical approach results in more liberal standards for low frequency and high task loads than either of the other approaches. Mital (1985a) states that the psychophysical approach can provide a more accurate determination of manual material handling capability of an individual if frequency of lift is considered and the task is corrected for work duration than other lifting approaches.

2.2.2 Height and Vertical Range of Lift

It is known that the mechanical work is a function of the distance moved. So the energy expended is proportional to the height of lift. Not only that but it depends also on the height range of lifting, i.e., lifting from floor to knuckle height is different from shoulder height to reach height as different muscle groups are involved in these lifts (Aquilano, 1968, Garg, 1976, and Mital, 1980).

For instance, lifting from the floor is more stressful than lifting from a table since the greatest compressive and shear forces occur during the first few seconds of a lift from the floor. Capacity can be decreased by 23% if a lift starts at shoulder height instead of knuckle height (Ayoub and Mital, 1988). Basically, as the vertical lift height increases, an individual's lifting capability decreases. If vertical distance is held constant, lifting strength increases or decreases depending on the horizontal distance between the spine and the load (Martin and Chaffin, 1972).

Mital (1980) and Asfour (1980) reported that interaction effect of the frequency and height of range on the oxygen uptake was significant.

Intaranont (1983) found no significant VO2 max differences between the floor to knuckle and knuckle to shoulder heights of lift. He also concluded that the interaction between the frequency and height of lift was not statistically significant.

Khalil, et al., (1985), however, claimed that VO2 max for three heights of lift (floor to knuckle, knuckle to shoulder, floor to shoulder height) were significantly different from each other. They reported that VO2 max for lifting from floor to shoulder height was the highest, followed by VO2 max values for the floor to knuckle and knuckle to shoulder heights of lift.

2.2.3 Angle of Twist of the Body

Although Troup (1965) reported that many of the back injuries in industry were caused by the twisting movement of the spine, little has been published about the effect of the angle of twist of the body on either the energy cost of the lifting and lowering tasks or the lifting and lowering capacity of individuals. Herrin, et al., (1974) pointed out the need for studying the effect of angle of twist of the body on the lifting capacity of workers.

Asfour (1980) investigated the effects of "spinal twist" (0, 90 degree) on the lifting and lowering capacity using both the physiological and psychophysical approaches. He reported that the heart rate was affected very slightly by the angle of twist. He also reported that lifting or lowering boxes with an angle of twist was less stressful physiologically but more stressful biomechanically than lifting or lowering with the spine in the normal position. From his data, approximately an average of 5% decrease in maximum acceptable weights of load for both lifting and lowering may be generally accepted.

Warwick et al. (1980) reported a 38% decrease in maximum static strength when the subject was rotated 90 or 135 degree from the sagittal plane at the shoulder height and more than a 50% decrease in static strength when the subject was rotated by 90 degree at the knee height.

Ljungberg et al. (1982) reported that the subjects chose a load only half as heavy for horizontal lifting from left to right as that found in previous studies of vertical lifting.

Garg et al. (1986) conducted a laboratory study to determine the effects of asymmetric lifting on psychophysically determined maximum acceptable weights and maximum voluntary isometric strengths. The effect of three different box sizes and three different angles of asymmetry (30, 60 and 90 degree) were investigated for the lifting range from floor to an 81-cm high table. They reported that the maximum acceptable weights and static strengths for asymmetric lifting were significantly lower than those for symmetric lifting in the sagittal plane for three box sizes. There was a consistent decrease in the percentages of the maximum acceptable weight and static strength with an increase in the angle of asymmetric lifting. They concluded that the correction factors of 7, 15, 22% for maximum acceptable weights and 12, 21 and 31% for static strength at 30, 60 and 90 degree of asymmetric lifting were recommended.

2.2.4 Task Duration

The effect of task duration depends on the individual's endurance (Bonjer, 1962; Deivanayagam and Ayoub, 1979; Garg, 1980). Generally, as the task duration increases, the task burden should decrease, and appropriate rest allowances provided. Figures 4 and 5 demonstrate the decrease of load weight with time for males and females.

Mital (1983) conducted an experiment to verify the psychophysical methodology used for determining maximum acceptable weight of lift for individual workers. After estimating, during a 25-min period what they could lift for 8 hours, an additional 20 minute of adjustments were allowed to simulate a 12-hour shift. Then they were asked to lift these selected weights for an actual 8-hour and 12-hour periods. Males lifted 65% of the estimated value, while females lifted 85% for an 8-hour period. When the period was increased to 12 hours the males lifted only 61% and females lifted 77% of the estimated weights by themselves. He concluded that the psychophysical method tends to overestimate the maximum acceptable weight of load.

Karwowski and Yates (1986) evaluated the psychophysical method for setting lifting standards for the lifting range from floor to 76 cm above the floor using seven female college students. Four different frequencies (1, 3, 6, and 12 lifts/min) were used. Subjects were allowed to adjust the weights of carton during the four hour lifting tasks. The weight of carton with empty jugs was 3.25 Kg, while the maximum weight of the full carton was 21 Kg. They reported the average weight and oxygen consumption rate at 30 minute, 120 min, and 240 minute. The average weights lifted were 12.60, 12.20, 9.83, and 9.33 Kg at 30 minute and 13.74, 11.71, 9.69, and 7.19 Kg at 240 minute for frequencies 1, 3, 6 and 12 lifts/min, respectively. The oxygen consumption rate were 0.36, 0.50, 0.72, 0.90 l/min at 30 minute, and 0.36, 0.48, 0.64, 0.87 l/min at 240 minute for frequencies 1, 3, 6, and 12 lifts/min, respectively. The weight chosen by the subjects at 30 minute did not differentiate significantly from the 4 hour values for frequencies of 1, 3 and 6 lifts/min. However, at 12 lifts/min the weight decreased with time such that the 4 hour value was 23% lower than the weight chosen after 30 minute. Oxygen consumption rate was unchanged over time and accounts for 19, 25, 35, and 45.5% of VO2 max for frequencies 1, 3, 6, and 12 lifts/min respectively. They concluded that the psychophysical method in its present for should not be used to lifting standards for frequencies higher than 6 lifts/min.

Fernandez (1986) conducted an experiment to verify the Mital's work. He reported that the MAWL decreased to 88.32% and 83.62% respectively at 2 lifts/min and 8 lifts/min. The weight lifted over the 8-hour decreased to 85.97% MAWL on the average. He concluded that the psychophysical approach is therefore a good method to measure lifting capacity, as the decrement is not significant over time.

Mital, Karwoski and Yates, and Fernandez are in agreement that a decrement in the MAWL is observed over time. The MAWL was estimated during a 25 minute task simulation. This result should be considered when designing manual lifting tasks.

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insert Figures 4 and 5

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2.2.5 Work-space and Posture

Workplace effects worker capacity since restrictions of workspace may lead to unnatural postures and movement. Drury

(1985) offers several work pattern changes due to inadequate workspace. According to Mital (1986c), the effect of restricted space on manual materials handling capability is one of the most profound task variables. Both males and females show reduced manual materials handling capacity when working under space restrictions. Additionally, abnormal postures may cause instability which results in more cautious, slower movement.

Postures normally assumed during manual tasks include the stoop (straight legs), squat (straight back) or free style (semi-squat). Biomechanically, the squat posture is less stressful than the stoop posture (Garg and Herrin, 1979; Leskinen, et al., 1983a, b). Squatting is recommended for lifting tasks. If the load does not fit between the knees, however, the squat should not be assumed (Ayoub and Mital, 1988; Chaffin and Park, 1973). The stoop posture can be used because this posture allows the worker to place his trunk over the load which reduces the spine-to-load distance (Park, 1973). This posture, however, places great stress on the muscles of the back since it prevents compression of the spine.

Physiologically, the stoop posture requires low metabolic expenditure (Garg and Herrin, 1979; Kumar and Magee, 1982; Kumar, 1984). When neither the squat or stoop are desired, the free-style posture can be assumed. Overall, the free-style lift is the least stressful. Therefore, biomechanically, it is expected that the squat posture is preferred, while psychophysically, the free-style lifting posture seems to be preferred.

2.3 Material/Container Characteristics

2.3.1 Weight of Load

It is well-known fact that as the load lifted increases, the mechanical work needed to lift it increases, which in turn will lead to an increase in the amount of energy expenditure by the worker. Frederik (1959), Aquilano (1968), Hamilton and Chase (1969), Garg (1976), and Mital (1980) have shown that an increase in the load to be lifted leads to an increase in the metabolic energy rate.

Even though Snook (1978), Ayoub, et al. (1978) agree on the MAWL of a particular group of population, the literature is controversial regarding the weight to be lifted by a particular individual. Ayoub, et al. (1978), Garg (1976), Jorgensen and Poulsen (1974) and Poulsen (1970) do not agree on the amount of weight to be safely lifted by an individual under different conditions of task variables.

2.3.2 Container Size and Shape

The effect of box size in the sagittal plane (box length) on lifting capacity of workers received most of the researchers' attention. On the other hand, not many research has been done to investigate the effect of the box size in the transverse plane (box width ??) and the box size in the frontal plane (box height ??) on the lifting capacity of workers.

Tichauer (1971) adopted a biomechanical approach to study the effect of the box size in the sagittal plane on lifting capacity. He introduced the concept of weight/bulk ratio, which implies that the lifting stress exerted on the vertebral column does not depend only on the weight of the load lifted but also on the moment arm of the load; i.e., the bulkiness of the object.

Ayoub, et al., (1978) utilized a psychophysical approach to study the effect of the box size in the sagittal plane on lifting capacity of workers. They reported a linear relation between the weight lifted and box size, the amount of weight lifted being inversely proportional to the box size in the sagittal plane.

Ciriello and Snook (1978) found no significant difference in the amount of weight lifted when two box widths, in the frontal plane, (35.0 in and 22.5 in) were studied. However, they reported that the weight lifted decreased as the length of the box in the sagittal plane, increased from 14.2 in to 29.5 in when lifting from floor to knuckle height.

Mital (1980) utilized the physiological approach in studying the effect of box dimensions on the energy cost of MMH tasks. He concluded that the oxygen uptakes for lifting and lowering tasks increase with the box width and box length. The height of the containers does not affect metabolic energy expenditure of an individuals. He also reported that unit change in box width found to be more expensive in terms of metabolic energy expenditure than unit change in box length up to 22 inches. Beyond this, the unit change in box length became critical.

Asfour (1980) also concluded that the oxygen consumption of individuals increase with the increase of box length and box width for both lifting and lowering. The maximum acceptable weight of load for lifting/lowering decreases with the increases of box length and box width.

Asfour, Ayoub, and Genaidy (1984) reported that the box length and the width were statistically significant at the one percent level, in the case of maximum acceptable weight, for both lifting and lowering. As for oxygen consumption, box width was not significant for lifting, but was significant for lowering at the five percent level.

As a summary box length and box width have a significant effect on the maximum acceptable weight of load and the oxygen consumption for both lifting and lowering.

According to Garg and Saxena (1980), for two-handed carrying tasks, non-collapsible, rectangular bag containers increase in volume as maximum acceptable weights of lift decrease, however, collapsible, bag containers increase in volume as maximum acceptable weights of lift increase. For one-handed carrying tasks, non-collapsible containers increase in volume as maximum acceptable weights of carry increase. Contrary to the results of one-handed carrying tasks, it appears that a greater amount of weight, approximately 18% more (Mital and Okolie, 1982), can be lifted using collapsible containers than using non-collapsible containers. The shape of the collapsible container, however, does not affect the amount lifted, but the dimensions do affect the amount lifted.

2.3.3 Material Handled

Load distribution and stability can also effect the maximum acceptable weight handled. When handling asymmetrical objects or liquid-filled containers, the center of gravity becomes important. When the center of gravity aligns with the side of the body each vertebra rotates on the adjacent vertebra. This causes torsional stress which can result in the reduction of the maximum acceptable weight of lift or carry (Mital and Manivasagan, 1983a; Mital and Okolie, 1982; Mital and Fard, 1986; Mital and Ilango, 1983b; Ayoub, et al., 1979; Mital, 1986c). It appears that torsional stress is the cause of the adjustment since physiological demands remain the same once the worker has chosen the maximum acceptable conditions (Mital and Fard, 1986). According to Ayoub, et al., (1979), Mital and Fard (1986), and Mital and Manivasagen (1983), a lateral offset of approximately 10 cm in the center of gravity can reduce capacity by up to 10%.

Handling liquids can be a problem if the container is not full because the center of gravity is continuously changing as the liquid moves. Lifting capacity can be reduced by as much as 31% due to torsional stresses on the lumbar column and high-low torque at the coupling (Mital and Okolie, 1982). If partially filled containers must be handled, carrying capacity can be greatly enhanced by partitioning the container.

2.3.4 Couplings

Equipping the load with appropriate couplings facilitates its handling (Mital, 1980) and reduces the possibility of dropping it thus reducing probability of injury.

Himbury (1962) and Koskela, et al. (1968) pointed out the importance and need for full grasp handles to avoid injuries.

Early work (reviewed in Drury, 1980) concentrated on size, shape and texture of handles, reaching the conclusion that handles should be about 110 mm long, about 25-40 mm in diameter, cylindrical in shape and with a smooth, non-slip surface (Drury and Deeb, 1986a). An industry survey (Drury et al., 1982) showed that the most frequently used hand positions on boxes without handles were asymmetric, with symmetrical positions only being used with heavy, compact boxes. Using the handle position convention shown in Figure 6, positions 3/7 (asymmetrical) and 8/8 (symmetrical) were those used most frequently. However a laboratory experiment using a static box-holding task at waist height, reported by Coury and Drury (1982), showed that the asymmetric positions (3/8, 6/8) gave the lowest physiological and perceived strain while the symmetrical position (8/8) gave the lowest hand-forces on the handles (Drury and Deeb, 1986a).

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Fig 6. Handle position from Drury

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The best angle of handle to the box horizontal axis was found by allowing the handles to pivot. The pivoted angle, corrected for the residual wrist deviation and slippage between hand and handle, was found to be around 50 at floor level and 80-

120 at greater task height. Overall, an angle of 70 was recommended as a reasonable compromise (Drury and Deeb, 1986a).

Garg and Saxena (1980) reported that the maximum acceptable weights for boxes without handles were lower than those for boxes with handles. In their study, the average decrease in maximum acceptable weight due to lack of handles was 7.2%. They concluded that the recommendations for maximum acceptable weights of the load based on boxes with handles need to be adjusted when applied to boxes without handles or to some other types of containers.

Chaffin and Freivalds (1982) found that the MAWL decreased by 1.5% with handles, even though the box without handles reduced the fraction of maximum strength workers were willing to exert.

Smith and Jiang (1984) found that the MAWL was 26.21 kg with handles and 23.56 kg without, a difference of 2.65 kg or 10.6%. They also measured the oxygen uptake, but only gave handles/no handles differences of 0.10 l/min, or 6.1 %, and 0.05 l/min, or 3.8%, in their two experiments.

Drury (personal communication, 1988) compared handles and no handles in a palletization/depalletization task. Because they used two fixed box weights of 9 kg and 13 kg, they were able to express the handles/no handles difference in terms of the equivalent box weight change required to have the same effect on the measured variable. For heart rate, they found an equivalent weight change averaging 3.63 kg, which is 33% of the mean box weight of 11 kg. For psychophysical measures (RPE and discomfort scores) the effect was even higher at 5.61 kg (51%). These effects were measured for the best handle position tested, and were averaged across palletization, depalletization and symmetrical lifting tasks.

Overall there is little agreement on the exact correction to be applied for MMH with and without handles. The most direct way to combine the data is perhaps to combine the percentage effects from the published studies, ignoring the large psychophysical effect from Drury et al. Thus it is suggested that the handles factor be fixed at 10% (i.e. multiply the with-handles weight by 0.90) until further information is available.

2.4 The Environment Component

It is generally accepted that the environmental factors can affect an individual's performance. However, there has been little research to substantiate assumptions made of environmental variables. Temperature, humidity, noise, illumination, vibration and altitude are environmental variables that have been studied.

Excessive heat and humidity can cause detrimental health effects, and low levels of heat stress can cause discomfort. Discomfort can reduce work rate as well as increase irritability, carelessness, a feeling of fatigue (Pepler, 1963), and increased accident rates (Brouha, 1967; Edholm, 1967; Belding, et al, 1961). Since many jobs require workers to perform under adverse temperature conditions, it is recommended to provide a work-rest schedule. Also, working efficiency is a function of the worker's ability to get rid of excess heat (Brouha, 1967).

Snook and Ciriello (1974) found that the hot environment significantly reduced work load, and significantly increased heart rate and rectal temperature. They reported that the work load was reduced 20% for lifting, 16% for pushing, and 11% for carrying. They concluded that, when unacclimatized man manually handles materials at his own pace, he compensates for increases in heat stress by reducing his work load. Furthermore, they reported that the amount that man reduced his work load appeared to vary, depending on the levels of heart rate and rectal temperature.

Hafez (1984) conducted a psychophysical experiment using three temperature levels: 22, 27 and 32 C WBGT, and three frequencies of lift: 0.1, 3 and 6 lifts/min. She reported that the statistical analysis of the results showed that the weights selected by the subjects at 27 C WBGT were not significantly different than the weights selected at 22 C WBGT. On the other hand, the weights selected at 32 C WBGT as well as most of the physiological responses at 32 C WBGT were significantly different from those at 22 C WBGT. The reduction in weight selected at 32 C WBGT as compared to that at 22 C WBGT was approximately 12%. She also reported that the temperature by frequency interaction affected the lifting capabilities of individuals. Generally the trend was for a decrease in weight selected as frequency and temperature increased. She claimed that the resting and working body temperature and heart rate were affected by the environmental temperature. She reported that the thermal stress induced by the environmental heat while lifting could not be assessed independently of the physiological stress.

At the other extreme, cold conditions are risky because of the clothing worn. Stability and grip strength problems arise from the use of gloves (Hertzberg, 1955).

Noise, illumination, vibration, and altitude can effect the worker physiologically and, therefore, should be considered, however, no studies have been conducted in the context of manual materials handling.

3. Psychophysical Design Criteria

3.1 Lifting Capacity Data Base

The most commonly used psychophysically based databases include Snook (1978, 1988) and Ayoub (1978) for two-handed lifting tasks (See Table 1). The method by which the data were collected is discussed here since, as previously noted, the methodology used for data collection does affect the results.

General classification of lifting height is shown in Figure 7.

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Insert Fig. 7 Classification of Lifting Height

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Table 1. Lifting Capacity Data Bases

LIFTING CAPACITY DATA BASES

SOURCE	HEIGHT	IND/POP	MALE	FEMALE	COMB.	VARIABLES
Ayoub, et al. 1978	F-K F-S F-R K-S K-R S-R	POP	M	F	--	Age, Sex, Body Weight, Shoulder Height, Abdominal Depth, Arm Strength, Back Strength, Dynamic Endurance
Snook 1978 1988	0-30 in 30-60 in 60-90 in	POP	10% 25% 50% 75% 90%	10% 25% 50% 75% 90%	--	Box Width, Vertical Distance, % of Population, Frequency

3.1.1 Liberty Mutual Data Base

Snook (1978) compiled the results of the seven manual handling studies conducted by Liberty Mutual Insurance Co. Subjects were industrial workers who participated in repetitive, dynamic work tasks that lasted for several hours. All task variables were held constant except one, usually the weight of the object. The subject was responsible for the manipulation of this independent variable according to its acceptability which was based on subjective feelings of exertion and fatigue.

In each case, industrial tote boxes with handles were lifted. Weight was adjusted by adding or subtracting lead shot to the box which was known to have a false bottom. A weight in the false bottom, which was varied randomly, was used to minimize visual cues.

Five days of training were required to allow subjects to learn to monitor feelings of exertion and fatigue as a result of object weight changes. The work task requires that the subject lift on an incentive basis such that he does not become unusually tired, weakened, overheated or out of breath.

Results of this survey are displayed in Table 2.

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insert Table 2. Snook-1978

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Snook (1988) used the same procedure to compile recent data. Table 3 displays the results.

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insert Table 3 Snook - 1988

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The MAWL for 1988's were, generally, less than the 1978's. For female, MAWL for 1988's were almost half of the 1978's. One comparison of these two data bases are shown in the Figure 8.

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Insert

Fig 8. Comparison of Liberty Mutual's 1978 and 1988 data bases.

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Table 3. Maximum acceptable weight of lift for males (kg).

Width (a)	Distance (b)	Percent (c)	Floor level to knuckle height: One lift every 5 s	9 s	14 s	1 min	2 min	5 min	30 min	8 h	Knuckle height to shoulder height: One lift every 5 s	9 s	14 s	1 min	2 min	5 min	30 min	8 h	Shoulder height to arm reach: One lift every 5 s	9 s	14 s	1 min	2 min	5 min	30 min	8 h
		90	8	11	12	15	16	20	22	23	9	12	14	14	14	17	18	19	7	10	11	13	13	16	17	18
		75	10	14	15	18	20	25	27	29	12	16	18	17	18	21	23	24	9	12	14	16	17	20	21	23
	76	50	13	17	19	22	24	30	33	36	14	19	21	21	23	27	28	30	11	15	18	20	21	25	26	28
		25	16	20	23	26	28	36	39	42	17	22	25	26	27	32	34	36	13	18	21	24	25	29	31	33
		10	18	24	26	30	32	41	45	48	19	25	29	29	31	36	39	41	14	21	24	27	29	34	36	38
		90	8	11	12	15	16	21	23	24	10	13	15	15	16	19	20	21	7	11	12	14	15	18	19	20
		75	11	14	16	19	20	26	28	31	13	17	19	20	20	24	26	27	10	14	15	18	19	22	24	25
75	51	50	14	18	20	23	25	31	34	37	15	20	23	24	25	30	32	34	12	17	19	22	23	28	30	31
		25	16	21	24	27	29	37	41	44	18	24	27	29	30	36	38	40	14	20	23	27	28	33	35	37
		10	19	24	27	31	33	42	46	50	20	27	31	33	35	41	43	46	16	23	26	31	32	38	40	43
		90	10	13	15	17	18	23	25	27	12	16	18	18	19	22	24	25	9	13	14	17	18	21	22	23
		75	13	17	19	21	23	29	32	34	15	20	22	23	24	28	30	32	11	16	18	21	22	26	28	30
	25	50	16	21	23	26	28	35	39	42	18	24	27	28	30	35	37	40	14	20	22	26	28	33	35	37
		25	19	25	28	31	33	42	46	50	21	28	32	34	35	42	45	47	17	24	27	31	33	39	41	44
		10	22	29	32	35	38	48	52	57	24	32	36	39	41	48	51	54	19	27	31	36	38	45	48	50
		90	9	12	13	16	17	22	24	26	9	12	14	14	14	17	18	19	7	10	11	13	13	16	17	18
		75	12	15	17	21	22	28	31	34	12	16	18	17	18	21	23	24	9	12	14	16	17	20	21	23
	76	50	15	19	21	26	28	35	39	42	14	19	21	21	23	27	28	30	11	15	18	20	21	25	26	28
		25	17	23	26	31	33	42	46	50	17	22	25	26	27	32	34	36	13	18	21	24	25	29	31	33
		10	20	26	30	36	38	49	53	58	19	25	29	29	31	36	39	41	14	21	24	27	29	34	36	38
		90	9	12	14	17	18	23	25	27	10	13	15	15	16	19	20	21	7	11	12	14	15	18	19	20
		75	12	16	18	22	23	30	32	35	13	17	19	20	20	24	26	27	10	14	15	18	19	22	24	25
49	51	50	15	20	22	27	29	37	40	43	15	20	23	24	25	30	32	34	12	17	19	22	23	28	30	31
		25	18	24	27	32	35	44	48	52	18	24	27	29	30	36	38	40	14	20	23	27	28	33	35	37
		10	21	27	31	37	40	51	55	60	21	27	31	33	35	41	43	46	16	23	26	31	32	38	40	43
		90	11	14	16	19	20	26	28	31	12	16	18	18	19	22	24	25	9	13	14	17	18	21	22	23
		75	14	18	21	24	26	33	36	39	15	20	22	23	24	28	30	32	11	16	18	21	22	26	28	30
	25	50	18	23	26	30	33	41	45	49	18	24	27	28	30	35	37	40	14	20	22	26	28	33	35	37
		25	21	28	31	36	39	49	54	59	21	28	32	34	35	42	45	47	17	24	27	31	33	39	41	44
		10	25	32	36	42	45	57	62	67	24	32	36	39	41	48	51	54	19	27	31	36	38	45	48	50
		90	10	13	15	18	19	24	26	29	10	13	15	14	15	18	19	20	7	10	12	13	14	16	17	19
		75	13	17	20	23	25	31	34	37	13	17	19	18	20	23	24	26	9	13	15	17	18	21	23	24
	76	50	17	22	25	29	31	39	43	46	15	20	23	23	24	29	30	32	11	16	19	21	22	27	28	30
		25	20	27	30	34	37	47	51	55	18	23	26	28	29	34	37	39	14	19	23	26	27	32	34	36
		10	24	31	35	40	42	54	59	64	20	26	30	32	34	40	42	45	16	22	26	30	31	37	39	41
		90	10	14	15	18	20	25	27	30	11	14	16	16	17	20	21	22	8	11	13	15	16	18	20	21
		75	14	18	20	24	26	32	36	38	13	18	20	21	22	26	27	29	10	15	16	19	20	24	25	27
36	51	50	17	23	26	30	32	40	44	48	16	21	24	26	27	32	34	36	13	18	20	24	25	30	32	34
		25	21	28	31	36	38	49	53	57	19	25	28	31	33	39	41	44	15	22	25	29	30	36	38	40
		10	24	32	36	41	44	56	61	66	21	28	32	36	38	44	47	50	18	25	28	33	35	41	44	47
		90	12	16	18	21	22	28	31	33	13	17	19	19	20	23	25	26	9	13	15	18	18	22	23	25
		75	16	21	24	27	29	37	40	43	16	21	24	24	26	30	32	34	12	17	19	23	24	28	30	32
	25	50	20	27	30	34	36	46	50	54	19	25	28	31	32	38	40	43	15	22	24	28	30	35	37	40
		25	25	32	36	40	43	55	60	65	22	29	33	37	38	45	48	51	18	26	29	34	36	42	45	48
		10	29	37	42	46	50	63	69	75	25	33	38	42	44	52	56	59	21	30	33	39	41	49	52	55

(a) Width of object away from body (cm).
(b) Vertical distance of lift (cm).
(c) Percent of industrial population.

Table 2. Maximum acceptable weight of lift for females (kg)

Width (a)	Distance (b)	Percent (c)	Floor level to knuckle height								Knuckle height to shoulder height								Shoulder height to arm reach							
			One lift every								One lift every								One lift every							
			5	9	14	1	2	5	30	8	5	9	14	1	2	5	30	8	5	9	14	1	2	5	30	8
				s			min			h		s			min			h		s			min			h
		90	6	8	9	11	12	15	16	17	8	10	10	10	10	12	12	13	5	8	9	9	9	11	12	12
		75	8	10	11	13	13	17	19	20	8	11	11	11	12	14	15	15	5	9	9	10	10	12	13	14
	76	50	9	12	13	14	15	20	21	23	9	12	12	13	13	16	17	18	6	9	10	11	11	13	14	15
		25	10	13	15	16	17	22	24	26	10	13	13	14	15	18	19	20	6	10	11	12	13	15	16	17
		10	11	15	17	18	19	25	27	29	11	14	14	16	17	20	21	22	7	11	12	13	14	16	17	18
		90	7	9	10	11	12	15	17	18	8	11	11	11	11	13	14	15	5	9	10	10	10	12	13	14
		75	8	10	12	13	14	18	19	21	9	12	12	12	13	15	16	17	6	10	11	11	12	14	15	15
75	51	50	9	12	14	15	16	20	22	24	10	13	13	14	15	18	19	20	6	11	12	12	13	15	16	17
		25	10	14	15	17	18	23	25	27	11	14	14	16	17	20	21	22	7	12	13	13	14	17	18	19
		10	12	15	17	19	20	25	28	30	12	15	15	18	19	22	23	25	8	12	14	15	15	18	19	20
		90	8	10	11	13	14	17	19	20	9	12	12	13	13	16	17	18	6	10	11	12	12	14	15	16
		75	9	12	14	15	16	20	22	24	11	14	14	15	15	18	19	20	7	11	13	13	14	16	17	18
	25	50	11	14	16	17	18	23	25	27	12	15	15	17	18	21	22	23	8	13	14	14	15	18	19	20
		25	12	16	18	19	20	26	28	31	13	17	17	19	20	23	25	26	8	14	15	16	17	20	21	22
		10	14	18	20	21	23	29	32	34	14	18	18	21	22	26	28	29	9	15	16	17	18	21	23	24
		90	7	9	11	13	14	17	19	20	8	10	10	10	10	12	12	13	5	8	9	9	9	11	12	12
		75	9	11	13	15	16	20	22	24	8	11	11	11	12	14	15	15	5	9	9	10	10	12	13	14
	76	50	10	13	15	17	18	23	25	27	9	12	12	13	13	16	17	18	6	9	10	11	11	13	14	15
		25	11	15	17	19	20	26	28	31	10	13	13	14	15	18	19	20	6	10	11	12	13	15	16	17
		10	13	17	19	21	23	29	31	34	11	14	14	16	17	20	21	22	7	11	12	13	14	16	17	18
		90	7	10	11	13	14	18	20	21	8	11	11	11	11	13	14	15	5	9	10	10	10	12	13	14
		75	9	12	13	15	16	21	23	25	9	12	12	12	13	15	16	17	6	10	11	11	12	14	15	15
49	51	50	10	13	15	17	19	24	26	28	10	13	13	14	15	18	19	20	6	11	12	12	13	15	16	17
		25	12	15	17	20	21	27	29	32	11	14	14	16	17	20	21	22	7	12	13	13	14	17	18	19
		10	13	17	19	22	23	30	33	35	12	15	15	18	19	22	23	25	8	12	14	15	15	18	19	20
		90	9	11	13	15	16	20	22	24	10	13	13	13	13	16	17	18	6	10	11	12	12	14	15	16
		75	10	14	15	17	18	23	26	28	11	14	14	15	15	18	19	20	7	11	13	13	14	16	17	18
	25	50	12	16	18	20	21	27	29	32	12	15	15	17	18	21	22	23	8	13	14	14	15	18	19	20
		25	14	18	20	22	24	30	33	36	13	17	17	19	20	23	25	26	8	14	15	16	17	20	21	22
		10	15	20	23	25	26	34	37	40	14	18	18	21	22	26	28	29	9	15	16	17	18	21	23	24
		90	8	11	12	14	15	19	21	22	8	10	10	10	11	13	13	14	5	8	9	9	10	12	13	13
		75	10	13	14	16	17	22	24	26	9	12	12	12	12	15	16	17	6	9	10	11	11	13	14	15
	76	50	11	15	17	19	20	25	28	30	10	13	13	14	14	17	18	19	6	10	11	12	12	15	15	16
		25	13	17	19	21	22	28	31	34	11	14	14	15	16	19	20	21	7	11	12	13	13	16	17	18
		10	15	19	21	23	25	32	35	37	12	15	15	17	18	21	22	24	7	12	13	14	15	17	18	19
		90	9	11	13	14	15	20	22	23	8	11	11	11	12	14	15	16	6	9	10	11	11	13	14	15
		75	10	13	15	17	18	23	25	27	9	12	12	13	14	17	18	19	6	10	11	12	12	15	16	17
36	51	50	12	16	17	19	21	26	29	31	10	14	14	15	16	19	20	21	7	11	13	13	14	16	17	18
		25	14	18	20	22	23	30	32	35	11	15	15	17	18	21	23	24	8	12	14	14	15	18	19	20
		10	15	20	22	24	26	33	36	39	12	16	16	19	20	24	25	27	8	13	15	16	16	19	21	22
		90	10	13	15	16	18	22	24	26	10	13	13	14	14	17	18	19	7	11	12	13	13	16	17	18
		75	12	16	18	19	20	26	28	31	11	15	15	16	16	19	21	22	8	12	14	14	15	17	19	20
	25	50	14	18	20	22	23	30	32	35	12	16	16	18	19	22	24	25	8	14	15	16	16	19	21	22
		25	16	21	23	25	26	33	37	40	13	18	18	20	21	25	27	29	9	15	16	17	18	21	23	24
		10	18	23	26	27	29	37	41	44	15	19	19	23	24	28	30	32	10	16	17	18	19	23	24	26

(a) Width of object away from body (cm).
(b) Vertical distance of lift (cm).
(c) Percent of industrial population.

Table 3 for males and females was not legible in the original copy.

3.1.2 Texas Tech Data Base

Ayoub, et al., (1978) conducted a study similar to Snook's to determine and model the lifting capacity of male female industrial workers. Seventy-three male and 73 female subjects lifted a box (width X depth X length in inches - 12 X 7 X 12, 12 X 7 X 18, 12 X 7 X 24), using six different height levels and four frequencies (2, 4, 6, and 8 lifts/minute). Height levels include: (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 defined in Table 4.

Table 4 Lifting Range Assignment (KL = Knuckle Level)

Point of Lift Initiation (inches)	Point of Lift Termination (inches)	Range Assignment*
0 to KL/2	0 to KL + 10	1
	Kl + 10 to KL + 30	2
	KL + 30 and Above	3
KL/2 to KL	KL/2 to KL	1
	KL to KL + 30	4
	KL + 30 and Above	5
KL to KL + 10	KL to KL + 30	4
	KL + 30 and Above	5
KL + 10 to KL + 20	KL + 10 to KL + 20	4
	KL + 20 and Above	6
KL + 20 and Above	KL + 20 and Above	6

Source: Ayoub et al., 1978.

* Range 1 = floor to knuckle, 2 = floor to shoulder, 3 = floor to reach, 4 = knuckle to shoulder, 5 = knuckle to reach, 6 = shoulder to reach.

Unique to Texas Tech's data, is that there are capacity adjustments based on sex, box size, population percentage, and ranges of motion which are based on the six different height levels. Mathematical equations were fitted to the data and a sample output is presented in Table.

****

insert Table 5 from NIOSH Table 5.7

****

3.1.3 Comprehensive (combined) Data Base

Mital (1984) created a database for the maximum acceptable weight of lift for both male and female industrial workers for shifts of eight hours. Mital (1984) then compared his data with data collected by Snook (1978) and Ayoub, et al., (1978). Since all data was compatible, Mital (1984) was able to integrate all the data into a comprehensive database (see Tables 6 and 7.).

****

insert Tables 6 and 7

****

The above data bases have some limitations. First, the acceptable range of frequency of lift is between 0.1 and 12 lifts/minute. The lower limit was chosen arbitrarily because at some as yet undetermined point (approximately 0.1 lifts/min) the capacity of lift becomes equivalent to the one-time maximum capacity of lift. Therefore, at very low frequencies of lift it becomes meaningless to make adjustments in capacity of lift based on frequency.

The second limitation is that they fail to take into account the effects of twisting while lifting and the presence or absence of container handles on capacity of lift. However, the findings

Table 5 : Maximum recommended weights based on dynamic strength (Kg.)

Height of Lift	Horz. (cm)	Freq. (lift/min)	Female 25%ile	Female 50%ile	Male 50%ile	Male 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 (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

Table 6 Comprehensive data base for the maximum weight (kg) acceptable to male industrial workers for 8-hours of lifting

		Frequency of lift (lifts per minute)											
		1			4			8			12		
	Box size (cm)	30·48	45·72	60·96	30·48	45·72	60·96	30·48	45·72	60·96	30·48	45·72	60·96
Floor to	$\bar{X}$	20·56	18·21	17·22	16·81	16·38	14·99	15·10	13·72	13·33	12·28	10·93	10·05
knuckle height	S	8·56	7·78	7·78	6·70	9·46	7·47	7·83	6·29	5·16	5·45	3·89	3·89
Knuckle to	$\bar{X}$	16·82	18·65	15·13	15·08	16·53	13·75	13·30	13·84	11·62	11·23	10·77	10·21
shoulder height	S	7·00	6·23	6·23	7·09	8·74	7·47	5·39	5·34	7·29	3·89	3·89	3·89
Shoulder to	$\bar{X}$	15·48	13·99	14·36	14·32	12·97	12·50	11·06	11·12	11·40	8·95	8·44	8·64
reach height	S	7·00	5·45	5·45	6·52	5·32	4·99	3·85	4·12	4·12	3·89	2·33	2·47

Note: $\bar{X}$ = Mean, S = Standard deviation.

Table 7 Comprehensive data base for the maximum weight (kg) acceptable to female industrial workers for 8-hours of lifting

		Frequency of lift (lifts per minute)											
		1			4			8			12		
	Box size (cm)	30·48	45·72	60·96	30·48	45·72	60·96	30·48	45·72	60·96	30·48	45·72	60·96
Floor to	$\bar{X}$	15·70	14·17	12·60	12·88	10·70	10·72	10·90	9·52	9·25	9·24	8·65	8·30
height knuckle	S	3·11	3·11	3·11	3·47	4·89	2·74	3·76	2·07	2·67	3·11	2·88	2·72
Knuckle to	$\bar{X}$	11·88	11·26	10·78	10·92	10·78	10·07	9·83	9·37	8·83	8·54	7·91	7·78
shoulder height	S	2·33	2·73	2·38	2·09	2·38	3·21	3·62	3·03	2·35	1·55	2·04	2·31
Shoulder to	$\bar{X}$	10·44	9·28	9·41	9·17	8·53	8·68	7·62	7·32	6·82	6·09	5·77	5·92
reach height	S	2·05	1·61	1·55	2·09	1·48	1·82	2·17	2·14	2·39	1·03	1·55	1·26

Note: $\bar{X}$ = Mean, S = Standard deviation.

Adapted from Mital (1984)

of other researchers can provide adjustment factors based on these variables.

3.2 Models to Predict Lifting Capacity

The databases described above provide the necessary information needed to develop lifting capacity models. Listed are several lifting capacity models which have been reported in the literature.

Some models allow for capacity adjustments for a chosen population percentage. Other models allow for capacity predictions for the individual. Because different methodologies were used to collect data, it is not appropriate to combined results, or to recommend a particular set of data. It is suggested to adopt recommendations that most closely resemble the experimental lifting conditions. Table 8 gives a list of lifting capacity data and table 9 gives a list of models for lifting capacity estimation.

Table 8.

LIFTING CAPACITY TABLE

SOURCE	HEIGHT	IND/POP	MALE	FEMALE	COMB.	VARIABLES
ILO 1962	----	POP	M	F	--	Age
Ayoub, et al. 1978	F-K F-S F-R K-S K-R S-R	POP	M	F	--	Age, Sex, Body Weight, Shoulder Height, Abdominal Depth, Arm Strength, Back Strength, Dynamic Endurance

Snook 1978 1988	0-30 in 30-60 in 60-90 in	POP	10% 25% 50% 75% 90%	10% 25% 50% 75% 90%	--	Box Width, Vertical Distance, % of Population, Frequency
Mital 1984	F-K K-S	POP	50%	50%	--	Box Size, Frequency, Lifting Range
Khalil et al. 1985	F-K F-S K-S	POP	M	--	--	Lifting Range, Frequency

Table 9.

LIFTING CAPACITY MODELS

SOURCE	HEIGHT	IND/POP	MALE	FEMALE	COMB.	VARIABLES
McConville & Hertzberg 1966	F-K	POP	M	--	--	Box Width
Poulsen 1970	F-TAB TAB-HEAD	IND	--	--	C	Back Strength, Body Weight, Arm Push (left & right) * (One-hand Lifting)
Poulsen & Jorgensen 1971	F-TAB	IND	M	F	--	Back Strength
McDaniel 1972	F-K	IND	M	F	C	Sex, Height, RPI, Fitness Index, Static Endurance, Dynamic Endurance, Static Effect, Arm Strength, Back Strength, Leg Strength
Dryden 1973	K-S	IND	M	F	C	Height, RPI, Chest Circumference, Fitness Index, Fat % Static Effect, Dynamic Effect, Dynamic Endurance
Knipfer 1974	S-R	IND	M	F	C	Age, Sex, Body Weight, Forearm Circumference, Dynamic Effect, Back Strength, Shoulder Strength, Horizontal Pushing Strength

Ayoub, et al. 1978	F-K F-S F-R K-S K-R S-R	IND	M	F	--	Age, Sex, Body Weight, Shoulder Height, Abdominal Depth, Arm Strength, Back Strength, Dynamic Endurance
Mital, et al. 1978	F-K F-S F-R K-S K-R S-R	IND	M	F	--	Age, Sex, Shoulder Height, Abdominal Depth, Arm Strength, Back Strength, Dynamic Endurance
NIOSH 1981	0-70 in	POP	25% 99%	1% 75%	-- --	Box Width, Horizontal Loc. Vertical Loc. Vertical Travel Distance, Frequency
Asfour 1980	F-K K-S	IND	M	--	--	Body Weight, Box Length, Box Width, Frequency, Vertical Distance, Twist Angle
Garg 1980	---	IND	M	--	--	Max. Isometric Strength, 3 sec MAWL Static vertical lift strength
Pytel & Kamon 1981	F-113 cm	IND	M	F	--	Sex, Dynamic lift strength, Dynamic back extension strength Dynamic Elbow flexion strength
Kamon, Kiser, & Pytel 1982	F-113 cm	IND	M	--	--	Elbow flexion (one), Elbow flexion (two)

Ayoub, et al. 1982	F-K F-S F-R	POP				Six-ft Lift
Aghazadeh 1983	F-S K-S	IND	M	--	--	Container Code (Box or Bag) Frequency, Shoulder strength, Leg strength
Ayoub, et al. 1984	F-K F-S F-R K-S K-R S-R	POP	ALL	ALL	--	Sex, Body Weight, Frequency, Box Size, Population %
Jiang 1984	F-K K-S	IND	M	--	--	Six-ft Lift, Back Strength
Karwowski & Ayoub 1984	F-K	POP IND	M M	-- --	-- --	Frequency, Age, Body Weight, Shoulder Strength
Aghazadeh, Ayoub 1985	F-S K-S	IND	M	--	--	Lifting height, Frequency, Dynamic Strength, Shoulder Strength, Leg Strength
Asfour et al. 1985	F-K F-S K-S ALL	POP	M	--	--	Frequency
Ayoub et al. 1986	F-K F-S F-R K-S K-R S-R	IND	--	--	C	Shoulder Height, Abdominal Depth, Arm Strength, Back Strength, Dynamic Endurance, Frequency, Box size,
Khalil et al. 1987	ALL	IND	M	F	--	Maximum Acceptable Effort, Sex, Frequency, Body Posture

where,

F-K = Floor to Knuckle Height
F-S = Floor to Shoulder Height
F-R = Floor to Reach Height
K-S = Knuckle to Shoulder Height
K-R = Knuckle to Reach Height
S-R = Shoulder to Reach Height
F-TAB = Floor to Table Height
TAB-HEAD = Table to Head Height

IND = Lifting Capacity Model for Individual
POP = Lifting Capacity Model for Population
M = Male
F = Female
C = Combined male and female

-- = Undecided or Not applicable

3.2.1 Lifting Capacity Models for Population

There are few lifting capacity models for population. The model developed by McConville and Hertzberg (1966) has only one variable which is box size. The model by NIOSH (1981) is only for AL and MPL. The models developed by Karwowski and Ayoub (1984) and Asfour and et al. (1985) has only one variable which is frequency. These models may not be useful for general model for population. The model developed by Ayoub and et al. (1983) is the only one general model for population thus far. The following section will discuss the use of Ayoub et al.'s model.

3.2.1.1 Ayoub's Model

Ayoub (1983) offers the models for population percentile capacity estimations. Ayoub combined the data bases of Ayoub, et al., (1978) and Snook (1978) and used regression analysis to determine predicted population lifting capacity based on frequency of lift, container size, sex, and population percentage for six ranges of lift. A free-style method of lift was assumed. In using the models, capacity of lift for the six ranges of lift is first predicted based on frequency of lift as shown in Table 10. These predicted capacities are then adjusted base on container size as shown in Table 11. Finally, the predicted capacities are adjusted based on the population percentage of interest as shown in Table 12. Table 13 lists the z-scores corresponding to several population percentages.

As an example of the use of these equations, suppose you wished to determine the capacity of lift given the following:

Sex = Male
Population Percentage = 95% population (or 5th percentile)
Range of Lift = From 0 to 57 inch height (F-S)
Frequency = 2 lifts/min
Box Size = 16 inch (40.64 cm) in sagittal plane

From table 10, 11, 12, 13

$$\begin{aligned} \text{Cap (F-S)} &= 23.3 - 0.91 * (FY - 1) + 0.30 * (46 - BX) \\ &\quad + Z * (6.86 - 0.24 * (FY - 1)) \\ &= 23.3 - 0.91 * (2 -1) + 0.30 * (46 - 40.64) \\ &\quad + (-1.6449) * (6.86 - 0.24 * (2 - 1)) \\ &= 13.1 \text{ kg} \end{aligned}$$

****
Insert Table 10, 11, 12, 13

Table 10. Adjustment of Prediction Equation for Lifting Capacity Based on Frequency of Lift.

Table 11. Adjustment of Lifting Capacity Based on Container Size.

Table 12. Adjustment of Lifting Capacity Based on Standard Deviation and Frequency.

Table 13. Z-scores for Various Population Percentages.

****

Table 10 Capacity Prediction Equations for Lifting Capacity Based on Frequency of Lift

	Frequency of Lift (FY) (lifts/min)			
Range of Lift[a]	0.1 < FY < 1.0	(Eq.)	1.0 < FY < 12.0	(Eq.)
	Male Capacity			
[illegible]	$26.0^{*}FY^{-[illegible]}$	1	26.0 − 0.91(FY − 1)	7
[illegible]	$23.3FY^{-[illegible]}$	2	23.3 − 0.91(FY − 1)	8
[illegible]	$22.4FY^{-[illegible]}$	3	22.4 − 0.91(FY − 1)	9
[illegible]	$23.3FY^{-[illegible]}$	4	23.3 − 0.91(FY − 1)	10
[illegible]	$22.7FY^{-[illegible]}$	5	22.7 − 0.91(FY − 1)	11
[illegible]	$22.0FY^{-[illegible]}$	6	22.0 − 0.91(FY − 1)	12
	Female Capacity			
[illegible]	$17.0^{*}FY^{-[illegible]}$	13	17.0 − 0.5(FY − 1)	19
[illegible]	$14.1FY^{-[illegible]}$	14	14.1 − 0.5(FY − 1)	20
[illegible]	$12.8FY^{-[illegible]}$	15	12.8 − 0.5(FY − 1)	21
[illegible]	$14.0FY^{-[illegible]}$	16	14.0 − 0.5(FY − 1)	22
[illegible]	$12.4FY^{-[illegible]}$	17	12.4 − 0.5(FY − 1)	23
[illegible]	$12.0FY^{-[illegible]}$	18	12.0 − 0.5(FY − 1)	24

[a] F = floor; K = knuckle; R = reach; S = shoulder.

[illegible] capacity for lift based on data from Ayoub et al. (1978) and [illegible] for various ranges of lift for the 50th percentile and 1.0 lift/min. [illegible] Ayoub et al. [illegible] A design guide for manual lifting. OSHA. Reprinted with permission.

Table 11 Adjustment of Lifting Capacity Based on Box Size

	Box Size (BX) in Sagittal Plane[a] (CM)			
Lift	31 ≤ BX ≤ 46	(Eq.)	BX 46	(Eq.)
	Male Capacity			
	CAP + 0.30(46 − BX)	1	CAP + 0.14(46 − BX)	7
	CAP + 0.30(46 − BX)	2	CAP + 0.14(46 − BX)	8
	CAP + 0.30(46 − BX)	3	CAP + 0.14(46 − BX)	9
	CAP + 0.20(46 − BX)	4	CAP + 0.14(46 − BX)	10
	CAP + 0.20(46 − BX)	5	CAP + 0.14(46 − BX)	11
	CAP + 0.20(46 − BX)	6	CAP + 0.14(46 − BX)	12
	Female Capacity			
	CAP + 0.2(46 − BX)	13	CAP + 0.07(46 − BX)	19
	CAP + 0.2(46 − BX)	14	CAP + 0.07(46 − BX)	20
	CAP + 0.2(46 − BX)	15	CAP + 0.07(46 − BX)	21
	CAP + 0.10(46 − BX)	16	CAP + 0.04(46 − BX)	22
	CAP + 0.10(46 − BX)	17	CAP + 0.04(46 − BX)	23
	CAP + 0.10(46 − BX)	18	CAP + 0.04(46 − BX)	24

Ayoub et al. (1983). *A design guide for manual lifting.* OSHA. Reprinted with permission.
Capacity of lift as determined in Table 7.2.5.

Table 12 **Adjustment of Lifting Capacity Based on Standard Deviation and Frequency**

	Frequency (FY)		
Range of Lift	0.1 ≤ FY < 1.0	(Eq.)	1.0 ≤ FY ≤ 12.0
	Male Capacity		
F-K	CAP + Z·7.66FY[illegible]	1	CAP + Z[7.66 [illegible]
F-S	CAP + Z·6.86FY[illegible]	2	CAP + Z[6.86 [illegible]
F-R	CAP + Z·6.58FY[illegible]	3	CAP + Z[6.58 [illegible]
K-S	CAP + Z·6.67FY[illegible]	4	CAP + Z[6.67 [illegible]
K-R	CAP + Z·6.31FY[illegible]	5	CAP + Z[6.31 [illegible]
S-R	CAP + Z·6.11FY[illegible]	6	CAP + Z[6.11 [illegible]
	Female Capacity		
F-K	CAP + Z·3.12FY[illegible]	13	CAP + Z[3.12 [illegible]
F-S	CAP + Z·2.60FY[illegible]	14	CAP + Z[2.60 [illegible]
F-R	CAP + Z·2.35FY[illegible]	15	CAP + Z[2.35 [illegible]
K-S	CAP + Z·2.57FY[illegible]	16	CAP + Z[2.57 [illegible]
K-R	CAP + Z·2.28FY[illegible]	17	CAP + Z[2.28 [illegible]
S-R	CAP + Z·2.20FY[illegible]	18	CAP + Z[2.20 [illegible]

Source: Ayoub et al. (1983). *A design guide for manual lifting.* OSHA. Reprinted with permission.

TABLE 13

Z-SCORES FOR VARIOUS POPULATION PERCENTAGES

Population Percentage	Z-score
95	-1.6449
90	-1.2816
85	-1.0364
75	-0.6745
50	0.0
25	0.6745
15	1.0364
10	1.2816
5	1.6449

3.2.2 Lifting Capacity Models for an Individual

Even though there are many lifting capacity models, presently, there exist only two models to predict individual lifting capacity for all lifting ranges based on psychophysical data. These are Ayoub's and Mital's.

To utilize these models following measurements are taken: 1) arm strength, 2) shoulder strength, 3) back strength, 4) abdominal strength, and 4) dynamic endurance. These measurements are used in conjunction with regression coefficients given in Table 14. The following is an example of procedure used to determine an individual's lifting capacity according to Ayoub, et al., (1978).

3.2.2.1 Ayoub's Model (1978 AND 1986)

Predicted Lifting Capacity for Individual (lbs) - (1978)

TABLE 14

Regression Coefficients for Maximum Acceptable Weight of Lift plus Body Weight (kg) for Both Males and Females *

Regression Terms	Lifting Ranges F-K	F-S	F-R	K-S	K-R	S-R
Constant Term	-32.733	-65.958	-18.718	-25.020	-35.921	-16.982
Sex Code	-12.852	-7.332	-8.824	-8.370	-8.581	-8.883
Weight Code	10.996	5.410	7.337	5.307	7.835	9.232

Arm Strength	0.143	0.185	0.210	0.265	0.297	0.096
Age	-0.251	-0.271	-0.382	-0.275	-0.226	-0.269
Shoulder Height	0.556	0.652	0.344	0.348	0.042	0.402
Back Strength	0.056	0.077	0.068	0.105	0.018	0.099
Abdominal Depth	2.229	2.936	2.821	2.853	2.338	2.146
Dynamic Endurance	0.797	1.183	0.647	0.642	0.962	0.494

* Adjusted to 5 lifts/min, box size of 45.72 cm in sagittal plane

where,

SEX_CODE = 0 for Male
1 for Female
AGE = years
BW_CODE = 0 if body weight is equal to or below the median
1 if body weight is above the median
Median body weight = 61.23 kg for females
77.11 kg for males
SHOULDER_HT = shoulder height in cm
ABDO-DEPTH = abdominal depth in cm
ARM_ST = arm strength in kg

BACK_ST = back strength in kg
DYNAMIC_END = dynamic endurance in minutes.

<Example> Prediction of the lifting capacity from floor to knuckle (FK) height of an individual with the following data.

Sex = Male (SEX_CODE = 0)
Body Weight = 81.65 kg (BW_CODE = 1)
Age = 30 Years (AGE = 30)
Arm Strength = 40.82 kg (ARM_ST = 40.82)
Shoulder Height = 150 cm (SHOULDER_HT = 150)
Back Strength = 65.77 kg (BACK_ST = 65.77)

Abdominal Depth = 20 cm (ABDO_DEPTH = 20 cm)
Dynamic Endurance = 2 min (DYNAMIC_END = 2)
Frequency = 6 lifts/min

```
Cap (F-K) = - 32.733 - BW
            - 12.852 * SEX_CODE - 0.251 * AGE + 10.996 * BW_CODE
            + 0.556 * SHOULDER_HT + 2.229 * ABDO_DEPTH
            + 0.143 * ARM_ST + 0.056 * BACK_ST + 0.797
            *  DYNAMIC_END
          = - 32.733 - 81.65
            - 12.852 * 0 - 0.251 * 30 + 10.996 * 1
            + 0.556 * 150 + 2.229 * 20
            + 0.143 * 40.82 + 0.056 * 65.77 + 0.797 * 2
          = 28.18 kg
```

Predicted Lifting Capacity for Individual - (1986)

TABLE 15

REGRESSION COEFFICIENTS FOR MAXIMUM ACCEPTABLE WEIGHT OF LIFT PLUS BODY WEIGHT (kg) FOR BOTH MALES AND FEMALES *

Regression Terms	Lifting Ranges F-K	F-S	F-R	K-S	K-R	S-R
Constant Term	-101.17	-115.83	-96.62	-83.47	-94.30	-96.59
Arm Strength	0.232	0.097	0.014	0.208	0.253	0.011
Shoulder Height	0.804	0.863	0.710	0.620	0.730	0.794
Back Strength	0.266	0.220	0.268	0.244	0.172	0.221
Abdominal Depth	2.707	3.138	3.264	3.077	2.854	2.746
Dynamic Endurance	0.640	1.370	0.134	0.164	0.541	0.246

* Adjusted to 5 lifts/min., box size of 18 inches in sagittal plane

<Example> Prediction of the lifting capacity from floor to knuckle (FK) height of an individual with the following data.

Body Weight = 81.65 kg (BW_CODE = 1)
Arm Strength = 40.82 kg (ARM_ST = 40.82)
Shoulder Height = 150 cm (SHOULDER_HT = 150)
Back Strength = 65.77 kg (BACK_ST = 65.77)
Abdominal Depth = 20 cm (ABDO_DEPTH = 20 cm)
Dynamic Endurance = 2 min (DYNAMIC_END = 2)
Frequency = 6 lifts/min

```
Cap (F-K) = - 101.17 - BW
            + 0.804 * SHOULDER_HT + 2.707 * ABDO_DEPTH
            + 0.232 * ARM_ST + 0.266 * BACK_ST + 0.640 *
              DYNAMIC_END
          = - 101.17 - 81.65
            + 0.804 * 150 + 2.707 * 20
            + 0.232 * 40.82 + 0.266 * 65.77 + 0.640 * 2
          = 20.17 kg
```

3.2.2.2 Jiang's Model (1987)

Jiang (1984) developed a prediction model for individual and combined MMH activities. MMH capacity was defined as the maximum amount of weight that a subject will handle plus his body weight for a duration of one hour. Three different MMH frequencies were used, 1 handling per hour, 1 handling per minute, and 6 handlings per minute. Jiang (1984) used the isoinertial six feet weight incremental lifting test and the isometric back strength test to predict individual capacity. He developed prediction models for combined MMH capacities using a limiting individual lifting capacity as a predictor.

Jiang and Ayoub (1987) developed a model to predict a person's MAL (Maximum Acceptable Load of Lifting) for given task conditions (frequency and range of lift), and described the individual's physical characteristics in terms of strength and anthropometric scores. They claimed that the advantage of the factor-score-based model lay in its providing a more explainable and meaningful structure for determining a worker's MAL, and in its describing a person's physical characteristics by use of simple factors with quantitative scores. They also insisted that their model allows the use of a single model to predict MAL for all six different ranges of lift and for both genders.

Following is an example of the use of their model.

Jiang and Ayoub's Model (1987)

$$MAWL = C + 0.238 * STR + 1.595 * ANT - 0.303 * FREQ - BW$$
$$STR = 0.211 * SHO + 0.212 * ARM + 0.216 * BACK + 0.225 * LEG + 0.226 * COM$$
$$ANT = 0.483 * BW + 0.561 * ABD$$

where,

STR = Strength Score
SHO = Shoulder Strength (Kg)
ARM = Arm Strength (Kg)
BACK = Back Strength (Kg)
LEG = Leg Strength (Kg)
COM = Composite Strength (Kg)
ANT = Anthropometric Score
BW = Body Weight (Kg)
ABD = Abdominal Depth (cm)
FREQ = Frequency of Lifting (lifts/min)
C = Constant

Floor to Knuckle	2.962
Floor to Shoulder	0.697
Floor to Reach	-0.952
Knuckle to Shoulder	1.708
Knuckle to Reach	-1.232
Shoulder to Reach	-2.705

<Example> Prediction of Maximum Acceptable Weight of Load

Age = 30 Years
Floor to Knuckle Height Lifting
Body Weight = 81.65 Kg
Shoulder Strength = 39.15 Kg (SHO = 39.15)
Arm Strength = 30.47 Kg (ARM = 30.47)
Back Strength = 60.56 Kg (BACK = 60.56)
Leg Strength = 105.80 Kg (LEG = 105.80)
Composite Strength = 89.10 (COM = 89.10)
Abdominal Depth = 20 cm (ABD = 20)

```
STR = 0.211 * SHO + 0.212 * ARM + 0.216 * BACK + 0.225 * LEG
      + 0.226 * COM
    = 0.211 * 39.15 + 0.212 * 30.47 + 0.216 * 60.56
      + 0.225 * 105.80 + 0.226 * 89.10
    = 71.74

ANT = 0.483 * BW + 0.561 * ABD
    = 0.483 * 81.65 + 0.561 * 20
    = 50.66

MAWL = C + 0.238 * STR + 1.595 * ANT - 0.303 * FREQ - BW
     = 2.962 + 0.238 * 71.74 + 1.595 * 50.66 - 0.303 * 6
       - 81.65
     = 17.37 Kg
```

3.2.2.3 Garg's Model (1980)

Garg, et al. (1980) developed a lifting capacity model such that a single strength is assessed, static or dynamic.

The simplicity of the form is attractive, although they discovered that static vertical lift strength measured at the origin of the lift may lead to an underestimation of dynamic lifting capacity. It is suggested that specific static strength tests be constructed to accurately estimate a person's dynamic strength.

```
(1).  T1  =  22.6 + 1.02  * T2        (R-SQUARE = 0.48)
          =  27.5 + 0.299 * T3        (R-SQUARE = 0.56)
          = - 2.1 + 1.49  * T4        (R-SQUARE = 0.79)
```

(2). T5 = 20.0 + 0.473 * T2 (R-SQUARE = 0.56)

Where,
T1 = Maximum acceptable weight from the psychophysical methodology (dynamic lifting strength, Kg)
T2 = Maximum Voluntary Isometric Strength at the origin of lift (Kg)
T3 = Static Vertical lift strength close to the body
T4 = Maximum acceptable weight that a subject could hold for 3 seconds
T5 = Maximum acceptable weight with a slow vertical lift

3.2.4 Aghazadeh (1983)

Aghazadeh (1983) studied the relationship between box/bag lifting capacity and subject's strength test. Three task related variables and five operator related variables were studied. Task variables were container type (bag or box), frequency of lift (2 or 6 lifts/min) and lifting ranges (F-S and K-S). Operator related variables were static strength (arm, stooped back, standing back, composite, shoulder and leg), dynamic strength measured from Cybex (F-S and K-S), endurance (static and dynamic), PWC, subject's height and weight. Nine dynamic models and nine static models were developed. Both static models and dynamic models could predict the maximum acceptable lifting capacity with a reasonable degree of accuracy (R-square with the range of 0.452 to 0.862). However, the use of the dynamic models reduced the absolute error between the actual and predicted load up to 44% as compared to the static models. A single dynamic model involving only one operator strength measure was thus found to be a good predictor of lifting capacity.

Aghazadeh (1983)

Prediction models for the Maximum Acceptable Weight of Lift (MAWL) using static strength test.

Table 16. Prediction Models for the MAWL (Kg) using Static Strength

MODEL CODE	CONSTANT COEFF.	CONTAINER COEFF.	LIFT-TYPE COEFF.	FREQUENCY COEFF.	SHLDRST COEFF.	LEGST COEFF.
BXBGD	2.24	-4.39	-0.02	-1.00	0.24	0.12
BGD	-0.05	-----	-0.03	-0.87	0.24	0.09
BXD	-8.65	-----	-0.01	-1.14	0.23	0.16
BXBGDKS	-11.08	-3.41	-----	-1.00	0.32	0.16
BXBGDFS	12.20	-5.38	-----	-1.01	0.15	0.09
BGDKS	-14.52	-----	-----	-0.85	0.35	0.13
BGDFS	8.76	-----	-----	-0.88	0.14	0.05
BXDKS	-17.86	-----	-----	-1.16	0.30	0.19
BXDFS	-0.49	-----	-----	-1.13	0.17	0.13

where,

BXBGS = General static models for box and bag lifting
BGS = Static models for bag lifting only
BXS = Static models for box lifting only
BXBGSKS = Static models for box and bag lifting from K-S
BXBGSFS = Static models for box and bag lifting from F-S
BGSKS = Static models for bag lifting from K-S
BGSFS = Static models for bag lifting from F-S
BXSKS = Static models for box lifting from K-S
BXSFS = Static models for box lifting from F-S
CONTAINER_CODE = 1 for Box (BOX_OR_BAG)
= 2 for Bag
LIFT_TYPE = 50.8 for K-S (HT)
= 127 for F-S
FREQUENCY = 2 for 2 lifts/min
= 6 for 6 lifts/min
SHLDRST = Static Shoulder Strength
LEGST = Static Leg Strength

Prediction models for the Maximum Acceptable Weight of Lift (MAWL) using dynamic strength test.

Table 17. Prediction Models for the MAWL (Kg) using Dynamic Strength

MODEL CODE	CONSTANT COEFF.	CONTAINER COEFF.	LIFT-TYPE COEFF.	FREQUENCY COEFF.	DYNSTKS COEFF.
BXBGD	24.82	-4.39	-0.02	-1.00	0.89
BGD	19.59	-----	-0.03	-0.87	0.10

BXD	16.88	-----	-0.01	-1.14	0.15
BXBGDKS	18.77	-3.41	-----	-1.00	0.16
BXBGDFS	23.14	-4.39	-----	-1.00	0.12
BGDKS	13.58	-----	-----	-0.85	0.14
BGDFS	19.94	-----	-----	-0.88	0.05
BXDKS	13.72	-----	-----	-1.16	0.19
BXDFS	18.97	-----	-----	-1.13	0.12

where,

BXBGD = General dynamic models for box and bag lifting
BGD = Dynamic models for bag lifting only
BXD = Dynamic models for box lifting only
BXBGDKS = Dynamic models for box and bag lifting from K-S
BXBGDFS = Dynamic models for box and bag lifting from F-S
BGDKS = Dynamic models for bag lifting from K-S
BGDFS = Dynamic models for bag lifting from F-S
BXDKS = Dynamic models for box lifting from K-S
BXDFS = Dynamic models for box lifting from F-S
CONTAINER_CODE = 1 for Box (BOX_OR_BAG)
= 2 for Bag
LIFT_TYPE = 50.8 for K-S (HT)
= 127 for F-S
FREQUENCY = 2 for 2 lifts/min
= 6 for 6 lifts/min
DYNSTKS = Knuckle to Shoulder Dynamic Strength (ft-lb)

The following is an example to how this model is used.

<Example> Prediction of MAWL

Container type = Box (CONTAINER_CODE = 1)
Knuckle to Shoulder Lifting (LIFT_TYPE = 50.8)
Frequency = 6 lifts/min (FREQUENCY = 6)
Shoulder Strength = 56.70 Kg
Leg Strength = 165.11 Kg
Knuckle to Shoulder Dynamic Strength = 13.49 Kg-M

BXBGS = 2.24 - 4.39 * CONTAINER_CODE - 0.02 * LIFT_TYPE
- 1.00 * FREQUENCY + 0.24 * SHOULDER_ST + 0.12 * LEG_ST
= 2.24 - 4.39 * 1 - 0.02 * 50.8
- 1.00 * 6 + 0.24 * 56.70 + 0.12 * 165.11
= 24.25 Kg (Based on general Static model)

BXBGD = 24.82 - 4.39 * CONTAINER_CODE - 0.02 * LIFT_TYPE
- 1.00 * 6 + 0.89 * DYNSTKS
= 24.82 - 4.39 * 1 - 0.02 * 50.8
- 1.00 * 6 + 0.89 * 13.49
= 25.42 Kg (Based on general Dynamic model)

Aghazadeh and Ayoub (1985) developed static and dynamic strength models for the prediction of weight lifting capacity of individuals. They reported that both the dynamic and static models developed in their study can predict the maximum acceptable amount of lift with a reasonable degree of accuracy. They, however, reported that a comparison of the models revealed that the use of of the dynamic model with one operator variable resulted in less absolute error between the actual and predicted load than the static model. They claimed that the dynamic approach may be superior to the static approach.

4. Relationship between Lifting Strength and Capacity

In evaluating lifting capabilities, often, the words lifting strength and lifting capacity are used. In addition the literature available indicates the existence of a relationship between lifting strength or capacity and muscular strength.

Different methods have been utilized in attempt to measure muscle strength. These methods can be grouped according to two types of strengths classification. These are static and dynamic strengths. Static strength has been defined as the maximal force can exert isometrically in a single voluntary effort. Dynamic strength is defined by Neilson and Jensen (1972) as "... the ability to apply force through the range of motion." The resistance which dynamic muscle contractions can overcome can be used as an index of muscle strength (Ayoub, 1982).

4.1 Lifting Strength and Lifting Capacity, and Muscle Strength

The physical activity may involve a single contraction or it may involve repeated contraction of the muscles involved. In dynamic exercise, the contractions are related to movement and can be concentric (shortening) or eccentric (lengthening) in nature. A maximal effort involving either type of the contractions can be identified as the "strength" of the particular type of contraction. Repeated submaximal contractions can be expressed in absolute terms as the power produced by concentric contractions or the power received by eccentric contractions. In relative terms, the repeated contraction can be expressed as percent of the maximal voluntary contraction for the particular type of contraction, or "capacity" (Knuttgen, 1975).

In order to develop and present data norms for manual materials handling, distinction must be made between strength and capacity. Strength in this context is defined as the maximum voluntary force a person is willing to exert in a single attempt. Capacity is the force a person is willing to exert repeatedly for an extended period of time without "feeling fatigued". For the purpose of this guide, strength is the ability to lift infrequently, and capacity is the ability to lift frequently. There is no specific cutoff between capacity and strength categorizations, nor is there a separate category labeled "infrequent" manual materials handling. Snook (1978a) and Ciriello and Snook (1983) report significant differences among maximum acceptable weights of lift for tasks performed every five minutes, thirty minutes, or eight hours.

The rationale behind the use of strength test is that a direct relationship exists between the probability of injury and percentage of strength utilized by the worker in the performance of his job. Static strength tests do not take into account the repetitious nature of most tasks and ignore the physiological limiting factors, such as cardiac and pulmonary functions. Static strength tests are limited to the measurement of isometric muscle contractions, which are not a sufficiently complete and realistic assessment of the muscular abilities actually required in manual material handling (Kroemer, 1983). To compensate for these shortcomings, isokinetic or isoinertial tests have been considered. Isokinetic tests measure muscle strength capabilities while body segments move at constant speed. Isoinertial tests establish the maximal amount of mass that a person can handle. The amount of mass is increased to the]maximum that the individual can lift. This task is similar to actual material lifting in that, within limitations imposed by the test protocol, the subject is free to select any suitable lifting technique.

4.2 Isometric Strength

DEFINITION

Static strength is the maximal force muscles can exert isometrically in a single voluntary effort.

An isometric activity requires the muscle to contract with no change in length. Since the distance moved is negligible in the isometric activity, no mechanical work is done. Holding or carrying containers or suitcases are typical examples. This activity also demands energy and can be very fatiguing.

Measuring isometric strength would entail the individual exerting as much force as possible against an instrument which could measure the applied force. Since the exertion is voluntary, the subject is at minimal risk of injuring himself. Subjects are instructed not to jerk, but to increase exertion to a maximum during a 4 or 5 second period, and to stop if any abnormal discomfort is felt.

Isometric strength tests have a well-established testing procedure relying on static biomechanical modeling. It is mainly applicable to force exertions, where the body does not move or moves very slowly and smoothly (Chaffin, 1981). This however is seldom encountered in the performance of many physically demanding tasks.

4.3 Isokinetic Strength

DEFINITION

Isokinetic strength can be defined as the maximal force muscles can exert dynamically at a given fixed velocity of movement (rpm) in a specified range of joint movement.

Isokinetic strength is produced by applying force against a lever moving at a set velocity, therefore the speed of movement of the limb is controlled and held constant. The strength (torque) which the subject can develop during the motion is measured. According to Kroemer (1983) this technique is being validated and should soon be applicable to dynamic manual material handling (Kamon, Kiser and Pytel, 1982; Marras, 1981). Aghazadeh and Ayoub (1985) developed and used isokinetic strength measurement apparatus to compare dynamic strength model and the static strength model.

A major disadvantage of the isokinetic strength test is that the movement speed must be preselected and remain relatively constant during the motion.

4.4 Isoinertial Strength

Isoinertial strength is the maximal amount of weight that a person can lift. A preselected mass is lifted which is constant during each test trial.

In the isoinertial technique (familiar to many from competitive sports, gymnasiums, and health clubs), the task is similar to actual material lifting in that, within limitations imposed by the test protocol, the subject is free to use any subjectively suitable lifting technique. According to Newton's Law, the exerted force (strength) depends on the acceleration applied to the constant mass. While apparently more "realistic" than the isokinetic technique, the isoinertial strength test has binary nature (success or failure) compared to the quantitative isokinetic measurement (Kroemer, 1985).

Jiang and et al. (1986) used the six-ft isoinertial incremental lifting equipment to make comparison between isometric and isoinertial strength test to predict the manual material handling capacities of individuals. They report that isoinertial strength testing is recommended as a promising single test.

Kim, Ayoub, Smith, and Selan (1986, 1987) conducted a study to determine the relationship between performance on a series of simulated maintenance lifting activities and performance on an isoinertial strength test. They claimed that high correlations were obtained between simulated task performance and isoinertial strength test performance (0.55 to 0.93) and the prediction equations for the tasks resulted in R-square values ranging from 0.51 to 0.87.

4.5 Comparison between Static and Dynamic Strength

Both static and dynamic strength assessment are valuable for lifting strength assessment. However, it is generally accepted that dynamic strength assessment is more generalizable than static strength assessment. Repeated, static strength tests on a particular muscle group are highly reliable, while the strengths of different muscles, even within subjects, are only weakly correlated (Thordsen, et al., 1972; Laubach, et al., 1972). This weak correlation suggests that a worker's predicted lifting capability on a particular job element is most accurate when the job demands are approximated in the strength test (NIOSH, 1981).

Garg, et al., (1980) reported a lack of consistency when predicting dynamic lifting strength for occasional lift from isometric lifting strength. Pateman (1981), however, compared measured, average, maximal dynamic lift of young males and values using Poulsen's formula and reported only a 6% difference between the two measures. On the other hand, many studies have been unsuccessful in establishing dynamic lifting capabilities of individuals for either frequent or occasional MMH from isometric strength (Mital and Ayoub, 1980; Pytel and Kamon, 1981: Kamon, et al., 1982; Mital, et al., 1986c). It was found that isokinetic strength is a better predictor of dynamic exertion for occasional handling than isometric strength, however, to increase prediction reliability, other operator variables must be added (Pytel and Kamon, 1981; Kamon, et al., 1982; Mital, et al., 1986c).

Aghazadeh (1983) states that, of the dynamic and static strength models that he developed, dynamic models are superior to static strength models when the average absolute error is assessed. It should not be surprising that a prediction based on a dynamic strength test better approximates actual performance of a dynamic task than a prediction based on a static strength test approximates actual performance of a dynamic task.

Ayoub (1982) compared static and dynamic strength testing procedures. This is outlined in Table 18. Testing procedures, experimental conditions, subject identifiers, and data presentation are discussed.

****

Insert Table 18 Testing Procedure

****

Table 18

TESTING PROCEDURES

STATIC	DYNAMIC
(I) Protocol for Measurement	
(1) A maximum steady exertion for a total of 3 seconds should be performed.	(1) A maximum steady state range of movement at a given speed should be completed.
(2) The strength score should be taken as the mean or maximum score during the 3 seconds.	(2) The strength score is a continuous position dependent value. Values at different angular position (or similar other identifiers) should be reported.
(3) N/A	(3) Speeds are normally varied to establish the functional relationship between dynamic strength and speed of movement.
(II) Subjects	
(1) Subjects should be screened prior to selection (can be a function of the purpose).	
(2) Subject is usually instructed not to jerk, but to increase exertion to maximum during a 4 or 5 second period.	(2) Subject usually instructed to jerk but "pick up" the instrument and apply maximum force during the prescribed movement range.
(3) Provide qualitative feedback to the subject about their general performance. Elicit any comments about any problems he/she may have experienced.	
(4) Rewards and/or competitive incentives change levels of motivation and hence bias the strength scores.	
(5) Rest periods should be provided. These rest periods should not be less than 2 minutes.	

Table 18 (Cont.)

(III) EXPERIMENTAL CONDITIONS

(1) Describe the segment of the body involved (or the muscles involved). Describe the movement (flexion, extension, abduction, . . ., etc.).

(2) With interest in space activities, the level of gravity should be also described.

(3) Body posture assumed should be described. Is the subject sitting, standing, prone, supine, . . ., etc.

(4) If the subject is strapped, the experimentor should describe it.

(5) The device or equipment used should be fully described with particular reference to how the coupling between the subject and the device is accomplished.

(6) Special attention should be given to the moment arm through which the force is applied. It's length should be reported.

(7) If strength is measured in units of force, the this vector should be described in terms of direction and magnitude. If it is measured in units of torque, then direction, magnitude and moment arms should be given.

(IV) SUBJECT IDENTIFIERS

(1) The sample size, the population it represents and how the sample was stratifed should be reported.

(2) If any screening of subjects was made, the criterion or criteria used for screening should be reported.

(3) Sex and age of the subject, height and weight, or other characteristics of interest for the study (body build, lean body mass, ethnic origin, . . ., etc.) should be reported.

(4) Any training received relating to strength prior to testing should be discussed.

(V) DATA PRESENTATION

(1) Generally, the mean and standard deviation are reported. Median and mode occasionally reported. Fifth, 50th, and 95th percentiles are occasionally reported.

(2) The underlying distribution should be reported if known. If assumed normal, this should also be identified. Skewness should also be reported.

(3) Minimum and maximum values should also be reported.

Adapted from Ayoub (1982).

5. Advantages and Disadvantages of the Psychophysical Approach

5.1 Advantage of Psychophysical Approach

1. Psychophysics permits the realistic simulation of industrial work. For example, lifting can be a dynamic task through a given vertical distance, and not just as isometric pull. Task frequency can be varied fast rates to very slow rates.
2. Psychophysics can be used to study the very intermittent tasks that are commonly found in industry. A physiologically steady state is not required.
3. Psychophysical results are consistent with the industrial engineering concept of a 'fair day's work for a fair day's pay' (e.g. the standard task of walking at 3 mph). With the exception of very fast frequency tasks, psychophysical results are consistent with metabolic criteria of continuous or occupational work capacity.
4. Psychophysical results are very reproducible.
5. Psychophysical results appear to be related to low-back pain. Several investigators have found that when workers are asked to subjectively rate the degree of physical effort or strain in their jobs, low-back pain appeared significantly more frequently in those who believed their work to be harder (Snook, 1985).

5.2 Disadvantage of Psychophysical Approach

1. Psychophysics is subjective method that relies upon self-report from subjects. It will probably be replaced when and if more objective methods become available.

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

3. Psychophysics does not appear sensitive to the bending and twisting motions that are often associated with the onset of low-back pain. For, example, psychophysical results are higher for the floor to knuckle height lift than for the knuckle height to shoulder height lift. It is true that stronger back and leg muscles are used when lifting from the floor, but it is also true that this particular bending motion is associated with almost half of the compensative cases of low-back pain.

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COMPARISON OF BIOMECHANICAL, PHYSIOLOGICAL, AND PSYCHOPHYSICAL FATIGUE CRITERIA

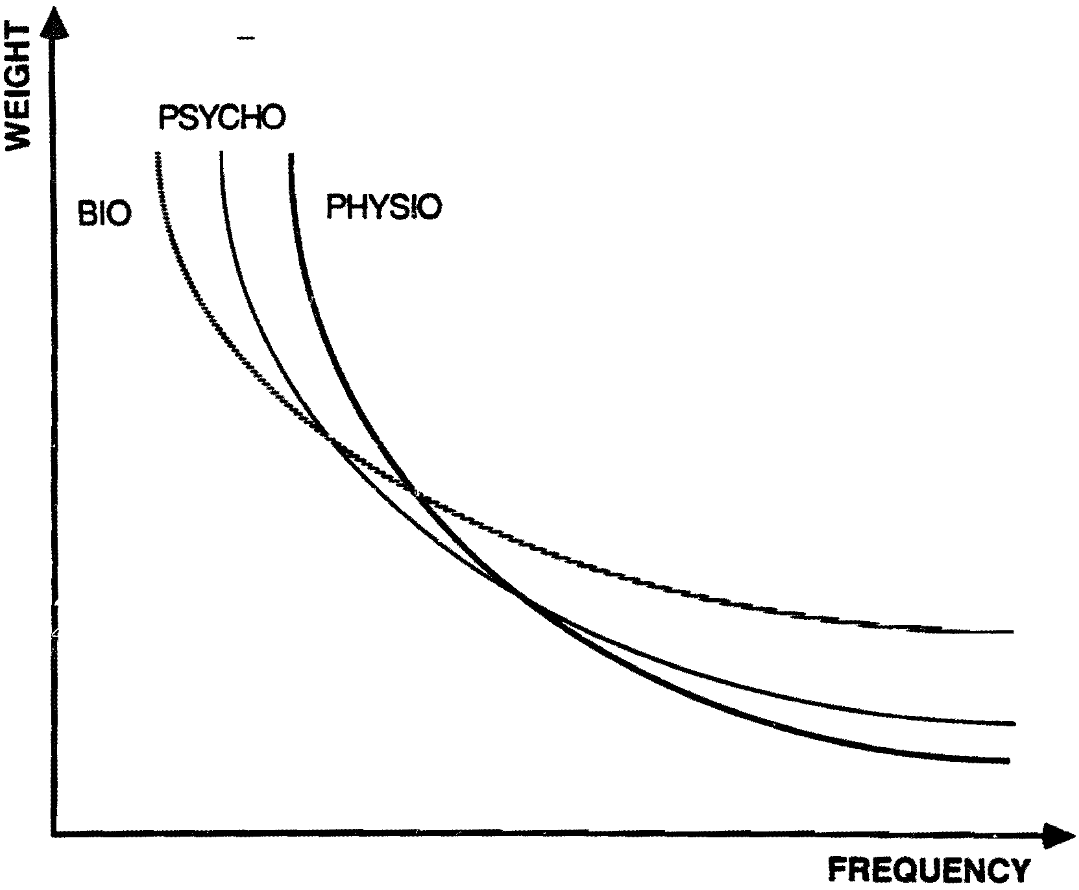

Figure 1.

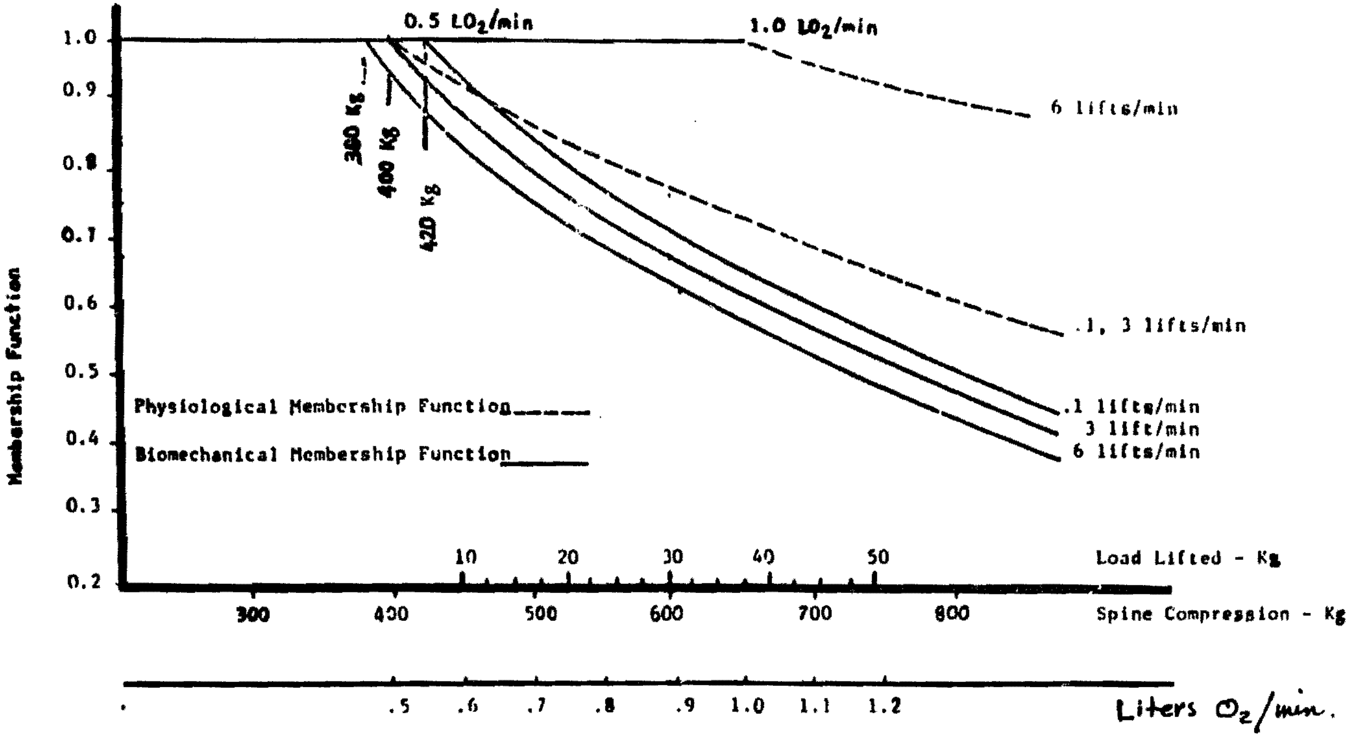

Figure 2. Biomechanical and Physiological Functions
(Ayoub and Hafez)

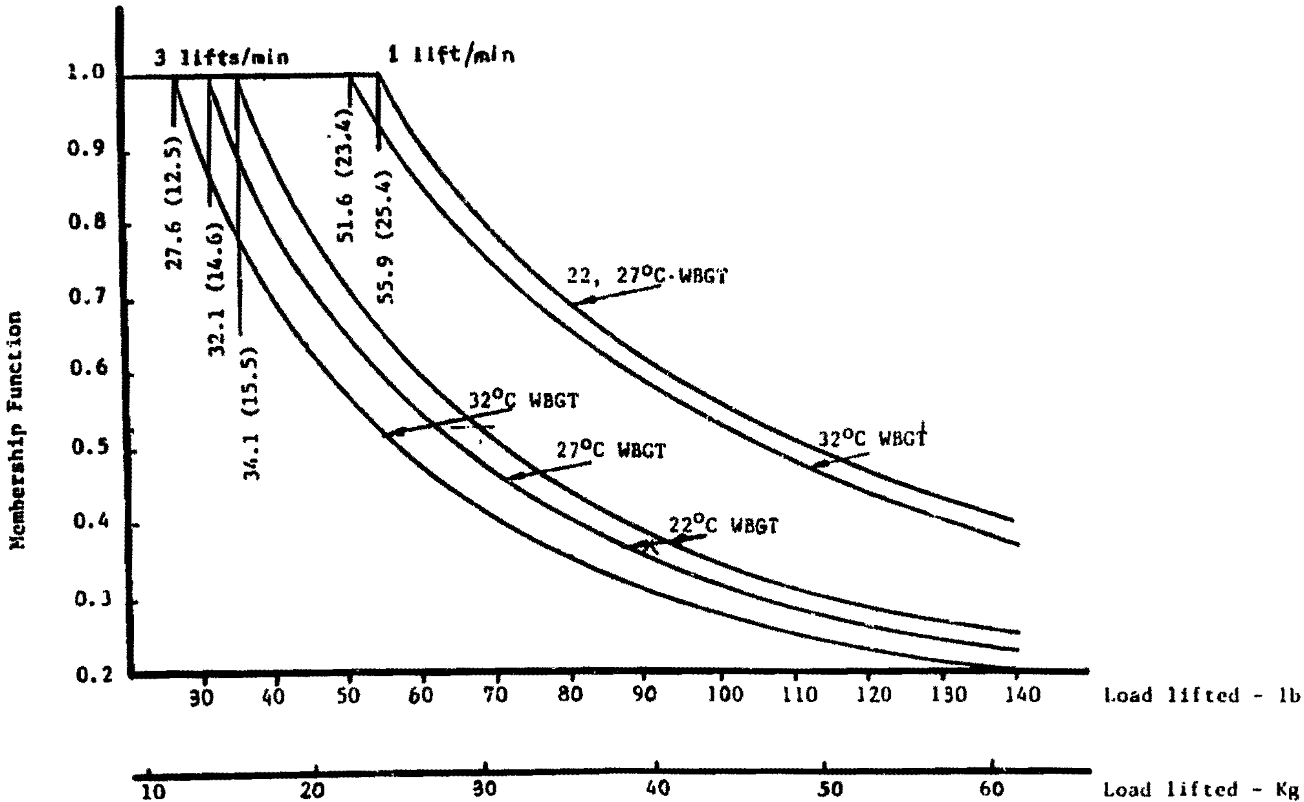

Figure 3. Psychophysical Membership Function
(Ayoub and Hafez)

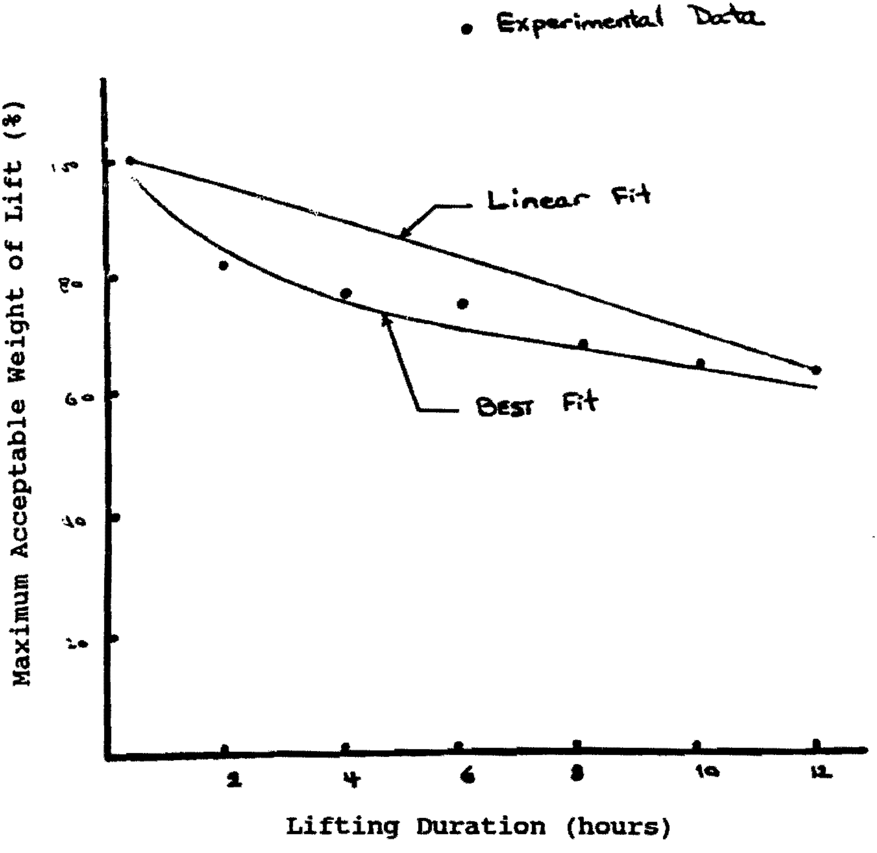

Figure 4. Change in Maximum Acceptable Weight of Lift with time for males (Mital, et al., 1986c)

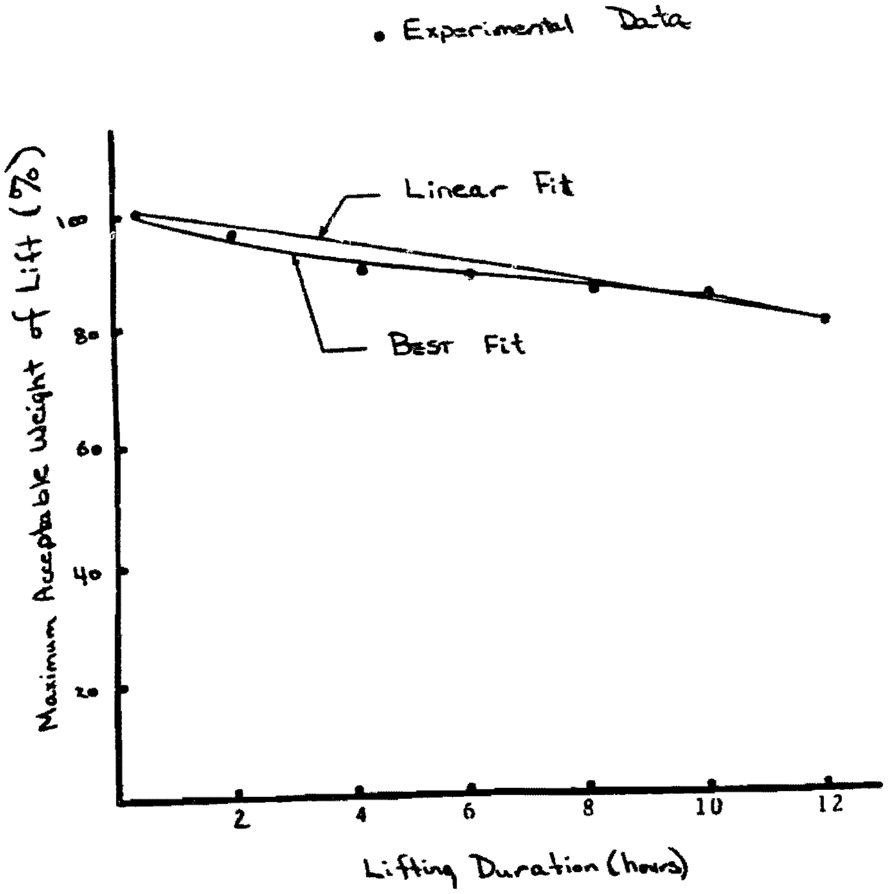

Figure 5. Change in Maximum Acceptable Weight of Lift with time for females (Mital, et al., 1986c)

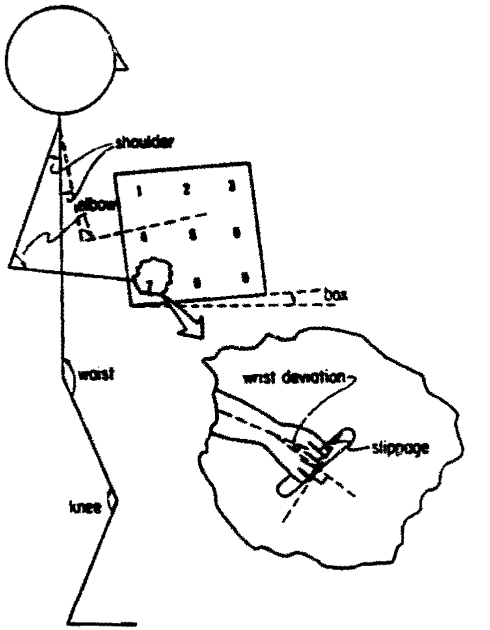

Figure 6. Definition of Handle Positions (Drury and Deeb, 1986)

Source : Ergonomics 29(6), 1986 743-768.

"Handle positions and angles in a dynamic lifting task. Part I: Biomechanical considerations

by C.G. Drury and J.M. Deeb

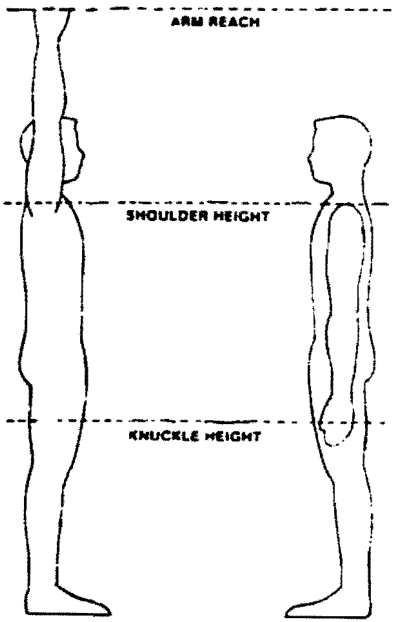

Figure 7. Classification of Lifting Height

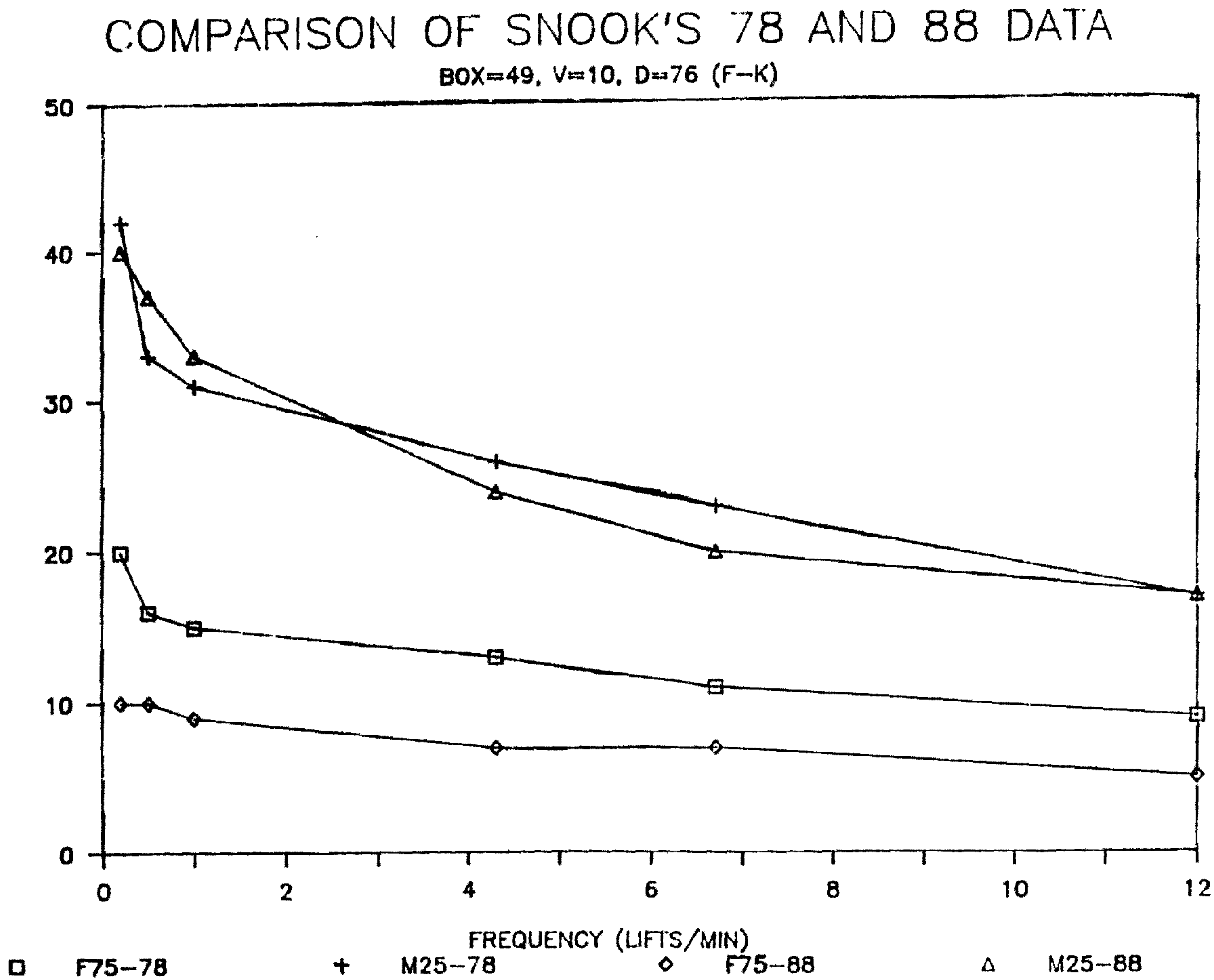

Figure 8. Comparison of Snook's 1978 and 1988 Data Bases