Scientific Support Documentation for the Revised 1991 NIOSH Lifting Equation: Technical Contract Reports

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Physiological Basis for Manual Lifting Guidelines

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The Physiological Basis of the Manual Lifting Guidelines

Outline

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The Physiological Basis of the Manual LIfting Guidelines

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

I. Factors Affecting Local Muscle Strength and Fatigue

A. Biomechanical

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

B. Physiological

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

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

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

If a muscle's effort is heavy but very short (under 3 seconds continuous duration) and occurs less than 6 times per minute, it can obtain most of its energy from glycogen and oxygen already stored in the muscle cells. Therefore, the temporary blood supply interruption that occurs with a short, heavy force exertion does not result in significant fatigue. Fatigue will develop if the heavy effort is sustained for longer periods, and the muscle will need a substantially longer recovery period to return to its previous state.

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

1. Duration - Work/ Recovery

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

2. Lifting Frequency

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

3. Estimating Effort Levels

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

4. The Interaction of Factors

Based on the local energy demands of muscle work and the need for blood flow to satisfy them, one can estimate maximum lifting frequencies that can be sustained without accumulating significant amounts of lactic acid in the muscle cell. This will depend on the % of MVC used, the continuous time of strength application, and the repetition rate per minute. The total duration of the effort and the location of the lift (below or above waist level) will also affect the acceptability of the lifting task and is considered later in this chapter. Figure 4 illustrates the relationship between effort times, total cycle time of the lifting task, and the muscle's effort level. (Rodgers, 1987) It is derived from Figure 2. Assuming that lifts are made within a 3 second time frame, it is apparent that only heavy effort lifts will limit acceptable frequencies substantially (to about 8 to 9 per minute from 20/minute for lighter lifts). If lift and carry combinations are used and effort time for the muscle increase to 6 seconds, for example, the acceptable frequency will decrease as a function of weight. For light loads, acceptable lift frequency will be a little less than 10 per minute, but for moderate loads the acceptable frequency drops to less than 5 per minute and for heavy loads it is about 2.5 lifts per minute. As holding time increases, these differences between heavy, moderate and light lifts becomes greater; when the muscles are active for 20 seconds, heavy lifting and handling acceptable frequencies are 1 per 4 minues compared to an acceptable frequency of just under 1 per minute for moderate effort and about 2.5/min. for light effort. In designing lifting tasks, it is important to reduce the static work (or continuous duration effort time) to as low a value as possible, especially when moderate to heavy effort is required.

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

II. Metabolic Limits in Lifting Tasks

Although local muscle fatigue may limit the acceptable weights in lifting tasks that are done for short, intensive periods during a work shift, it is the energy expenditure demands of repetitive lifting tasks that have the most profound effect on acceptability. The location of the lift (above or below 30 inches or 75 cm) determines how much of the body weight has to be moved with the load (low lifts) and what muscle mass is available (upper body capacity versus whole body capacity). The load weight, frequency of lifting, and duration of continuous work all influence the acceptability of repetitive lifting tasks. A review of research on repetitive lifting and factors that influence the energy expenditure requirements of these tasks follows.

A. Measuring the Metabolic Cost of Lifting Activies

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

Some controversy exists concerning the relationship between O_2

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

One possible explanation for the different findings involves the relationship between lifting frequency and weight of lift. It is known that for a given lift height, the metabolic demands, expressed in kilocalories per footpound of work, changes (Frederik, 1959). Thus, if a progressive test increases the weight of the lift and holds the frequency of lift constant, efficiency changes. This change in efficiency is illustrated by the data of Garg and Herrin (1979). They plotted the lifting frequency that resulted in a metabolic rate of 5.2 Kcal/min against lift weight in kg (Figure 5). A weight of 25 kg could be lifted over 5 times/min while a weight of 7 kg could be lifted 11 times/min. Over 125 kg of weight can be lifted per minute when lifting 25 kg while only 77 kg of weight is lifted per minute when a 7 kg unit is handled; yet both work loads result in the same metabolic cost. Thus, for this situation, O_2 uptake and work load are not linear. Other data show that the relationship between the two variables changes with the height of lift and the muscle mass involved (Genaidy et al., 1985). Given the complexity of lifting activities compared to treadmill or cycle ergometer activity, it is not unreasonable to suspect that the relationship between metabolic rate and work load is non-linear in certain situations.

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

B. Factors Influencing the Metabolic Costs of Lifting Tasks

1. Beginning Position and the Vertical Travel Distance

When considering the physiological cost of lifting, it is necessary to account for the cost of moving the load as well as the cost of moving the body. When a lift is made from the floor, the worker must lift his/her own body weight in addition to the weight of the box. The cost of lifting the body increases the energy requirements of the task when compared to the energy needed to lift the same weight from a table upward. Therefore, lifts which begin from the floor require more energy expenditure than lifts which begin from table level. For example, Aquilano (1968) published O_2 consumption values for 6 men who were lifting 10 and 25 pound cartons from the floor to waist level and from waist to head height. Estimates from figures published in the article show that lifting a 25 pound carton at a rate of 11 lifts/min required a total energy expenditure of approximately 4.4 Kcal/min for the waist to head lift. However, lifting the same carton from the floor to the waist required a total caloric expenditure of 6.3 Kcal/min, a 43% increase. The data of Frederik (1959) shown in Figure 6, support this point. The most efficient lifting range is from 40 to 60 inches for materials ranging from 20 to 60 pounds. LIfting from 0 to 20 inches results in the greatest energy expenditure for weights ranging from 20 to 55 pounds. These data emphasize the important role played by the beginning position of the lift in determining the total energy expenditure of the task.

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

2. Lifting Technique

The method used to lift the weight from the floor also has an impact on the physiological cost (Brown, 1971; Garg and Herrin, 1979). Three body postures used to lift objects from the floor have been studied: squat (straight back, bent knee), stoop (bent back, straight knee), and free style (as chosen by the worker). The squat lift results in higher levels of energy expenditure than the other forms of lifting. Garg and Saxena (1979a) showed that at a work load of 60 kgm/min, the free style lift resulted in a metabolic rate of approximately 4.2 Kcal/min while the squat lift required a metabolic rate of 5.7 Kcal/min. This 36% increase in energy expenditure is partially the result of raising and lowering the center of gravity of the body during the squat lift. The differences in metabolic rates between the styles of lifting relate to the total work performed, including the lifting frequency. At a work rate of 30 kgm/min, only a 14% difference exists between the two lifting styles (3.15 Kcal/min vs. 3.60 Kcal/min). Garg and Saxena followed up on this study by evaluating the lifting techniques of 6 male industrial subjects filling dry grocery orders in a warehouse (1979). They reported that the energy expenditure rate was 5.8 Kcal/min when using the free style technique compared to 7.5 Kcal/min with the squat technique. In addition, the workers were able to meet their performance index using the free style technique, but failed to meet the standard using the squat technique. Brown (1971) plotted the relationship between the weight of the lift and energy expenditure in Kcal/kg body wt·min. This method of expressing the energy expenditure serves to normalize the data relative to the body weight of the subject. The free style of lifting was still found to be more efficient than the squat lift.

Kumar (1984) reported that the stoop technique was less metabolically expensive than either the free style or the squat technique. This investigator measured the O_2 consumed while lifting a 10 kg weight from a beginning position of 13.5 cm to a final position of 91 cm, at a frequency of 6 lifts/min. The O_2 consumption values for the stoop, free style and squat techniques of lifting were 0.676, 0.804, and 1.06 liters/min, respectively. On a subjective basis, most people rated the squat technique as the most tiring and the free style technique the least tiring. Even though the stoop technique resulted in a lower metabolic rate, it was more tiring, subjectively, than the free style technique.

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

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

Frederik (1959) was one of the first to publish data concerning the metabolic cost of lifting (see Figure 6). His data indicate that the cost of lifting loads is a function of the weight of the object and the starting location of the lift. Hamilton and Chase (1969) also collected data concerning the relationship between O_2 consumption and the work rate when lifting 10 to 25 pounds at a height of 10 in. These authors stated that the relationship between the variables was linear over the range measured. The authors incorrectly interpreted this finding to mean that no optimal work load exists over the range of variables measured. However, their data clearly show that when two combinations of frequency and load result in the same work rate, the combination with the greatest weight and lowest frequency results in a lower metabolic rate. For example, lifting a 25 pound carton 9 times/min (a total weight of 225 pounds/min) yielded an energy expenditure of 5.85 Kcal/min (1.17 liter O_2/min). However, a lift involving a 15 pound carton and a frequency of 15/min (also 225 pounds/min) resulted in a metabolic rate of 6.88 Kcal/min (an 18% increase). The lift involved raising a carton from a table and placing it on a conveyor belt 10 inches above the table. Even though this study used a vertical lifting distance of only 10 inches, all of the weights studied (10, 15, 20, and 25 lbs) resulted in a metabolic rate greater than 5 Kcal/min when lifted at a frequency of 15/min. At 12 lifts/min only the 10 pound weight yielded a metabolic rate of less than 5 Kcal/min. At 6 lifts/min all of the weights were acceptable when based on a metabolic workload limit of 5 Kcal/min.

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

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

In an attempt to evaluate time standards set for industrial tasks, Aquilano (1968) had male subjects lift cartons of 10 and 25 pounds from the floor to waist height, floor to head height, and waist to head height. Depending upon the height of the lift, lifting frequencies ranged from 4 to 26/min. As the subjects increased the lifting frequency for a given weight, O_2 consumption increased in a linear fashion. However, the slope of the increase varied depending upon the weight being lifted and the location of the lift. For a given increase in work performed, the increase in energy expenditure was less for the heavier weight. This finding was related to the lesser change in frequency necessary for the heavier weight in order to result in the same absolute increase in workload. Data of Mital, Asfour and Ayoub (1982) support this principle.

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

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

max to recommend the lift load for combinations of frequency and lift height; however, the exact method used to arrive at these values is unclear. These data suggested that no lifting work should be performed at frequencies above 10/min for any height of lift. These data are not supported by others. Garg and Herrin (1979) found that a weight of approximately 7 kg resulted in a metabolic expenditure of 5.2 Kcal/min when lifted 11 times/min from the floor to knuckle height. Mital (1984) reported a O_2 uptake of 0.92 liters/min (4.6 Kcal/min) when subjects lifted a weight of 11.3 kg from knuckle to shoulder height at 12/min. Samanta and Chatterjee (1981) published data showing a metabolic rate of 4.89 Kcal/min when lifting a 9 kg load a vertical distance of 0.66 meters at 12 times/min.

It is unclear why such dramatic differences exist between the data of Khalil et al. (1985) and those of others. However, it is reasonable to assume that some errors result when VO_2 max is estimated from submaximal work loads. When performing this calculation it is assumed that the relationship between HR and work load and HR and O_2 uptake are linear. This relationship is under dispute and will be discussed in some detail below.

Jorgensen and Poulsen (1974) tested four males and four females while lifting loads of 10, 25, 50, and 75% of maximum capacity for a single lift. Each of these loads was lifted for 20 min at frequencies ranging from 2 to 12 L/min while HR and O_2 uptake were measured. They reported that, on the average, the maximum lifting capacity of females was 70% of that of males. This work also suggested that during repetitive lifting, capability is determined by maximum aerobic capacity as well as back strength. Doolittle (1989) supports the importance of aerobic capacity in repetitive lifting. He contends that many frequency-mass combinations (as determined from the 1981 NIOSH guide) will result in metabolic rates which exceed a lifting capacity based on 33% of maximum aerobic capacity for an 8-hour day. Thus, even with sound ergonomic design, the aerobic demands of frequent lifting must be considered in designing safe lifting tasks.

4. Lifting Versus Lowering

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

Garg (1976) and Petrofsky and Lind (1978a) measured the effects of lifting and lowering loads on metabolic rate when lifting and lowering below waist level. For light weight boxes and low work loads, the difference between the two tasks is minimum. However, as the weight of the load increased, lifting required significantly more energy expenditure than did lowering. Investigations using a psychophysical methodology showed that subjects were willing to lower more weight than they would lift (Ciriello and Snook, 1983; Mital et al., 1982). The negative (lowering) work results in an O_2 consumption of approximately 15% less that of positive (lifting) work (Ciriello and Snook, 1983).

5. Special Lifting Situations

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

a. Sitting - Yates and Karwowski (1987) measured the physiological demands of lifting from a sitting posture and compared them to standing lifts. Eight male subjects used the psychophysical method to chose MAWL (maximum acceptable weight lifted) while lifting at a rate of 1 and 4/min. Subjects lifted significantly less weight (8% to 25%) during sitting positions than during standing lifts. HR during sitting lifts was less than 88 b/min while O_2 consumption was always less than 17% of VO_2 max.

b. Asymmetric Lifts - If the psychophysical method is used to determine the MAWL during an asymmetrical lift, the resulting load will be less than that acceptable during a sagittal plane lift (Garg and Banaag, 1988; Mital and Fard, 1986; and Yates and Karwowski, 1987). Even through the MAWL is less during asymmetric lifts, O_2 consumption does not change when the results are compared to symmetrical lifts (Mital and Fard, 1986; Yates and Karwowski, 1987). Garg and Banaag (1988) have observed higher heart rates during asymmetric lifts, however.

c. Special Postures - Morrissey (1987) reviewed the effect of task posture on the physiological demands of lifting. Walking in a stooped posture (such as would occur in a medium or low seam coal mine) will increase O_2 consumption. Walking at a height of 60% of normal almost doubles O_2 requirements. When shovelling at a fixed rate, working in the kneeling posture will increase O_2 uptake over that which occurs while in normal posture. Gallagher and associates (1988) showed that lifting in the kneeling posture is more demanding than lifting in the stooped posture in terms of HR and O_2 uptake.

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

Determining the maximum acceptable weight during repetitive lifting is a complex task affected by many different factors. In attempting to solve this problem, investigators have taken a number of different approaches. The first approach, which was discussed above, involved determining the relationship between work rate and O_2 consumption to find which loads resulted in fatigue of the subjects. The occurrence of fatigue was judged by a variety of methods. The second approach involves letting the subject choose the weight which he feels is acceptable to lift at a given frequency and height of lift (psychophysical method). Many investigators have used the psychophysical method to determine acceptable lifting loads and then measured the resulting metabolic rate.

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

D. Oxygen Consumption Prediction Models

Garg, Chaffin and Herrin (1978) published an extensive prediction model based on measurements of metabolic rate during 28 manual materials handling tasks. A basic assumption of the model was that the job could be divided into simple tasks and that the metabolic expenditure of complex jobs could be predicted by summing the energy demands of the simple tasks. The metabolic rates predicted by the model were compared to the measured metabolic rates (range = 3.2 to 11.9 Kcal/min) on 48 different jobs. The model validation showed a correlation coefficient of 0.95 between the measured and the predicted metabolic rates and a coefficient of variation of 10.2 percent, which is on the same order as inter-subject variability. The mean absolute difference between the predicted and the measured metabolic rates was 8.6 percent (range = 0.2 to 33%) and 41 out of 48 jobs had a difference of less than 15%. The authors concluded that the model was sufficient for estimating energy expenditure rates of different manual materials handling jobs. One advantage of using such a model is that the portitioning of a job into tasks shows which particular tasks require the highest energy expenditure, and this is a useful focus for job redesign.

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

E. Determining Lifting Task Limits Based on Aerobic Work Capacities

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

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

1. Aerobic Work Capacities

Petrofsky and Lind (1978) addressed this issue by using a progressive resistance test to measure O_2 consumption on a cycle ergometer and on a staged lifting task using boxes of different weights (.91, 6.82, 22.73, and 36.36 kg) at increasing frequencies. The subjects used the free style method to lift from a height of 6 cm to 60 cm (24 inches). O_2 consumption was linearly related to work load for boxes of all weights; however, the slopes of the relationships were dramatically different. For the two lightest boxes, the limiting factor reported by the subjects was their inability to raise and lower the trunk, head, and box at a faster rate. With the heaviest box, the limiting factor was reported to be fatigue in the arms or hands. VO_2 max was highest for the cycle ergometer and progressively decreased as the weight of the lift decreased. HR followed a pattern similar to O_2 consumption. When the same amount of work was performed lifting boxes as when riding the cycle ergometer, O_2 consumption was significantly greater for lifting boxes than for riding the cycle ergometer. A follow-up study found that 50% of VO_2 max for each specific box weight could be maintained for a 4-hour period with 10 minute recovery periods each hour; however, clear evidence of fatigue was found (Petrofsky and Lind, 1978b). Blood lactate showed little increase up to 40% of VO_2 max but increased dramatically when O_2 levels increased above 1.0 liters/min. These data are in agreement with those of Astrand (1967). As a result of these data, Petrofsky and Lind (1978b) suggested that work rates not exceed one third of cycle ergometer VO_2 max.

Williams et al. (1982) reported slightly different results on seven female students. Measured VO_2 max values for treadmill, cycle ergometer and for lifting boxes of 15.9 and 22.7 kg were not significantly different. The differing results were ascribed to the fact that the women in this study preferred to use the squat method of lift while the men used the stoop method. Since the squat method of lifting involves the use of the legs and, therefore, requires more energy expenditure, the women achieved higher VO_2 max values for box lifting. Both methods of lifting resulted in a linear relationship between work load ad O_2 consumption. Based on loss of grip endurance following the lifting tasks, the authors recommended 30% of VO_2 max be used to set lifting standards.

2. Lifting as a Percent of Aerobic Capacity

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

Based on studies of industrial lifting, Rodgers (1976) supported a value of 33% of either whole body or upper body capacity. Rodgers suggests that this level of O_2 consumption will involve integration of factors such as biomechanical aspects of the materials to be handled and their location in space, environmental conditions in the work place, individual fitness and skill levels, and static components of the job. The 33% of VO_2 max (treadmill) value was chosen as the upper limit of oxygen consumption for the MPL (Maximum Permissible Limit) in the 1981 NIOSH Work Practices Guide for Manual LIfting and, therefore, has received widespread application. Based on an assumed aerobic capacity of 3.0 liters O_2/min for an average, young man, this puts the upper limit of O_2 consumption at 1.0 liter O_2/min for sustained manual materials handling. One liter of O_2/min is equivalent to 5 Kcal/min. These values are often quoted when determining maximum work capacity for lifting situations. However, as discussed above, VO_2 max is job specific. Therefore, one must be cautious when using the 1.0 liter O_2/min for all types of jobs. In addition, average VO_2 max for young females is closer to 2.0 l/min; therefore, an upper working limit of 1.0 liters O_2/min is closer to 50% of VO_2 max for females. Another factor which cannot be ignored is the decline in VO_2 max that naturally occurs with increasing age. As workers age, their maximum work capacity decreases; hence, the workload which results in a given percentage of VO_2 max also decreases. Jobs involving leg work have higher maximum work capacities than jobs involving arm work. Therefore, 33% of treadmill or cycle ergometer

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

3. Psychophysical Data on Total Workload Limits

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

O_2/min. Garg and Saxena (1979) reported different MAWL's for frequencies of 9 and 12 lifts/min of 0.97 and 1.11 liters O_2/min, respectively.

The difference between the results of Ciriello and Snook (1983) and Garg and Saxena (1979) may be due to the inability of people using the psychophysical method to accurately predict lifting capacity at high lifting frequencies. Numerous authors have come to the conclusion that the psychophysical method overestimates work capacity at high lifting frequencies (Ciriello and Snook, 1983; Karwowski and Ayoub, 1984; Fernandez and Ayoub, 1987; Karwowski and Yates, 1984; 1986; Mital, 1984a; 1984b; 1987). Karwowski and Yates (1984; 1986) showed that female subjects are unwilling to lift the psychophysically chosen weight at frequencies above 6/min over a period of 4 hours if given the chance to change it. At the end of the 4-hour period, subjects had decreased the weight of the lift by 23% from their MAWL which had been predicted at lifting rates of 8 or 12 lifts/min. These data lead to the suggestion of 25% to 30% of treadmill VO_2 max as the recommended upper limit for O_2 consumption when lifting for a continuous 4-hour period; this value is in close agreement with the 28% suggested by Mital (1984) for eight hours of lifting. As can be seen in Figure 7, there is only a small difference between 4 and 8 hours in terms of the percent of aerobic capacity that can be used without accumulating fatigue.

In summarizing the data concerning the limits of work capacity, it becomes clear that jobs requiring 50% of treadmill or cycle ergometer VO_2 max will exceed the capability of most workers. Values in the range of 40% of the job specific VO_2 max may be tolerated by some workers. However, most data now suggest that the range should be between 25 and 30% of treadmill or cycle ergometer VO_2 max for an 8-hour shift. For shorter or longer work periods, the work as a percent of aerobic capacity should follow the curve in Figure 7.

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

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

A. Components of the Frequency Correction Factor Table

There are three major components of the frequency factor table: corrections for lifting frequency; corrections for the lift location (above or below 30 inches or 76 cm); and an adjustment for the continuous duration of lifting(1, 1-2, 0r 2-8 hours). All of these parameters affect the amount of oxygen used to perform the lifting task, and they can also influence the amount of local muscle fatigue that develops in combinations of conditions. The assumptions made in choosing the baseline aerobic capacity and workload limits are reviewed in this section; the technique used to generate the frequency factors is also described.

In order to set some general guidelines for frequent lifting tasks that are reasonable and still protect less strong and less fit workers from overexertion injuries, the tasks have been designed conservatively. At the AL (Action Limit), at least half of the women and most of the men will find the tasks acceptable. Based on strength alone (infrequent lifts), the AL should accommodate about 75% of the women. To accommodate more women in frequent lifting tasks, one can reduce the workload by interspersing the lifting task with light work activities. This will lower the overall energy demands and permit people with lower aerobic work capacities to work without fatiguing. The continuous work duration columns illustrate that shorter lifting periods require less frequency factor correction, thereby raising the AL value.

B. Baseline Aerobic Capacity Assumptions

The goal of the lifting guidelines is to protect the large majority of workers from the risk of overexertion injuries. Since the workforce includes men and women ranging from 17 to 70 years of age, the aerobic capacity of a less fit worker has been used to establish the AL level. Based on earlier studies included in the 1981 NIOSH Work Practices Guide for Manual Lifting and on industrial studies (Eastman Kodak, 1986, pages 476-478), a value of 34 ml O_2/kg body weight min or 10.5 Kcal/min whole body aerobic work capacity has been used as the baseline for low lifting tasks. This is the aerobic capacity of an average 40 year old women as measured on a staged treadmill test. Some of the difficulties with using a work capacity measured on a treadmill or bicycle ergometer to predict lifting capacity have been discussed earlier in this chapter. It is probable that more than half of the female workforce may find a repetitive lifting task based on a 10.5 Kcal/min aerobic work capacity fatiguing because their lifting capacity will be lower than their walking capacity. The frequency factor corrections have been rounded down to be more conservative and to balance this overestimate, however. Workers can very often control their lifting pace and vary their activities to reduce accumulated fatigue, too. A design that accommodates 75% of the less fit population would limit workloads to the low moderate effort range for a large majority of the workforce, and that would be an inefficient design.

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

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

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

Figure 7 (earlier in this chapter) illustrates what percent of aerobic capacity can be used as a function of work duration. The duration values chosen for the frequency correction table are 1 hour, 1 to 2 hours, and 2 to 8 hours, and these can be sustained at loads of 50%, 40% and 33% of aerobic work capacity (measured as treadmill capacity), respectively. Table 1 illustrates the limiting energy expenditure values used to caluclate the frequency correction factors for high and low lifting tasks of different durations.

Table 1: Energy Expenditure Limits for Frequent Lifting

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

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

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

D. Frequency Factor Calculations

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

Stoop Lift

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

Squat Lift

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

Arm Lift

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

Where:

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

A stoop lifting technique (equation 1) was used to estimate energy expenditure for lifting from floor level to 0.8 m height. The use of squat lifting method will result in higher energy expenditure or lower allowable weight. It is worth mentioning that when using the NIOSH recommendations (Chapter 8), certain combinations of task variables may result in somewhat higher or lower energy expenditures than the values recommended. This is expected as the relationship between task variables at a given level of energy is not linear and certain variables have greater effect on compressive force and strength than on energy expenditure.

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

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

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

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

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

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

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

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

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

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

E. Determining the Frequency and Duration of Lifting

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

1. Measure the lifting frequency over a five minute period if it is done for less than 5 minutes at a time. Examples of such tasks would be unloading a pallet in a shipping task or loading chemicals into a reaction vessel. If 8 lifts are done in 1 minute followed by 4 minutes of light work, for instance, the lifting frequency should be calulated as 8 lifts in 5 minutes, or 1.6 per minute. Examples of light work include ticket work, labelling (without lifting), and monitoring.

2. Add up all of the periods of lifting in one shift to determine which of the duration categories should be used.

3. If high frequency lifting is done for a short time and slower

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

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

1. Continuous Work Duration of One Hour or Less

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

Light Work = 1.2 * Work Time in minutes
where WT is work time $\leq$ 60 mintues

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

2. Continuous Work Duration of 2 Hours or Less

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

Light Work = 0.30 * Work Time in minutes
where WT < 120 minutes

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

3. Continuous Work Duration of 8 Hours or Less

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

4. Guidelines

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

b. AL for 8 hours < object weight ≤ AL for 2 hours
WT ≤ 2 hours
RT (or Light Work) = 0.30 * WT

c. AL for 2 hours < object weight $\leq$ AL for 1 hour

WT $\leq$ 1 hours

RT (or light work) = 0.30 * WT

d. Weight > AL for 1 hour

Not recommended without administrative controls

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

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

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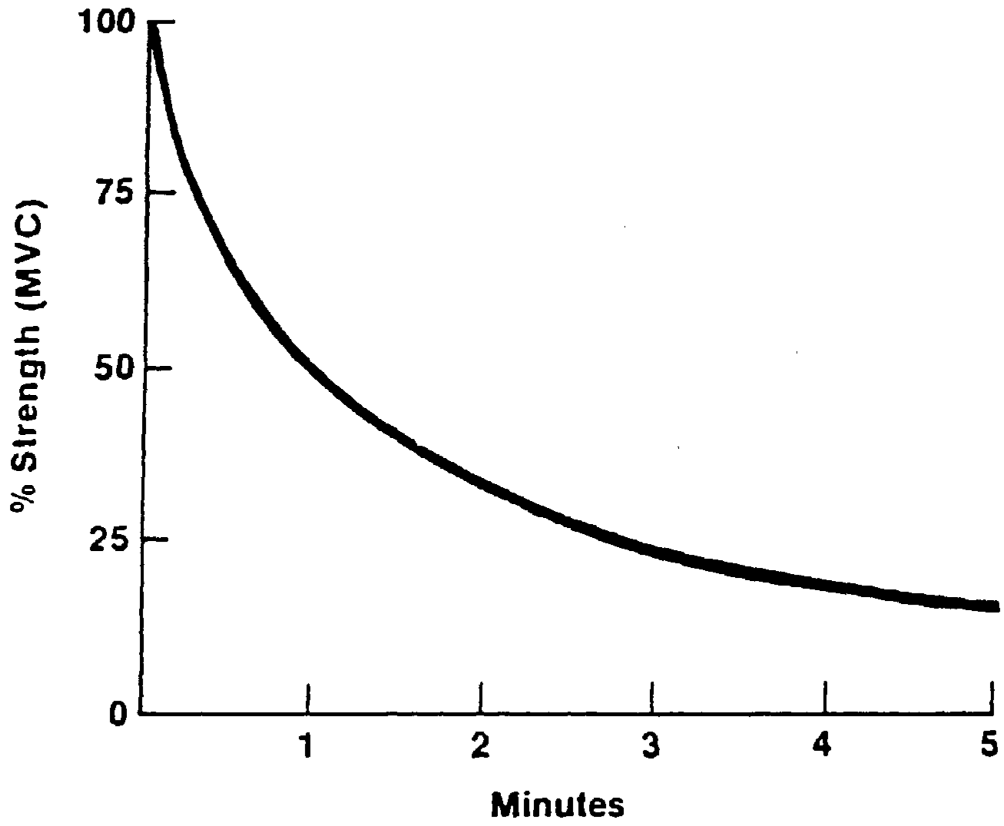

Figure 1: Intensity/Duration Relationship for Static Muscle Work (after Rohmert, 1973a; Scherrer and Monod, 1960).

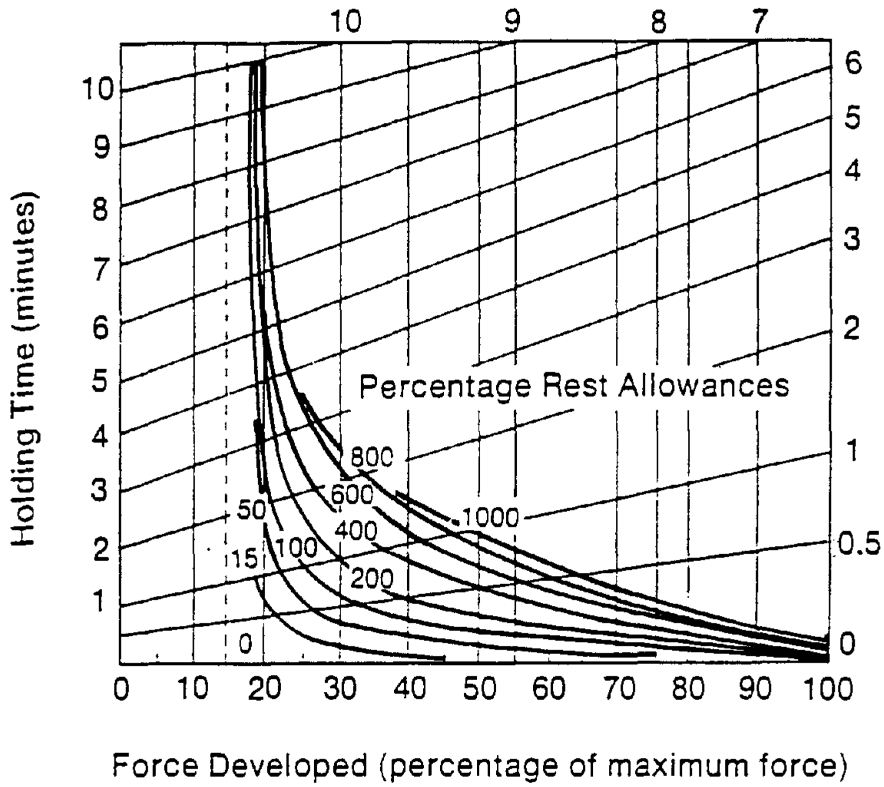

Figure 2: Rest Allowances for Static Muscle Work (after Rohmert, 1973a).

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

a. **Rating of Perceived Exertion (RPE)**

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

b. **Large Muscle Group Ratio Scale**

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

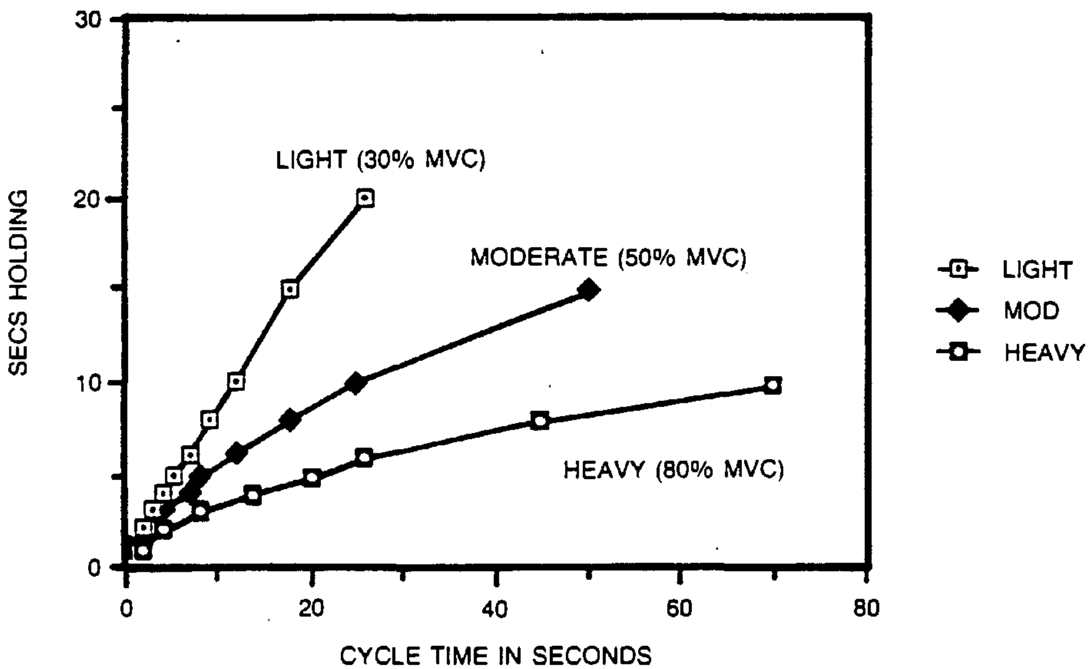

Figure 4: Work and Recovery Guidelines for Muscle Work as a Function of Effort Intensity, Duration, and Frequency (Rohmert, 1973a; Rodgers, 1987).

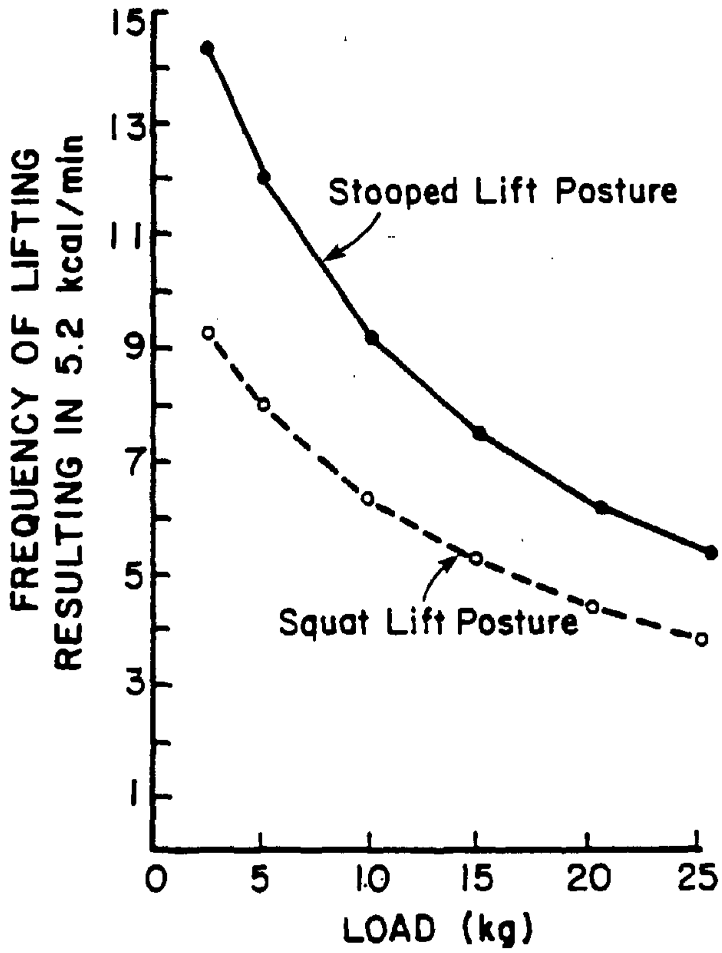

Figure 5: Estimated Maximum Frequency of Lift with Two Postures (Adapted from Garg and Herrin, 1979).

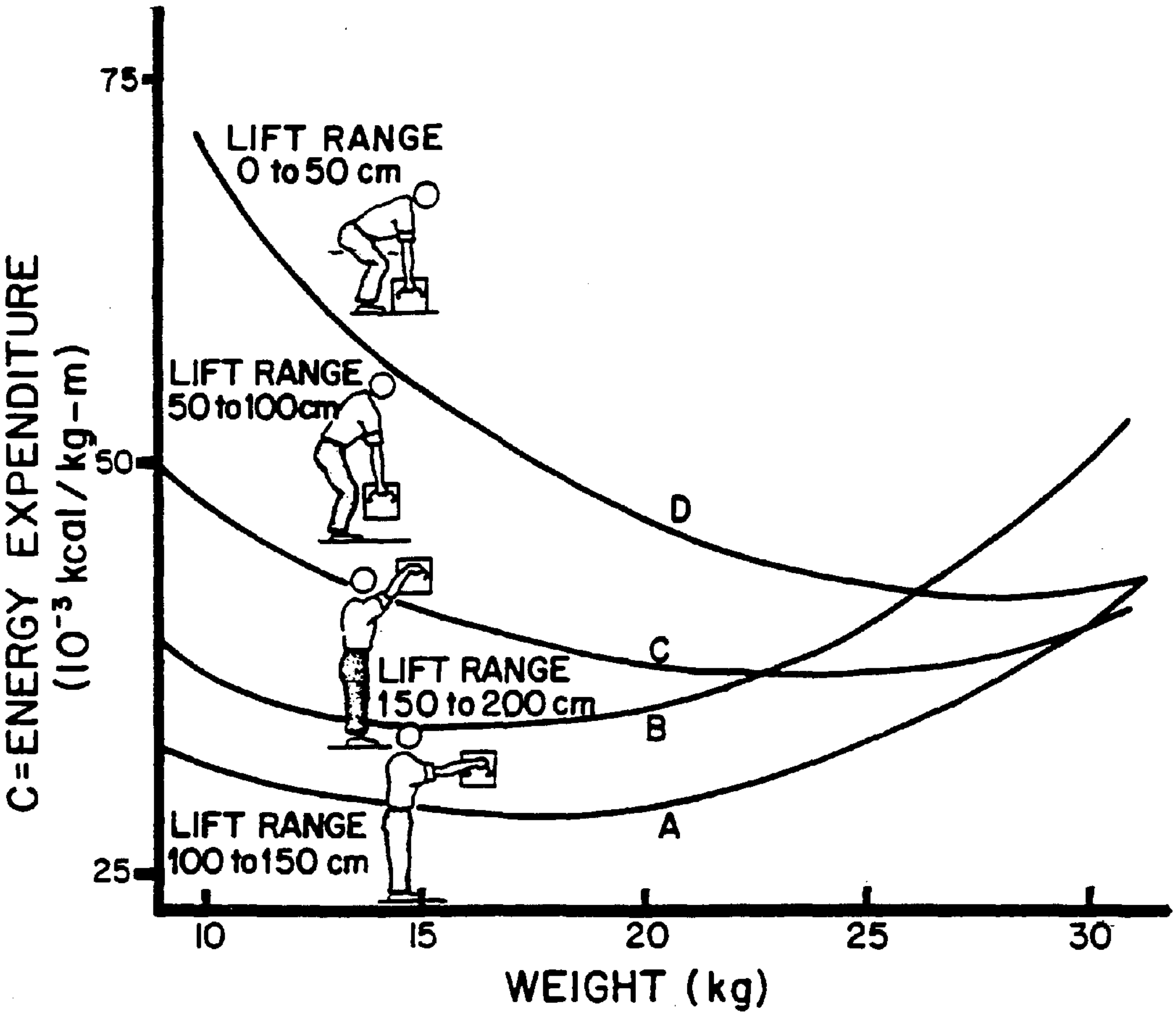

Figure 6: Energy Efficiency with Weight and Range of Lifting (Frederik, 1959).

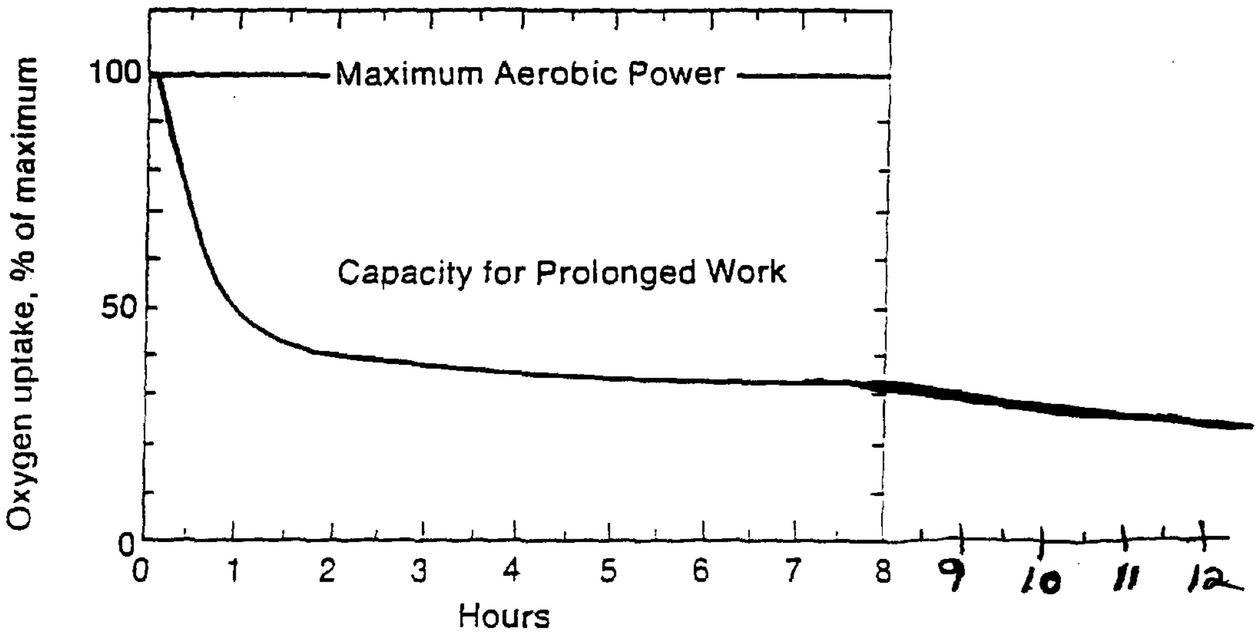

Figure 7: Effect of Work Duration on Percent of Maximum Aerobic Capacity Available for Work (after Astrand and Rodahl, 1970).

Epidemiological Basis for Manual Lifting Guidelines

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CHAPTER 2

BASIS FOR GUIDE: EPIDEMIOLOGICAL APPROACH

Arun Garg

Epidemiology can be defined as the science or discipline of the occurrence of illness in human populations including factors that influence and predict these patterns. The role of epidemiology in controlling low-back pain is to clarify the natural history and clinical course of the pain and to identify workplace and individual factors of importance (Andersson, 1981). This assumes that a set of factors is associated with low-back pain. Thus, epidemiology can play an important role in instituting preventive measures and eliminating risk factors.

One of the most serious and persistent problems in occupational medicine has been that of low-back pain (Brown, 1973). The importance of low-back pain syndrome is due to its high prevalence in the workers, and its effect on them in terms of pain and disability. Low-back pain is one of the most frequent and disabling conditions affecting workers in their productive years. In the United states, impairments of the back and spine are the most frequent cause of activity limitation in individuals less than 45 years old, and these conditions rank third, after heart disease and arthritis and rheumatism, in persons who are 45 to 64 years old (Kelsey et al., 1979). Further, recurrences are frequent, and three or more episodes have been reported in 30%-70% of the afflicted patients (Hult, 1954; Horal, 1969; Bergquist-Ullman and Larson, 1977). It is generally recognized that probably up to 80% of all people will experience back pain to some extent in their active life (Hult, 1954; Horal, 1969; Nachemson, 1976; Andersson, 1981; Snook, 1985). Further, low-back pain affects quality of life (Andersson, 1979); one out of 25 men changes his work because of low-back pain (Taylor, 1976); and it results in early retirement and disability pensions (Andersson, 1981).

According to Rowe (1983), "low-back pain is common symptom of many diseases affecting organs of lower abdomen and pelvis as well as soft tissues and bones and joints of the spine." Multiple causes, both in and around the spine, can contribute to the production of low-back pain (LBP). Back pain is a clinical manifestation that can be caused by a variety of known diseases and morphological changes (Bergquist-Ullman and Larson, 1977). However, the underlying pathaphysiology for back pain is unfortunately unclear. Rowe (1983) believes that it is not possible to make a definite diagnosis in the majority of cases in their early phases. The likelihood of identifying a specific cause for low-back pain is very small, in the order of 5-10% (Frymoyer et al., 1980) and a definite structural diagnosis can be reached in no more than 50% of all cases (Pope et al., 1979).

The problem is further complicated by the frequent presence of multiple causes in the same patient (Rowe, 1983). Further, there is a wide variation in individual patient response to seemingly similar degrees of pathological changes in the low back. This makes it difficult to judge even the severity of the condition. Lack of satisfactory etiological understanding and the inability to give a precise diagnosis are severe obstacles in the prevention, treatment and prognosis of low-back pain and disability.

LOW-BACK PAIN, IMPAIRMENT, DISABILITY AND COMPENSATION

A distinction should be made between low-back pain, low-back impairment, low-back disability and low-back compensation (Snook, 1985). Low-back pain is generally defined as lumbosacral pain as well as buttock pain and leg pain. It can be acute as well as chronic pain. Low-back impairment represents a decrease or loss of ability to perform various musculoskeletal activities. The decrease in ability is dependent upon the severity of low-back pain. Low-back disability is defined as the time lost from the job, or assignment to restricted duty. Low-back disability is very dependent upon the nature of the job (Rowe, 1983; Snook, 1985; Stubbs et al., 1986). Low-back compensation is reimbursement for lost wages and is dependent upon the nature of the compensation laws. These compensation laws vary from country to country and, in the United States, from state to state. Therefore, the same low-back disability may be compensatory in one state, but not in another. Some studies have shown that the physical demands of the job have little effect on the incidence of low-back pain, but have a much greater effect on the incidence of low-back disability and low-back compensation (Hult, 1954; Magora and Taustein, 1969; Cust et al., 1972; Bergquist-Ullman and Larson, 1977; Rowe, 1983). For example, Hult (1954) reported that 53% of the workers in the light occupations and 64% of the workers in the heavy occupations experienced low-back pain but low-back disability in the heavy occupations was twice as much as in the light occupations. Cust et al. (1972) found little difference between nurses and teachers in overall prevalence of low-back pain. However, LBP came earlier in nurses and was largely precipitated by occupational factors; whereas in the teachers, the incidence of LBP gradually increased with time and it was generally non-occupational in origin. Bergquist-Ullman and Larson (1977) found little difference in LBP between office workers and manual workers, but the latter group had a significantly longer period of disability during the initial and recurring episodes of LBP. Rowe (1983) believes that normally a sedentary worker might be able to perform with a level of low-back impairment which would be disabling for a person with a heavy job.

Rowe (1983) believes that the real objective should be to minimize low-back disability. Snook (1985) also believes that the primary emphasis should be to (i) reduce the number of painful episodes triggered by the job, (ii) allow the worker with the LBP to stay on the job longer, and (iii) permit the worker with LBP disability to return to the job sooner.

CAUSES OF LOW-BACK PAIN

Several different causes of LBP have been identified (Table 2.1). The most common diagnoses include lumbosacral strain and sprain, postural LBP, muscular insufficiency, "sprung back," sacroiletis, annular tears, building disc, degenerative spinal disease, or simply "low-back syndrome" (Benn and Wood, 1975). The most common cause of nonspecific LBP is the degeneration of intervertebral disc (Rowe, 1983). The general attributes of idiopathic LBP are the absence of true sciatica, an increase in pain with increased physical activity and relief with rest (Bergquist-Ullman and Larson, 1977; Damkot et al., 1984).

There in a considerable disagreement as to the cause of LBP (such as muscular deficiency, degeneration of intervertebral disc, facet joint theory, etc.). Kraus (1965), Chaffin et al. (1978), Horal (1969), Cady et al. (1979), Wiesel et al. (1984), and Mayer et al. (1985), etc., have indicated (directly or indirectly) muscle weakness as the cause for LBP. Horal (1969) found that lumbar spine insufficiency was most common in the young-age group, later lumbago set in and became predominant while sciatica developed still later and progressed with increasing age up to 59 years. Klein et al. (1984) reported that muscle strains and sprains constituted the largest single category of back injuries and accounted for 87% of all back compensation claims. Wiesel et al. (1984) reported that the majority of patients were diagnosed as having back strain. Hult (1954), Kellgren and Lawrence (1952) and Horal (1969) reported that more severely affected subjects had degenerative diseases of the spine, including disc disease with or without nerve root involvement and degeneration of the facets. Spangfort (1972) reported that the degree of disc herniation was the single most important factor for the incidence of persistent LBP. Rowe (1963, 1969) and Kelsey and Ostfeld (1975) reported that the prolonged intermittent LBP was often attributable to disc disease.

However, the relationship between the occurrence of disc degeneration and LBP is controversial. Disc degeneration per se is not symptomatic and is a more or less physiological aging phenomenon (Lawrence, 1969; Bergquist-Ullman and Larson, 1977; Andersson, 1981; Rowe, 1983; Pope et al., 1984). Degenerative discs are found in 10% of persons between the ages of 20 to 29, and there is an increase with age to 96% in those over the age of 60 (Lawrence, 1969). Though, there is a lack of conclusive

Table 2.1: Possible causes of low-back pain (Rowe, 1983)

A. Referred Pain from Abdominal or Pelvic Organs

1. Urinary Tract (kidney, ureter, bladder, prostate)
2. Gastro-Intestinal Tract (ileum, colon, rectum)
3. Female Genital System (uterus, ovaries, cervix)
4. Vascular System (aneurism, arterial insufficiency)

B. Pain Originating in the Spine

1. Abnormalities of Bony Structure
   a. Segmentation errors (4 or 6 lumbar, transitional vertebrae)
   b. Ossification defects (spondylolysis, spondylolisthesis)
   c. Dimension and angulation defects

2. Functional Abnormality
   a. Anterior-posterior trunk imbalance (pregnancy, potbelly obesity, pelvic tilt, poor workplace design)
   b. Lateral trunk imbalance (spine curvature, hearing or vision impairment, poor workplace design)

3. Inflammation
   a. Systemic infection or toxicity
   b. Infection of bones or joints (osteomyelitis, tuberculosis)
   c. Arthritis (ankylosing spondylitis, rheumatoid)

4. Metabolic or Hormonal
   a. Osteoporosis (post-menopausal, hyperthyroid or hyperparathyroid)
   b. Diabetes, gout, Paget's disease

5. Degenerative (discs, facet joints)

6. Tumor
   a. Primary of bone (multiple myeloma, hemangioma, etc.)
   b. Primary of spinal cord or nerve roots
   c. Metastases from other organs (breast, lung, prostate, etc.)

7. Injury
   a. Fracture of vertebral bodies or processes
   b. Sprains (ligaments) and strains (muscles)
   c. Acute rupture of disc

evidence, but there are a number of indirect indications that the disc plays a central role in the etiology of LBP (Nachemson, 1971). Also, back pain appears to be more frequent in those having severe degenerative changes involving several discs (Hult, 1954; Caplan et al., 1966; Rowe, 1963, 1965, 1969; Lawrence, 1969; Magora and Schwartz, 1976; Torgerson and Dotter, 1976; Wiikeri et al., 1978). The situation is less clear in moderate or light degeneration (Splithoff, 1953; Hult, 1954; Hirsch, 1969; Horal, 1969; Mogora and Schwartz, 1976) and some studies have reported no strong association between disc degeneration and LBP (Splithoff, 1953; Horal, 1969; Mogora and Schwartz, 1976; Pope et al., 1984). Disc degeneration has also been reported to be more frequent in workers who do heavy manual work (Hult, 1954; Kellgren and Lawrence, 1952; Lawrence, 1969), although the nature of the stress inducing the degenerative changes is not clear (Andersson, 1981). Also, it is not clear why some people with degenerative disc changes suffer LBP or become disabled and others do not. Although it is widely believed that disorders of the lumbar intervertebral disc may be the most common single factor to which back and sciatic pain may (directly or indirectly) be ascribed, there are a growing number who consider that disorders of the apophyseal joints are of equal importance (Farfan et al., 1970; Lamy et al., 1975; Fiorini and McCammond, 1976; Farfan et al., 1976, Pope et al., 1984; Gracovetsky, 1986). At present, it is misleading to select a single factor for the etiology of LBP. Distinctions which exist between these "causes" in theory are not always distinguishable in practice. As stated earlier, multiple causes can contribute to the production of LBP.

A musculoskeletal injury can be triggered by a direct trauma, a single overexertion, or repetitive loading. The strengths of various tissues are affected by such factors as age, fatigue, and concomitant diseases and, therefore, an injury can occur at different loading levels (Pope et al., 1984). In single overexertion injuries and repetitive loading, failure usually occurs at one level while in the case of direct trauma, several different structures can be damaged at the same time. Fatigue failure may not become obvious until complete failure occurs and the final event may be trivial (Pope et al., 1984). Bergquist-Ullman and Larson (1977) reported that the onset-of back pain was sudden in 44% of the group while 56% of the patients reported a more insidious onset. The insidious group also had a longer duration of the initial episode.

Generally, an injury will heal if given sufficient time. Based on a selected population of patients (acute and subacute LBP, duration of pain before entry $\leq$ 3 months and a pain-free year before the onset of current episode), Bergquist-Ullman and Larson (1977) reported that the pain disappeared within 1 month in 35% of the patients, within 2 months in 70% and within 3 months in 86% of the patients. An initial episode of pain lasting more than 6 months was found in 6% of the patients, while 4% still experienced pain after 1 year. More importantly, 62% of the patients had one or more recurrences of pain during the year of observation; 52% of the patients with acute pain changed their jobs; and the intensity of the pain at the first visit was no indication of the duration of pain (Bergquist-Ullman and Larson, 1977).

COMPARATIVE ANALYSIS OF RISK FACTORS: SOME CONCERNS

A voluminous literature exists in which almost every possible contributing factor has been studied. However, there are conflicting studies practically on most, if not all, risk factors identified in the literature. Direct comparisons between epidemiologic studies are often methodologically difficult. A comparative review is almost impossible because the variables studied (such as parameters chosen, population examined, methods of sampling and data collection, occupations studied, task and time scales, etc.) rarely coincide (Troup and Edwards, 1985). Studies are confounded by the high prevalence of LBP in the general population, the wide range of back disorders, its non-specific nature and its frequent association with non-occupational factors. The relationships between the LBP and the risk factors may become more apparent if a precise and accurate measure of outcome were available (Frymoyer et al., 1983). There is also an inherent problem in the epidemiological studies that the observed associations between the LBP and the variables studied may not be causal. It is impossible to determine whether some of the observed relationships were causal, or whether the workers had modified their behaviors, their activities and occupational demands because of low-back pain. There is also the possibility that some of the relationships may be coincidental as significant differences may occur by chance alone when several variables are tested against each other. These indications of possible correlations need to be validated by prospective studies. Therefore, caution is warranted in interpreting the data. In addition to the above concerns, the following problems are identified with the epidemiological data in the hope that future studies may address them in more detail:

(1) There is lack of consistency among investigators of back injuries or LBP with regard to definition of terms. Different definitions of low-back pain have been used. A clear distinction between low-back pain, low-back impairment, low-back disability and low-back compensation has not been maintained. It is widely believed that there is a significant difference in the four measures. Similarly, some studies have included chronic cases while others have studied acute or subacute cases or both.

(2) Different epidemiological measures and time scales were used to quantify the extent of low-back problems in groups of people (lifetime prevalence, period prevalence, point prevalence, incidence ratio, incident rate, etc.). Some researchers believe that different measures are assessing different back pain conditions (Stubbs et al., 1986).

(3) Some studies are based on a single population, occupation or restricted data base (individual insurance companies, specific industrial settings or samples from nationalized health systems) and, therefore, the sample may not be representative of the general population. Lack of controlled studies and differences in the methods of statistical analysis used compound the problem.

(4) In general, studies have relied on self-assessments of physical workloads by the subjects. Uhl et al. (1987) found that the workers perceived themselves to do much more physical work than the observational data could support. For example, the most frequently reported number of patient lifts by the nursing personnel on self-report was ten and the most frequent number of patient lifts by observation was zero. Similarly, Stubbs et al. (1986) found large and significant differences between subjective and observed estimates of time spent in working postures.

(5) Generally, the work has been arbitrarily classified as light, moderate or heavy. Rarely, task variables have been quantified and mechanical load on the spine has been defined and measured.

(6) There is an interactive effect between various personal and task variables. Both somatic and psychological variables may act at the same time and may influence one another (Dehlin and Berg, 1977). Since different workplace factors are often present at the same time, the association with a single factor is difficult to establish because of the interaction between them.

(7) There is a concern that the data derived from compensation claims may have an inherent bias (Venning et al., 1987). It rewards work-related causation but does not show temporary non-compensable disability. A patient is more likely to attribute LBP to a specific occupational event if there is a potential form of compensation (Damkot et al., 1984). Further, time off work may be more a reflection of the demands of the job than the severity of the back pain (Stubbs et al., 1986).

Many sufferers will attribute a cause to an episode of pain. Such associated events, in fact, could be triggers and the true cause may lie in cumulative events.

NEED

Knowledge on workplace and individual factors is far from complete. Certainly, there is a need for long-term, prospective and controlled studies of large samples of many variables to identify workplace factors from which individuals must be protected. Prospective studies are needed so that factors contributing to the development of low-back pain can be differentiated from factors resulting from low-back pain. Nevertheless, this current knowledge about risk factors is our only basis for controlling back injuries and for planning safety strategies (Bigos et al., 1986). There is also a need for developing an improved standardized reporting system in order to monitor the low-back problem.

RISK FACTORS

Many personal and job factors have been studied to determine their association with the incidence and prevalence of low-back complaints. These are summarized in Table 8.2. The capacity to perform the physical work varies considerably not only from individual to individual but within any given individual over time. Furthermore, the limitations of this capacity are complex and interrelated. Similarly, many aspects of the physical act of manually lifting a load have been identified as potentially hazardous to a person's musculoskeletal system. Understanding the relationship between these individual and job factors and the resulting risk of injury to the worker is a prerequisite to the development of schemes for safe workplace designs and placing people in jobs which do not compromise their health and safety. The following is a brief description of personal and job risk factors.

PERSONAL RISK FACTORS

Age

Age brings a reduction in the range of lumbar spinal motion, decline in muscle strength and aerobic capacity, slowing of muscle contraction speed, a decrease in mineral bone content, loss of gel from the nucleus, and an increase in the amount of disc degeneration and an increase in body weight. However, there is a wide variation in both the physiological and anatomical changes associated with aging.

Table 2.2: Risk factors identified in the literature

Personal Risk Factor	Job Risk Factor
Age	Heavy Physical Work
Gender	Lifting (weight, location, dimension, frequency duration, etc.)
Anthropometry (body weight, height)	
Physical Fitness and Training	Bending, Stretching and Reaching
Lumbar Mobility	Twisting
Strength	Pushing and Pulling
Medical History (repeated episodes of low-back pain)	Prolonged Sitting and Standing
Years of Employment	Accidents
Smoking	
Psychosocial Factors	
Structural Abnormalities	

With the usual exception of childhood and adolescence, LBP is common to all age groups. Some studies have shown that age has no significant association with back pain, back abnormalities or time off from work (Magora, 1970; Chaffin and Park, 1973; Kelsey and Ostfeld, 1975; Frymoyer et al., 1983; Astrand, 1987; Uhl et al., 1987). A few studies have reported that younger workers are at a higher risk for back injuries (Ward et al., 1968; Horal, 1969; Blow and Jackson, 1971; Stubbs and Nicholson, 1979; Afacan, 1982; Bigos et al., 1986). Lack of experience or training in handling loads and a tendency to take substantially greater physically demanding tasks are offered as some of the reasons for a higher incidence of LBP among younger workers. On the other hand, the majority of studies has shown that the prevalence of back pain (point and lifetime prevalence, incident rate, etc.) increases with an increase in age up to a certain age (Figure 2.1) (Hirsch et al., 1969; Magora, 1970; Karvonen et al., 1980; Porter et al., 1980; Biering-Sorensen, 1982; Valkenburg, and

Haanen, 1982; Rowe, 1983; Owen and Darmon, 1984; Videmann et al., 1984). Whether this is because older workers are not as likely to be exposed to injury producing stresses of manual materials handling, or whether only those older workers who have survived a rigorous history of earlier stresses remain in the workforce, is not clear.

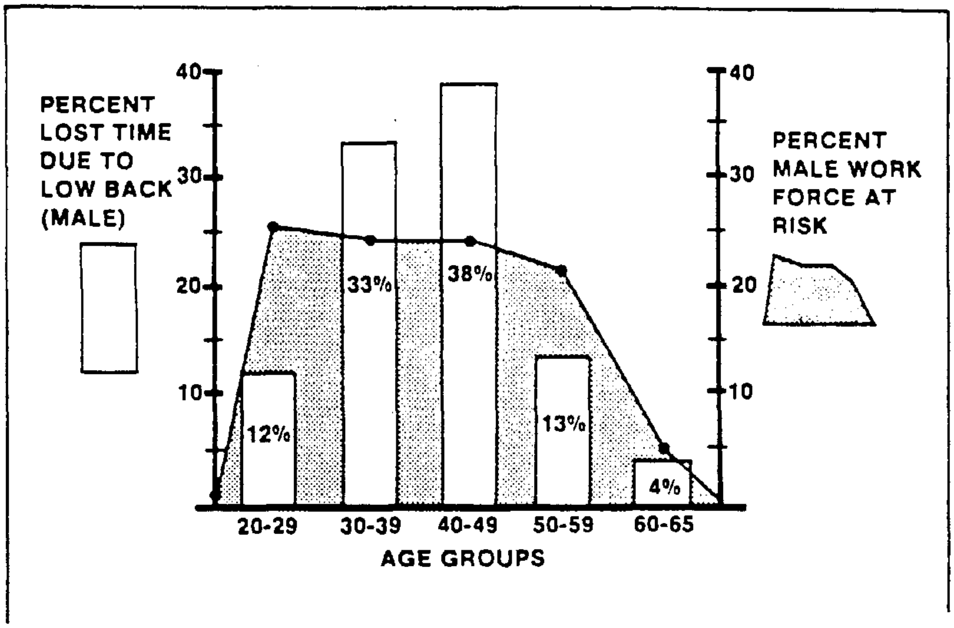

Figure 2.1: Lost time by age. (Men in their thirties and forties, who constitute 46% of the total male work force, account for 71% of lost time from work attributable to low-back conditions (Rowe, 1983)).

The highest incidence of LBP occurs in the thirties and/or forties (Caplan et al., 1966; Hirsch et al., 1969; Rowe, 1969; Brown, 1973; Kelsey and Ostfeld, 1975; Biering-Sorenson, 1982). Most patients who have operations for disc herniations are in their thirties and forties (Rowe, 1965; Spangfort, 1972; Pope et al., 1984). The 31 to 40 year old age group is most susceptible to high cost back injuries (Bigos et al., 1986). However, long-term disabilities and recurrences are more pronounced in the older age group, about 45 to 70 years of age (Hirsch et al., 1969; Horal, 1969; Haber, 1971, Wood and McLeish, 1974; Dehlin et al., 1976). Rowe (1969) believes that LBP attacks usually begin in the late twenties or early thirties, reach a maximum frequency and intensity in the late thirties and forties, and then taper off in the fifties and become more infrequent in the sixties.

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During the twenties and early thirties LBP is likely to appear as a series of sudden acute attacks of short duration and recovery is usually prompt (3 to 10 days). Around the mid and late thirties the pain is more localized. In the forties, radiation of pain down the back of a leg is a frequent occurrence showing positive neurological findings (Row, 1983).

In summary, it appears that (i) LBP usually begins early in life, (ii) the maximal frequency is between the ages of about 35 to 55 years, (iii) recurrences, duration of symptoms and disability increase with increasing age, and (iv) maximum disc surgeries occur between 35 and 45 years of age. Age must, therefore, be viewed as a potential risk factor but the exact form of this risk is not yet fully understood.

Gender

In general, women have lower strength and aerobic capacity than men. Female to male strength ratios range from 35% to 74% (Troup and Chapman, 1969; Laubach, 1976; Chaffin et al., 1977; Yates et al., 1980; Pheasant and Grieve, 1981; Griffin et al., 1984; Garg et al., 1988). It appears that on the average, women's lifting strengths (primarily arm and torso strengths) are about 60% of men's (Asmussen and Heeboll-Neilson, 1962; Troup and Chapman, 1969; Petrofsky and Lind, 1974; Laubach, 1976; Chaffin et al., 1977; Snook, 1978). Hence, if asked to handle moderate to heavy loads, the average woman is more highly stressed than the average man relative to their strengths. Similarly, on the average, a female's aerobic capacity is about 70% of that of a male (Astrand and Rodahl, 1977). The average female is more likely to be fatigued than the average male on those jobs where energy expenditure requirements are moderate to high. However, there are large variations in the strengths and aerobic capacities of both males and females. In other words, there are females who have significantly higher strength and/or aerobic capacity than those of an average male. Gender, thus, becomes secondary to strength and endurance factors per se.

LBP appears as frequently in females as in males (Horal, 1969; Svensson and Andersson, 1982; Valkenburg and Haanen, 1982). There are no differences between men and women regarding duration of back pain and subsequent absence from work (Bergquist-Ullman and Larson, 1977). Hirsch et al. (1969) found a lower frequency of LBP among females than in males. However, when the work situation is taken into account, the pattern may change due to the above mentioned reasons. For example, Magora (1970) reported that 35% of the women in physically heavy jobs had LBP as compared to 19% of the males. Brown (1973) reported similar results. In Sweden, there are higher absence rates in women with physically heavy work than in men doing the same job (Pope et al., 1984). Bigos et al. (1986) reported that women tended to have a higher-than-expected number of high cost claims but lower-than-expected number of low cost claims. Leavitt et al. (1971) and Snook et al. (1978) also reported that women comprised a large percentage of expensive back claims. However, the above statistics are not supported by others. Chaffin and Park (1973) studied both men and women performing equally demanding light-to-moderate load handling jobs and reported an equal incidence of LBP cases. Operations for disc herniations seem to be performed about twice as often in males as in females (Spangfort, 1972; Brown, 1973; Kelsey and Ostfeld, 1975; Lawrence, 1969; Weber, 1983). Workers' compensation claims show that about 75% to 80% of back injury claims are filed by males (Leavitt et al., 1971; Snook et al., 1978; Woodyard, 1980; Johnston, 1982; Klein et al., 1984). It is not clear why men have a greater number of surgical cases for herniated lumbar intervertebral discs and worker's compensation claims. Partially, it may be because more men traditionally have jobs with heavier physical demands than women (Bergenudd and Nilsson, 1988). Chaffin and Park (1973) reported that women were found to be working on jobs with lifting strength rating (LSR) values of about 63% of the men's.

Future studies are needed to study the effect of gender on LBP, while controlling the job physical demands. Based on the current knowledge, it does not appear that gender is a significant risk factor.

Anthropometry

Body weight, stature and body build have been studied to determine their effects on an individual's risk of an injury during manual materials handling. In general, a heavier person is usually stronger than his lighter counterpart and usually has the mass necessary to counter-balance the handling of large objects (Troup and Chapman, 1969; Konz et al., 1973; Chaffin et al., 1976). When lifting, a heavy person may transmit some part of the vertical force directly through the abdomen and thighs to the lower limbs when these parts are in physical contact with the object (Troup and Edwards, 1985). Body weight is also a major factor for most pushing and pulling activities. However, body weight has a direct effect on energy expenditure while lifting and carrying loads (Garg et al., 1978). A heavier person would have a greater metabolic rate and concommitant circulatory load, which would lead to earlier fatigue (Petrofosky and Lind, 1974). Further, obesity prevents carriage of the loads close to the body and may result in greater compressive force on the low-back while lifting and carrying. Also, there is a very wide range of strength in each subgroup, regardless of age, sex, body weight, stature or body build, etc.

Anthropometric data are conflicting, but in general indicate that there is no strong correlation between stature, body weight, body build and LBP. Some studies have reported that people with back-pain are, on the average, taller than those without it

(Rowe, 1965; Tauber, 1970; Gyntelberg, 1974; Kelsey, 1975; Merriam et al., 1983; Biering-Sorensen, 1983). Taller persons often complained of back-hip sciatic pain and had more severe radiological changes. However, height did not appear to play an important role in determining the onset and progress of disc degeneration (Lawrence, 1955).

Brown (1972) suggested that excessive weight made an individual more susceptible to back symptoms. Cust et al. (1972) reported that nurses who were relatively underweight and those who were overweight had a higher prevalence of LBP than those in the normal range. Ikata (1965) and Karvonen et al. (1980) reported that obesity was associated with backache. However, the bulk of epidemiological studies have not been able to support the notion that neither fat nor thin nor tall nor short people are at a signficantly higher risk of LBP (Hult, 1954; Hirsch et al., 1969; Westrin et al., 1972; Chaffin and Park, 1973; Svensson and Andersson, 1982).

It is concluded that the selection of individuals for manual materials handling jobs based on their anthropometry is not justified in terms of low-back pain incidence rates. There is, however, the need to design workplaces based on anthropometric dimensions of U.S. population in terms of reach, mobility and strength. Further, those jobs that do not allow for a large range of anthropometric variation in the population should be identified and specific function limiting dimensions should be stated in the job descriptions.

Physical Fitness and Training

It is widely believed that there would be a reduction in injuries and an increase in capacity for work with an improvement in physical fitness. However, it is not clear exactly what this training should be and how it can be given to the naive worker without harm. Individuals with high aerobic capacity may be fit for those jobs which require high oxygen uptake, but will not necessarily be fit for those jobs which require high static and dynamic strengths and vice versa. In general, fitness for most physical activities requires combinations of strength, endurance, flexibility, musculoskeletal timing and coordination (Cady et al., 1979).

Kraus (1967) believes that more than 80% of low-back pain is due to lack of adequate physical activity. Astrand (1987) reported a strong association between back pain and perceived health and general working capacity. Cady et al. (1979) evaluated male fire fighters and concluded that physical fitness and conditioning had significant preventive effects on back injuries (least fit 7.1% injured, moderately fit 3.2% injured and most fit 0.8% injured). But the most fit group suffered the most severe back injuries. It is possible that more physically fit individuals may have a higher tolerance for minor injuries and, therefore, a higher threshold for injury reporting. In this regard, Brooke (1967) and Scott and Gijsbers (1981) did find an association between athletic performance and pain tolerance.

Based on extensive functional restoration program (specific exercises, training in functional tasks, work hardening, education, psychological counseling, etc.), Mayer et al. (1985) reported that approximately 80% of the chronic LBP patients showed improvement in the functional capacity measures and psychologic measures, and about twice the number returned to work as compared to the comparison group.

Other studies have found that physical fitness and training had either little or no effect in preventing back injuries. Dehlin et al. (1978, 1981), based on the effect of training to increase trunk and quadriceps strengths, reported that increased strengths resulted in a perceived reduction of workload and back symptoms were shorter in duration but not less frequent or intense. They concluded that the effect of training on low-back symptoms was negligible. Cox et al. (1981) concluded that given 20% participation in an exercise class, there is a potential for a 1% reduction in payroll costs resulting from reduced turnover and absenteeism. Kelsey (1975) reported that insufficient physical exercise, as well as participation in some sports (baseball, golf and bowling), were marginally associated with the risk for the development of a prolapsed lumbar disc. Videmann et al. (1984) found no difference in prevalence of back pain between those who were and were not physically fit. The study found that those who exercised two to three times weekly had a higher prevalence of sciatic symptoms than those who did so less often. Bergquist-Ullman and Larson (1977) found no difference in the course of back pain or rate of recovery from acute LBP episodes with improved physical fitness. Similarly, Frymoyer et al. (1983) found no difference between occurrences of LBP and a variety of sporting activities (tennis, football, baseball, basketball, downhill skiing and snowmobiling). On the other hand, cross-country skiing and jogging were associated with complaints of moderate non-disabling pain. Further, subjects with severe LBP had participated in sport activities during adolescence to the same degree as asymptomatic patients and those with mild pain, but had become relatively less active in later years.

In summary, the importance of physical fitness and training in reducing musculoskeletal injuries is generally accepted in the literature. However, epidemiological literature at present does not support the use of physical fitness and training as a primary criterion for preventing musculoskeletal and back injuries. Injuries from training and physical fitness programs are frequent and benefits and risks from these programs are not quite clear.

Lumbar Mobility

Presence of back pain may cause restriction in back movements, especially flexion, but lumbar stiffness itself may not interfere with normal activities, provided that the mobility of the hips and thoracic spine is unimpaired (Troup and Edwards, 1985). Most LBP patients also complain of increased pain when bending forward or extending their trunk. Increase of pain is not frequent in other planes of motion (lateral flexion and rotation) (Bergquist-Ullman and Larson, 1977). There is no evidence that the reduced spine mobility is a risk factor in the causation of low-back pain.

Horal (1969) found "normal mobility" (based on finger to floor distance on bending with straight knees) in 96% of individuals with no recent back pain and in 82% with recent back pain. Biering-Sorensen (1983) reported that the reduced flexibility of the back was more pronounced in subjects who experienced recurrences of LBP. Bergquist-Ullman and Larson (1977) did not find decreased lumbar flexion to have any influence on the risk of occurrence and duration of a LBP episode. Karvonen et al. (1980) found no strong relationship between lumbar mobility and subsequent back pain. Wickström et al. (1978) reported that restricted lumbar mobility was more closely related to age than to back pain.

Strength

Muscle strength has long been considered of importance in relation to LBP. Measurements of trunk strength have been used to determine if there are differences between subjects with and without LBP. Workers' strengths in relation to job physical requirements have also been studied to determine future risks of musculoskeletal and back injuries. This is discussed later in this chapter under prevention of low-back pain.

Many investigations have established that patients with LBP have lower mean trunk strength than healthy subjects (Alston et al., 1966; Nachemson and Lindh, 1969; Pedersen et al., 1975; Nummi et al., 1978; Berkson et al., 1977; Addison and Schultz, 1980; Hasue et al., 1980; McNeil et al., 1980; Nordgren et al., 1980; Langrana et al., 1984; Mayer et al., 1985). McNeil et al. (1980) reported that both male and female patients with LBP and/or sciatica had approximately 60% of the trunk strengths of the healthy subjects. Jorgensen and Nicolaisen (1987) found that the trunk extensor strength was independent of a person's earlier low-back episodes but the isometric endurance time was shorter in those with LBP to a degree that made work impossible than in others. Failure or poor performance in dynamic strength tests of trunk muscles (such as sit-up) is more common in those with previous back trouble (Rowe, 1971; Nummi et al., 1978; Troup and Edwards, 1985). However, this predictive value is not established.

Rowe (1963) reported that when patients were retested a few days later after clearing of the severe pain, some patients showed normal abdominal strength. Similarly, Nachemson and Lindh (1969) reported that those male patients who were incapacitated less than one month did not have significantly lower strength than the control groups. However, those who had been inactive for more than one month had lower extension and flexion strengths. The study concluded that the strengths of spinal and abdominal muscles are of doubtful importance for the prevention of low-back syndrome.

Muscle strength may be influenced by many factors, such as age, height, body weight, training, motivation and fear of pain, etc. Prolonged inactivity imposed by pain resulting in deconditioning, disuse and immobilization (bracing of back) appears to be a major cause for weak trunk flexors and extensors observed in chronic low-back patients (Alston et al., 1966; Nachemson and Lindh, 1969; Mayer et al., 1985). This appears to be true even though the initial syndrome might have been caused by acute muscle strain, disc disease or other organic disorder (Alston et al., 1966). Another major factor for reduced strength appears to be fear of pain and/or injury, intensified by psychological factors such as anxiety and somatization especially in chronic low-back patients (Alston et al., 1966; Nachemson and Lindh, 1969; Mayer et al., 1985). Pain can produce neuromuscular inhibition, joint splinting and lowered performance. Mayer et al. (1985) believe that there is some conscious effort on the part of some LBP patients to mislead the analyst.

The strengths of trunk flexors and extensors without relating these to job physical requirements are apparently of little significance in determining risk of future injury. It is not clear whether the trunk muscle weakness is the cause, effect or mere accompaniment of the low-back pain (Rowe, 1963). Though the mean values for normal healthy subjects tend to be more than for patients with back pain, there is a considerable overlap in isometric trunk muscle strength between those with and without LBP (Alston et al., 1966; Nachemson and Lindh, 1969; Berkson et al., 1977). Some subjects in both groups show similar strengths.

Medical History

Those with a history of back pain have a greater prevalence of back pain and prolonged disability (Lawrence, 1955), Recurrence of back symptoms are reported as high as 85% (Rowe, 1969; Nachemson, 1982) and as high as 50 to 60% in the first year after treatment (Bergquist-Ullman and Larson, 1977; Troup et al., 1981). Rowe (1983) found that 72% of the patients had a history of one or more episodes of low-back disability prior to the compensable incident. It is widely agreed that a previous history of back or sciatic pain is one of the most reliable predictive factors for subsequent work related back problems (Dillane et al., 1966; Rowe, 1971; Karvonen et al., 1980; Nordgren et al., 1980; Troup et al., 1981, 1987; Lloyd and Troup, 1983; Biering-Sorensen, 1983). Hult (1954) and Rowe (1969) recommended that good medical histories are necessary to determine personal risks of incurring repeated episodes. Chaffin and Park (1973) found previous history of LBP to be associated with an increased risk of low-back injury. The study recommended that if a person has a history of repeated LBP episodes, he/she should not be engaged in jobs requiring heavy lifting. It is concluded that the repeated episodes of LBP are a significant risk factor for heavy physical work.

Years of Employment

Some people believe that the lack of experience is associated with the risk of a musculoskeletal injury. However, epidemiological data does not support the above notion. Caplan et al. (1966) and Uhl et al. (1987) did not find length of employment to be a significant factor. Bergquist-Ullman and Larson (1977) reported that only 4% of the patients had been employed for less than one year and 28% had been employed for more than ten years. Harley (1972) reported that a majority of cases appeared after fifteen to twenty-five years at work. Magora (1970) found a positive relation between years of employment and frequency of back pain. Wiikeri et al. (1978) reported that the length of work exposure was strongly related to the degree of degeneration.

Smoking

An association has been identified between smoking and LBP (Svensson et al., 1983; Frymoyer et al., 1983; Owen and Darmon, 1984). Other studies found no association between smoking and LBP (Biering-Sorensen, 1983; Astrand, 1987). Svensson (1983) speculated that coughing leading to increased intradiscal pressure was the mediary in this relationship. Biering-Sorensen, 1983) also found an association between LBP and coughing (but not smoking). However, Frymoyer et al. (1983) found that coughing alone was insufficient to account for the observed differences in LBP patients. The study suggested that smoking might cause a reduction in vertebral-body blood flow. At present, the relationship between smoking and LBP and the role of smoking in the production of LBP are not clear. Future studies are needed on this issue.

Psychosocial Factors

Individual psychosocial factors are commonly found in patients with LBP. Some of these factors include a history of depression, hysteria, hypochondriasis, previous back surgery, alcoholism, extreme religious attitudes, job dissatisfaction, low education level, disabled relatives, family problems, and low level of recreational activities, etc. Although psychosocial factors are unproven as predictors of LBP and other musculoskeletal injuries, some people believe that psychological testing may predict an individual's response to treatment and surgery (Sternback et al., 1973). Others disagree (Kellgren and Lawrence, 1952; Westrin, 1970, 1973; Bergquist-Ullman and Larson, 1977, Currey et al., 1979).

Patients with chronic and disabling LBP often show abnormal findings such as hysteria, hypochondriasis, anxiety, emotional stability, somatization and depression (Sternback et al., 1973; Bergquist-Ullman and Larson, 1977; Frymoyer et al., 1980; Pope et al., 1984). The most widely used test is the Minnesota Multiphasic Personality Inventory (MMPI). However, it is not clear which comes first: the back disorders or psychological problems (Sternback et al., 1973; Magora, 1973; Dehlin and Berg, 1977; Bergquist-Ullman and Larson, 1977; Pope et al., 1984). Also, most of the above mentioned traits have a tendency to become normal after successful rehabilitation (Bergquist-Ullman and Larson, 1977).

Magora (1973) reported a higher incidence of LBP in subjects who were not satisfied with their occupation, place of employment and social status. Also, a higher incidence of LBP was found in those who felt that a higher degree of mental concentration and responsibility was required of them and those who complained of a relatively high degree of nervousness and fatigue after work. Similarly, Dehlin and Berg (1977) reported that nursing aides with back pain symptoms in general exhibited a lower level of overall satisfaction with the job, perceived more negative relations with their supervisors and workmates and perceived a greater demand for physical and psychic strength. Other studies have also shown that patients reporting monotony and dissatisfaction with their jobs have a higher incidence of LBP and a longer absence from work than the satisfied patients (Taylor, 1968; Bergquist-Ullman and Larson, 1977; Svensson and Andersson, 1983; Bigos et al., 1986, Bergenudd and Nilsson, 1988). Astrand (1987) reported that back pain was associated with occupational status, shorter education, duration of employment, low performance on cognitive tests and neuroticism. An association has also been reported between higher socio-economic status and increased occurrence of back and leg complaints (Kelsey and Ostfeld, 1975; Karvonen et al., 1980).

Low-back pain is dependent on a variety of objective and subjective factors and appears impossible to assess objectively. An assessment of psychosocial factors is difficult and often inexact (Magora, 1973). No firm conclusions about the importance of psychosocial factors or the mechanism of the causal association can be drawn from the results of these studies (Bergquist-Ullman and Larson, 1977). It is unclear whether these psychologic abnormalities are the cause or the result of the continued LBP symptoms. At present, the influence of psychosocial factors on LBP has not been fully elucidated.

Structural Abnormalities

A number of studies have been carried out for establishing if a relationship exists between skeletal defects, congenital or acquired, and low-back pain. Medical literature has numerous papers describing the relationship between certain structural defects of the lumbosacral region and the clinical behavior of the back. However, architectural peculiarities of bone are fairly common and can be seen in about 40% of all lower back x-rays (Rowe, 1983). It has been clearly established that different defects do not necessarily give rise to back pain (Splithoff, 1953; Hult, 1954; Rowe 1963, 1969; Horal, 1969, LaRocca and Macnab, 1969, Redfield, 1971; Hodgson et al., 1974; Magora, 1975; Andersson, 1981; Troup and Edwards, 1985).

Structural defects such as scoliosis, hyphosis, hypo- or hyper-lordosis, leg length discrepancy, increased lumbosacral angle, partial and complete sacralization, spina bifida occult, osteoarthritis, spondylolysis and spondylolisthesis do not seem to predispose LBP (Hult, 1954, Kellgren and Lawrence, 1958; Rowe, 1963, 1969; Horal, 1969; Hodgson, 1974; Magora, 1975; Magora and Schwartz, 1976, 1978). It appears that these abnormalities, with the exception of spondylolisthesis, have little predictive value in determining the long-term behavior of the back, at least as a single factor (Rowe, 1983). However, they may have a significance as contributing causes of low-back pain and are associated with increased risk of LBP. Sacralized transverse process is found with approximately equal frequency in patients and in the control population (Rowe, 1969). Spondylolysis does not appear to bear any relation to LBP (Torgerson and Dotter, 1976). Spina bifida occult appears equally frequently both in healthy subjects and those suffering from LBP (Splithoff, 1953; Hult, 1954; Horan, 1969; LaRocca and Macnab, 1969; Magora and Schwartz, 1976). Low-back pain appears to be more common in subjects with spondylolisthesis (Hult, 1954; Fisher et al., 1958; Horal, 1969; Kettelkamp and Wright, 1971; Wiltse, 1971; Magora and Schwartz, 1976), but there are several reports indicating the opposite (Splithoff, 1953; Rowe, 1963; LaRocca and Macnab, 1969). Spondylolisthesis, which occurs in about 6% of the U.S. population, does not always produce pain even over a lifetime of heavy work and is not a definite diagnosis (Rowe, 1983). Scoliosis has received special attention, but there is lack of hard evidence associating sciolosis to LBP (Collis and Ponseti, 1969). The authors reported that most patients with idiopathic scoliosis let active and productive lives despite spinal curvatures of more than 50 degrees in 71%. However, LBP may be more prevalent if the scoliosis is greater than 80 degrees, especially with the vertex in the lumbar region (Andersson, 1981).

Abnormal or asymmetrical placement of the facet joints and the degree of forward slope of the sacrum may have some significance as contributing factors to LBP, but there is insufficient evidence at this point (Rowe, 1983). Normally, facet joints face roughly in a lateral plane and check any tendency toward forward slip of the spine. When they face in the sagittal plane, they provide less stabilizing function, may result in increased shearing stress and may contribute to mechanical instability (Rowe, 1983).

Osteoarthritis (growth of bony bleaks, lips and spurs from the margins of vertebral bodies) occurs as frequently and as severely in patients with no back pain as in those with back complaints (Rowe, 1983). However, if the spinal canal is too small or has an abnormal configuration, disc protrusion of degenerative bony productive changes may produce pressure upon or may cause entrapment of nerve root elements within the canal (Rowe, 1983). Osteoporosis (decalcification of vertebral bone) with macro or micro fractures can cause LBP. However, osteoporosis is no more common in subjects with LBP than in those without it (Horal, 1969; LaRocca and Macnab, 1969). Similarly, no relationship was found between degenerative osteoarthritis and LBP (Magora and Schwartz, 1976).

JOB RISK FACTORS

Heavy Physical Work

One of the problems in the evaluation of the relationship between heavy physical work and LBP is the difficulty in defining and quantifying heavy physical work. Most studies have somewhat arbitrarily classified occupations as light, medium and heavy work. Some have used weight of the load and others high energy demand or subjective perceptions to define heavy physical work. In general, job physical requirements have neither been measured nor quantified. It is also clear that the above classifications of jobs as heavy physical work may not have any significant relationship with the load on the spine during work.

Several investigations have indicated a significantly higher incidence of LBP among heavy industry workers than among workers with less strenuous jobs (Kellgren and Lawrence, 1952; Magora and Taustein, 1969; Lawrence, 1969; Magora, 1970; Chaffin, 1974; Wickstrom, 1978; White and Gordon, 1982; Tabor, 1982; Stubbs et al., 1983; Videmann et al., 1984; Klein et al., 1984; Harber et al., 1985; Bigos et al., 1986; Jensen, 1987, 1988; Valles-Pankratz, 1989). Others have reported either a moderate difference or no significant difference in frequency of LBP between workers on light and heavy jobs (Hult, 1954; Rowe, 1963, 1969; Partridge and Duthie, 1968; Kelsey, 1975; Damkot et al., 1984). Information based on worker's compensation claims and insurance data shows that LBP is much more prevalent in heavy physical jobs (Dehlin et al., 1976; Bergquist-Ullman and Larson, 1977; Jensen, 1987, 1988). Workers with heavy manual jobs are more likely to develop compensable back injuries than other workers (Rowe, 1969, 1971; White and Gordon, 1982; Jensen, 1987, 1988). The severity of back pain is also significantly greater in manual workers than in workers in light jobs. Several studies have reported significantly longer durations of initial and recurrent episodes in heavy jobs than in light jobs (Caplan et al., 1966; Partridge and Duthie, 1968; Bergquist-Ullman and Larson, 1977; Wickstrom, 1978). Wickstrom (1978) reported that those with the heavy jobs had a four time greater lifetime prevalence of lumbar insufficiency, a three times greater prevalence for recurrent attacks of lumbago, and a two times greater prevalence of pronounced sciatica than those with light jobs. A higher prevalence of disc degeneration has also been reported among those who perform heavy physical work (Kellgren and Lawrence, 1952; Hult, 1954; Lawrence, 1969).

It is widely recognized that an increased load on the already afflicted back produces more pain (Hult, 1954; Rowe, 1969; Nachemson, 1971; Magora, 1974; Bergquist-Ullman and Larson, 1977). Also, it is reasonable to assume that back symptoms are much more likely to interfere with work when it is heavy, i.e., a worker with a backache would have more difficulty performing a heavy job than a light one (Rowe, 1969, 1983). For example, Hult (1954) reported that 43.5% in heavy work versus 25.5% in light work had been off work due to LBP. Individuals with severe LBP try to find a job without much manual materials handling (Jensen, 1988).

At present, the specific cause of LBP as related to heavy physical work is not fully clear. However, based on pathobiomechanics of disc degeneration and facet joints, the potential for producing low-back disability is higher in those whose jobs demand heavy physical activity (Rowe, 1983). The potential for overexertion injuries is also greater in heavy physical jobs. Workers in heavy physical work have a much greater need to report LBP symptoms. It is concluded that heavy physical work is a significant risk factor for low-back pain.

Lifting

It has been clearly established that back pain can be triggered by lifting. The combination of lifting, bending and twisting is believed to be the most frequent cause of back injuries. (Andersson, 1981; Rowe, 1983; Kelsey et al., 1984). Unexpected maximal efforts and repetitive heavy lifting are particularly harmful (Magora, 1972; Rowe, 1983; Frymoyer et al., 1983). Several investigations have found a strong relationship between lifting and incidence and duration of LBP (Hult, 1954; Lawrence, 1955; Horal, 1969; Ferguson, 1970; Chaffin et al., 1976; Snook et al., 1978; Ayoub et al., 1983; Frymoyer et al., 1983;

Biering-Sorensen, 1983; Svensson and Anderson, 1983; Greenwood, 1986; Bigos et al., 1986; Jensen, 1988; Klein et al., 1988). Snook et al. (1978) reported that manual handling tasks (i.e., lifting, lowering, pushing, pulling and carrying) were implicated as the specific act or movement associated with back pain in 70% of the injuries (Tables 2.3 and Figure 2.2). Other studies have implicated lifting tasks in 25% to 60% of the back injuries (Cust et al., 1972; Horal, 1969; Ferguson, 1970. Snook et al., 1978; Raistrick et al., 1981; Owen, 1987; Klein et al., 1984, Greenwood, 1986; Harber et al., 1985; Stubbs et al., 1983; Venning et al., 1987).

Many aspects of manually lifting a load have been identified as potentially hazardous to a person's musculoskeletal system (Herrin et al., 1974). These include weight or force required, horizontal and vertical location of the load, shape and size of the load, frequency of lifting, stability of the load, couplings, duration of lifting, workplace geometry, asymmetric lifting and environment, etc. Some of these are briefly discussed here.

Weight of the load handled is perhaps the most obvious factor which modifies risk of injury. As stated earlier under heavy physical work, several investigations have shown that both frequency and severity of back injuries are greater in heavy than in light industries. Herrin et al., (1986) showed that a single task in a job that produces excessive compressive force on the low-back or requires excessive strength would increase the risk of back injuries. Chaffin et al. (1976) reported that heavier jobs (in terms of maximum load lifted) resulted in increased severity of injuries (severe sprains, joint dislocations and bone fractures) in terms of total lost workdays or medical work restriction days. Chaffin and Park (1973) concluded that the "lifting of loads greater than about 35 pounds (16 kg) when held in close to the body, or equivalent conditions, such as 20 lbs. (9 kg) between 25 and 35 inches (64 and 89 cm) in front of the body, would be potentially hazardous for some people." Based on an epidemiological case-control study, Kelsey et al. (1984) concluded that jobs requiring lifting objects weighing more than 11.3 kg (25 lbs) more than 25 times per day had over three times the risk for acute prolapsed lumbar intervertebral disc as compared to those involving lifting less than 11.3 kg. Damkot et al. (1984) also reported that the maximal weight lifting requirements were greater in the severe LBP group as compared to no pain and moderate pain groups.

The physical dimensions of the load handled are important from a biomechanical, physiological, and psychophysical point of view. Several studies have demonstrated that the moment (the product of the weight of the load and the distance from the spinal axis) rather than the weight of the load or lifting method is most important in affecting stresses on the spine (Nachemson and Elfstrom, 1970; Martin and Chaffin, 1972; Tichauer, 1975;

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Chaffin et al., 1976; Chaffin and Andersson, 1984). Chaffin and Park (1973) reported that the incidence rate of LBP was strongly correlated with the lifting strength rating of a job (based on a combination of weight, horizontal and vertical locations of the object, and the strength of a large strong man) (Figure 2.3). In a subsequent study, Chaffin et al. (1976) concluded that "the more remote the load center of gravity from the body (due to either the bulk of the object being handled or the workplace layout), the greater the frequency and severity of musculoskeletal problems and contact injuries." It appears that position of the load relative to the body is as important as the weight of the load within a given range.

Table 2.3: Acts or movements associated with low-back injuries (Snook et al., 1978)

Act or Movement	Percentage of Injuries
Lifting	49
Twisting/turning	18
Bending	12
Pushing	9
Pulling	9
Lowering	7
Sudden change in posture	5
Carrying	5
Slipping/tripping	4
Standing	4
Falling	3
Squatting	2
Catching	2
Sitting	1
Throwing	0.5
Walking	0.5
Shoveling	0
Other	9

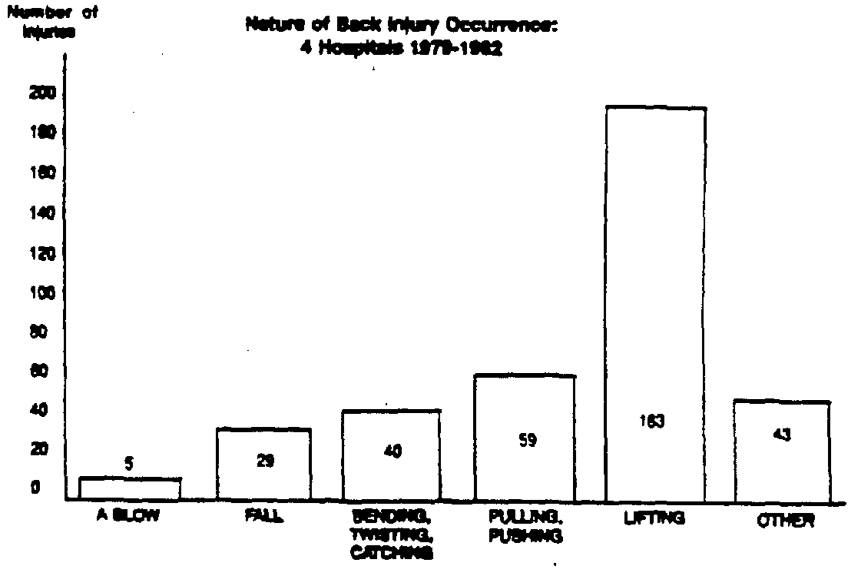

Figure 2.2: Nature of back injury occurrences from four hospitals (Greenwood, 1986).

Frequent lifting is important from both a physiological and psychophysical point of view. Recently, Brinckmann et al. (1988) have raised the possibility of a fatigue fracture with repetitive loading of the spine. In addition to fatigue fracture, moderate to high frequency lifting can cause muscle fatigue, an uncoordinated muscle action during a lift and could accelerate wear and tear in connective tissues. The combination of moderate to heavy loads and frequent lifting can result in physical fatigue as demonstrated by excessive energy expenditure, heart rate and subjective fatigue (Garg et al., 1986). Several investigations have shown that repetitive lifting of moderate to heavy loads is an important risk factor associated with the frequency, severity and resultant disability of LBP (Hult, 1954; Horal, 1969; Magora, 1970; Chaffin et al., 1976; Bergquist-Ullman and Larson, 1977; Frymoyer et al., 1980, 1983; Kelsey et al., 1984; Arad and Ryan, 1986; Venning et al., 1987). Chaffin et al. (1976) concluded 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." Frymoyer et al. (1983) identified repetitive lifting of 20 kg or more as the most important prognosis variable for LBP. Similarly, Frymoyer et al. (1980) found that the patients who reported LBP to the physician had occupations that required more repetitive lifting. Arad and Ryan (1986), based on a survey of nursing personnel in Australia, found a positive relationship between frequency of lifting per shift and one-month prevalence of LBP. Those who lifted 20 or more times per shift had about twice the one-month prevalence

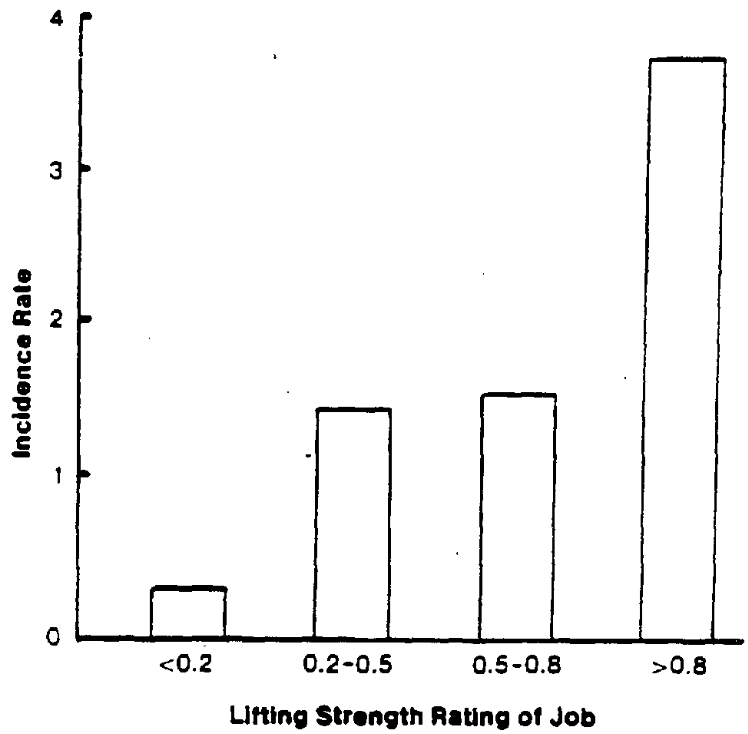

Figure 2.3: Incidence rates of back complaints (per 1,000 person-weeks) related to the lifting strength rating for the most stressful task in the job (from Jensen, 1988 based on data from Chaffin and Park, 1973).

of LBP (54%) than those who averaged zero lifts per shift. Damkot et al. (1984) reported a slight increase in the percentage of men with LBP and the severity of LBP with repetitive lifting. Bergquist-Ullman and Larson (1977) found a significantly longer duration of the initial episode of LBP in those who experienced daily fatigue in their backs and who were exhausted after work.

Sudden maximal physical efforts and unguarded moves have also been found to be related to LBP. Magora (1973) reported that sudden maximal physical efforts, characterized by their unexpectedness, were related to a high incidence of LBP. Bigos et al. (1986) reported haste, speed and inattention as the cause for 18% of all high-cost (> $10,000) low-back injuries. This may be due to sudden strain of soft tissues. Rowe (1965) recommends that the load should at all times be under the control of the person performing the lifting maneuver. Sudden unexpected moves, as in turning suddenly to catch a falling object or having a load shift or slip, may initiate an acute episode of LBP (Rowe, 1983).

Bending, Stretching and Reaching

As mentioned earlier, a decrease in ability to bend forward as well as an increase in pain when bending forward is common among those suffering from LBP. It appears that bending in combination with lifting is the most common cause for LBP (Lawrence, 1955; Troup et al., 1970; Cust et al., 1972, Bergquist-Ullman and Larson, 1977; Snook et al., 1978; Johnston, 1982; Rowe, 1983; Klein et al., 1984; Punnett et al., 1987, Takala and Kukkonen, 1987). Based on a case-referent study, Punnett et al. (1987) concluded that forward trunk flexion (mild or severe), twisting of the spine, and trunk lateral bending were significant risk factors and the risk increased if a person spent more than 10% of the work cycle in a flexed posture. Rowe (1983) suggests that work requiring the maintenance of a slightly trunk flexed posture, such as over a drafting board or a slightly low workbench, or making beds, frequently causes LBP. Cust et al. (1972) reported that bending was the most frequent precipitating event of occupational LBP in teachers. Lawrence (1955) concluded that prolonged stooping (number of years) is associated with loss of work, prolonged disability, multiple discs changes and severe disc degeneration. Snook et al. (1987) reported that 66% of the lifting tasks involved bending but they were associated with 78% of the lifting injuries. Takala and Kukkonen (1987) also reported that persons who lifted in bent positions had more LBP trouble during the preceding year. Garg (1989) reported significantly greater perceived stresses for the back for lifting from floor to bench height than for lifting from bench height to about shoulder height even though the weights at the higher height were about 8% to 30% greater than those at the lower height (Figure 2.4). In this regard, it should be noted that lifting above chest height may result in excessive stresses on shoulder and wrist joints (Figure 2.4). Rowe (1983) believes that lifting loads above chest level with arching of the back may precipitate LBP.

Damkot et al. (1984) found an association between stretching and reaching and LBP. The study reported that in the severe LBP group 59% had jobs requiring stretching and reaching as compared to 36% in the moderate pain group and 40% in the no pain group. The authors concluded that the severe LBP group respondents were more likely to reach with arms fully extended.

Twisting

The association between low-back pain and twisting and bending is difficult to evaluate separately, as lifting is usually also involved (Andersson, 1981). Lifting in combination with twisting and/or lateral bending has been implicated with low-back pain in several studies. Troup et al. (1970) found the combination of lifting, bending and twisting to be the most frequent cause of back injuries in England. Bending, lifting and twisting are believed to be especially representative of body movements contributing to nonaccidental low-back injuries (Figures 2.2 and 2.5). For example, nursing aids who have a much greater amount of lifting, bending and twisting as compared to nurses, also have a very high prevalence of LBP (Greenwood, 1986; Videmann et al., 1987; Jensen, 1987). Frymoyer et al. (1980) found that patients who reported LBP to the physician had occupations that required more twisting. Bergquist-Ullman and Larson (1977) concluded that frequent bending and twisting, fixed postures, lifting and forceful movements, general fatigue and daily back fatigue, etc., were all related to either a longer initial episode of pain or a longer absence from work or both.

Rowe (1983) suggests that lifting and twisting as in swinging luggage may precipitate an attack of LBP. Glover (1960) found that a twisting lift was the commonest cause of LBP in many patients (Figure 2.5). Snook et al. (1978) reported that twisting/turning accounted for 18% of all back injuries. Kelsey et al. (1984) concluded that there was an especially high risk for prolapsed lumbar disc if the job required lifting of objects weighing more than 11.3 kg (25 lbs) while twisting the body even if the lifting was done less frequently (less than 25 times/per day). Also, the authors concluded that lifting while twisting the body without bending the knees was more detrimental. Lifting of objects weighing less than 11.3 kg and twisting without lifting were not associated with an increased risk of prolapsed lumbar disc. In this regard, Punnett et al. (1987) found twisting of the spine and lateral bending to be significant risk factors even if no or relatively light loads were lifted. The study concluded that jobs requiring both mild flexion and twisting were particularly hazardous.

Pushing and Pulling

There are relatively few studies on pushing and pulling activities and their role in work related LBP. Klein et al. (1984), based on workers' compensation data, reported that pushing and pulling of objects accounted for 9% of all back strains and sprains. Snook et al. (1978) reported that pushing and pulling were associated with 18% of all back injuries. Frymoyer et al. (1980) found that low-back patients were more likely to do pushing and pulling tasks than were patients who sought medical attention for reasons other than low-back pain. Similarly, Damkot et al. (1984) reported that severe LBP respondents had much more pushing and pulling (as determined by weight multiplied by number of pushing efforts) than controls. The study also found that the severity of LBP increased with an increase in pushing and pulling requirements. White and Punjabi (1978) showed that high disc loads accompany these activities. It is believed that the coefficient of friction between the shoes and the floor is of primary importance as it would affect the static and dynamic pushing and pulling strengths. Studies by Fox

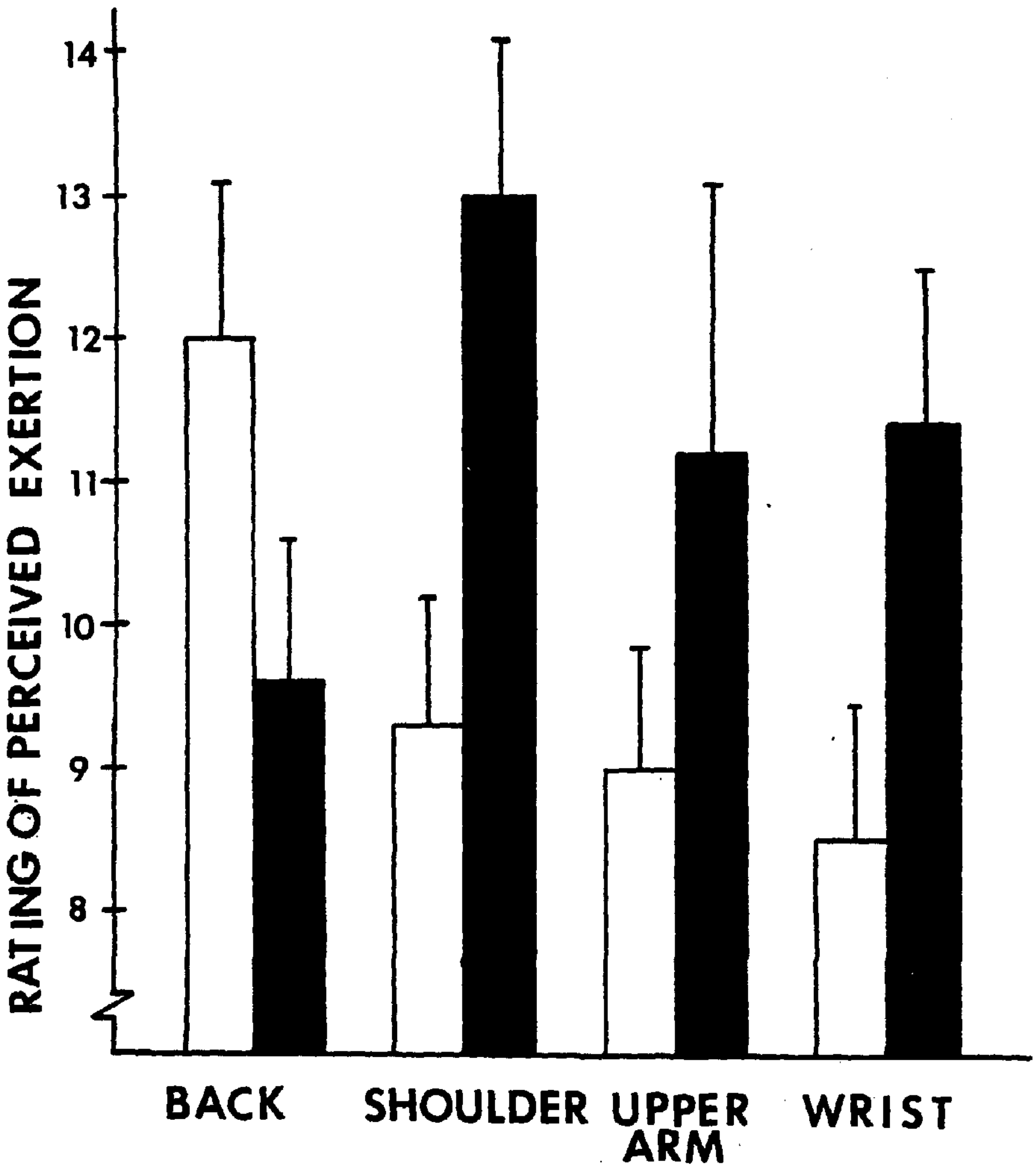

Figure 2.4: Mean ratings of perceived exertion for different body parts for lifting weights from floor level to 0.8 m height (O) and from 0.8 m to 1.5 m height (Garg, 1989).

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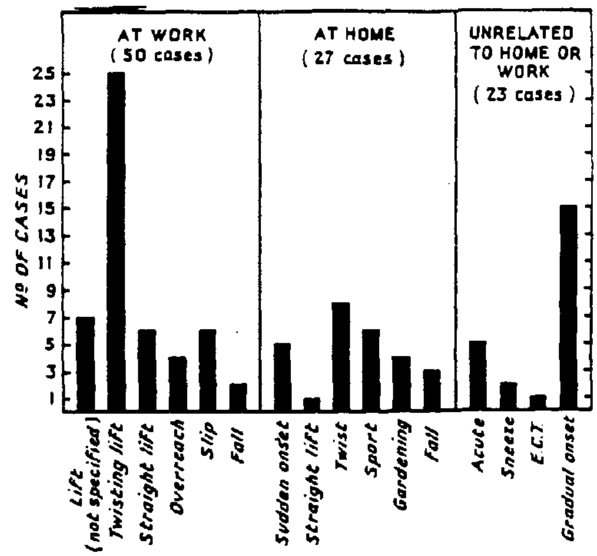

Figure 2.5: Causes of back pain in 100 cases (Glover, 1960).

(1967) and Kroemer and Robinson (1971) showed that the static pushing or pulling strength increased by about 50% (from 200 N to 300 N for healthy young males) with an increase in the coefficient of friction from 0.3 to 0.6. Also, the vertical height of the handle against which one pushes and pulls has a profound effect on pushing and pulling strengths (Martin and Chaffin, 1972; Ayoub and McDaniel, 1974; Lee, 1982; Chaffin et al., 1983, Garg et al., 1988). Based on a limited amount of data, the optimum height for a handle to be pushed or pulled appears to be approximately 90 cm (35.5 inches) to 115 cm (44.5 inches) (i.e., about hip height) to maximize strength and minimize compressive force (Pope et al., 1984).

Prolonged Sitting and Standing

Jobs that require workers to sustain a particular posture for prolonged periods may be associated with musculoskeletal problems related to those postures. Jobs demanding long periods of immobility, either standing or sitting, have been shown to cause muscle fatigue and to have ill effects upon discs (Magora, 1972; Rowe, 1983). Several investigations have shown that jobs that involved nearly all standing or nearly all sitting postures were associated with larger point prevalence or increased risk of LBP than were jobs involving changes in posture (Hult, 1954; Lawrence, 1955; Kroemer and Robinette, 1969. Nachemson and Elfstrom, 1970; Magora, 1972; Kelsey and Hardy, 1975; Bergquist-Ullman and Larson, 1977; Rowe, 1983; Jensen, 1988). Bent-over work postures also have an increased risk for low-back pain as discussed earlier.

Mogora (1972) reported that both too much or too little sitting or standing were related to a high incidence of LBP. Several investigations found an increase in risk of LBP in subjects who performed work in a predominantly sitting posture (Hult, 1954; Lawrence, 1955; Kroemer and Robinette, 1969; Magora, 1972). Kelsey and Hardy (1975) reported that men who spent more than half of their workday in a car had a threefold increased risk of disc herniation. However, it is not clear whether the increased risk is due to vibration or sitting. Nachemson and Elfstrom (1970) reported similar disc pressures for bending forward 20 degrees and sitting unsupported. Other studies did not find sitting to be a risk factor (Westrin, 1973; Bergquist-Ullman and Larson, 1977; Svensson and Andersson, 1983). Troup (1978) suggests that extended sitting may increase the pain and discomfort felt by individuals who already have some back problems. Bergquist-Ullman and Larson (1977) reported that patients who sat less than 2 hours per day bent and twisted their backs more than 10 times per hour and those who were forced into fixed postures for the greater part of the working day had longer durations of initial episodes.

The above studies show that occupations allowing a proper amount of variation of postures are preferable to those which require prolonged standing or sitting. It is important that a worker should be allowed to change work posture. In fact, some studies have reported that postural fatigue and sickness absences decreased when such changes were required (Griffing, 1960; Kroemer and Robinette, 1969; Magora, 1972).

Vibrations

There is no doubt that vibration is a significant risk factor in low-back disorders (Kelsey, 1975; Kelsey and Hardy, 1975; Troup, 1978; Frymoyer et al., 1980, 1983; Wilder et al., 1982; Pope et al., 1984). Vibrations are transmitted through the use of powered hand tools, floors on which the workers are standing (such as pallet jacks) or through the seats of vehicles. Frymoyer et al. (1983) reported that the overall cumulative exposure to vibrational equipment (such as jackhammers, chainsaws and rotary cultivators) was higher in both groups with LBP than in the asymptomatic group. Several studies have shown a relationship between vehicular exposure (vibrations) and frequency and severity of LBP (Kelsey and Hardy, 1975; Pope et al., 1980, 1984; Frymoyer et al., 1983; Damkot et al., 1984). Many vehicles and industrial devices vibrate at a fundamental frequency similar to the body's natural frequency (4 to 6 HZ) (Frymoyer et al., 1983) and amplification of imparted motion occurs in this range. Exposure to these vibrations can cause fatigue of the paraspinal muscles and ligaments and disc herniations (Pope et al., 1984). Kelsey (1975) reported that truck drivers were four times more likely and commuters traveling more than twenty miles/day two times more likely to have had a disc herniation as compared to those who did not hold such jobs.

Accidents

Traumatic events besides manual handling may contribute substantially to the incidence of work related LBP. Some back injuries can be caused by a specific event such as a stumble, a trip, a fall, or an impact (i.e., striking against an object or being struck by a moving object)(Jensen, 1988). In the United States, falls were implicated in 4.3% and involuntary motions in 4.7% of all cases classified as back sprain or strain (Klein et al., 1984). Other investigations have reported much higher statistics. Horal (1969) reported that about 25% of all LBP was due to accidents. Manning et al. (1984) reported that 47% of the true accidents and 24% of all attributable injuries were caused by slipping of feet. Further, the study found that about 26% of the back pain cases involved an unforeseeable event as the cause of the accident (slipping, tripping, stumbling, catching the foot on something, having the surface collapse or tilt suddenly, a sudden unexpected load on the back, blows to the back, and traffic accidents). Bigos et al. (1986) found that about 10% of back injuries were associated with falls and 19% with bodily motions. Also, back injuries due to accidents such as slips or falls had a much greater tendency to result in an expensive claim. Troup et al. (1981) also found that the duration of symptoms and subsequent expense tended to be greater for back injuries associated with an obvious accident such as a slip or fall. Conversely, prospective studies by Weber (1983) and Roland and Morris (1983), indicated that an insidious onset of symptoms rather than sudden onset (such as an accident) indicated a poor prognosis for those having LBP or disc herniation.

PREVENTIVE APPROACHES

Several different criteria have been used to prevent or reduce low-back pain in industry. Some of these include (i) selecting workers based on their anthropometry (age, sex, body weight, height, etc.), (ii) physical fitness, (iii) radiological screening, (iv) training in lifting technique, (v) preemployment strength testing, and (vi) ergonomic job design. The first two criteria were discussed under personal risk factors. The following is a brief discussion of the remaining four criteria:

Radiological Screening

In the past several companies used preemployment radiological screening and claimed a reduction in subsequent back injury rate (Troup and Edwards, 1985). A survey by Poda et al. (1982) showed that only 39% of the American Occupational Medicine Association members used preemployment X-rays routinely and 20% felt that X-rays were useful in predicting future risks. Based on a large study, Rowe (1969, 1971, 1983) concluded that routine radiological screening was "neither cost nor risk benefit effective." In general, there appears to be a consensus that radiological screening should be limited to those with significant back symptoms and/or a past medical history of back problems, except where there is a serious risk of back injury (Troup and Edwards, 1985).

Experience over the past several years has shown that X-rays are of little value (LaRocca and Macnab, 1969; Rowe, 1969; Leavitt et al., 1971; Redfield, 1971; Troup et al., 1974; Alexander et al., 1977; Snook et al., 1978), since individuals with various structural abnormalities of the spine do not appear to have a greater incidence of low-back pain than those with so-called "normal spines." Most structural defects are not significant risk factors for LBP, though some with severe scoliosis (greater than 80 degrees, and spondylolisthesis are more susceptible to low-back pain. There is also the risk that continued spinal radiographs may give rise to leukemia or anemia (Court-Brown and Doll, 1959; cited in Brown, 1973). Snook et al. (1978) reported that the number of injuries experienced by employers who used medical histories, examinations and X-rays were about the same as by employers who used no selection techniques. Leavitt et al. (1971) concluded that "one can not hope to obtain early identification of a major portion of high-cost cases by the use of screening methods." Rowe (1969) estimates that only about 10 percent of the workers who would become low-back disability problems can be identified by the present diagnostic methods at the time of hiring. Studies by LaRocca and Macnab (1969), Redfield (1971), Troup et al. (1974), and Alexander et al. (1977), supported the earlier findings of Splithoff (1953) and Rowe (1969) that the lumbosacral X-rays taken at the time of employment did not predict or screen out injury prone applicants. Redfield (1971) using the criteria of the Ad Hoc Committee on Low Back X-rays (1964) found a lower injury rate for the "high risk" than for the "low risk" group.

In summary, there is little evidence that routine occupational health screening can identify those who may be susceptible to a first attack of back pain. Routine medical examination of all workers is neither necessary nor desirable (Troup and Edward, 1985). However, full clinical assessment may be necessary if the initial screening shows a previous or current health problem relevant to heavy manual work.

Lifting Technique

A substantial amount of literature has been published on lifting techniques. Unfortunately, no controlled epidemiological study has validated any of the contemporary theories on the subject. Proponents of the straight-back, bent-knee lift posture predict their views on a simplistic mechanical logic. They assume that this posture would allow the load to be held close to the torso resulting in a small bending moment and a small and uniformly distributed compressive force on the back (Floyd, 1958; Davis, 1959; Munchinger, 1962; Himbury, 1967; Anderson, 1970; Nachemson, 1971). These analyses do not account for the practical fact that many heavy objects are too large to be lifted between the knees, as is required by the squat lift method. Further, the stresses on the knees and in some cases on the back could be excessive. When the knees are acutely flexed, the thighs and legs cannot exert the thrust needed to lift the load and the body. Also the feet usually are not flat on the floor and may not be far enough apart for good leverage (Davis et al., 1965; Owen, 1985). Troup (1965, 1977) believes that moderate flexion of the torso provides more effective abdominal pressure assistance during lifting and therefore decreases stress on the back musculature. Park and Chaffin (1974) and Garg and Herrin (1979) reported that a stooped over position resulted in about one-third less compressive force on the low-back than the squat posture when lifting bulky loads. Most researchers, however, agree that hyperflexion is potentially dangerous. Ekholm et al. (1982) reported that lifting with straight knees and lifting with bent knees resulted in about the same bending moment and compressive force for loads in front of the body. Several studies have disclosed that leg lifting from a squat position is metabolically more demanding, thus possibly leading to fatigue related injuries (such as slips and falls, dropping objects, etc.) (Brown, 1973; Jorgensen and Poulsen, 1974; Garg et al., 1978; Garg and Saxena, 1985).

Several different lifting techniques have been recommended over the past several years. Some of these include: straight-back, bent-knees (Floyd, 1958; Davis, 1959; Munchinger, 1962; Anderson, 1970; Nachemson, 1971); kinetic method of lifting (International Labor Office, 1967; Anderson, 1970; Davies, 1978); squat position with a flexed (curved) back (Williams, 1974; Adams and Hutton, 1985); squat posture, straddle foot stance and flat back (erect back) (Anderson and Chaffin, 1986); back flexed and knees slightly flexed (Caliet, 1981); free-style posture (Brown, 1971; Snook, 1978; Garg and Saxena, 1979; Garg et al., 1983); and flexed-back and flexed-knee position with feet about a shoulder length apart (Jones, 1973). Unfortunately, there is no concrete evidence that one method is safer than the others. The use of term "right" has led to a rigid discipline which does not allow for any variations within its framework (Brown, 1973). Andersson et al. (1976) believe that the method used to lift a load is relatively unimportant and the horizontal distance is much more important. In certain situations, the practicability of a recommended method is rendered almost impossible by the fact that time standards or production standards are invariably based on traditional work measurement techniques, which do not differentiate between stoop posture and the straight-back, bent-knee methods for determining allowed time for the task and fatigue allowances. Based on a study of three different warehouses, Garg and Saxena (1985) concluded that "it is practically impossible for most workers to meet companies' time standards when using the straight-back, bent-knee method. Time standards based on traditional work measurement techniques do not provide additional time for using the recommended straight-back, bent-knee method even though it is slower and more fatiguing."

Anderson (1970) and Brown (1973) concluded that the systems advocated in the official manuals are incorrect and likely to do more harm than good. Very little research has been carried out to determine the validity of the recommended methods of lifting. So far, lifting instructions have shown little or no effect in controlling low-back injuries (Brown, 1972; Dehlin et al., 1978, 1981; Snook et al., 1978; Stubbs et al., 1983; Wood, 1987; Venning et al., 1987). There is a wide variation in the manner of lifting, and very seldom is the prescribed straight-back, bent-knee method used (Brown, 1971; Garg and Saxena, 1985). This would indicate that either the indoctrination has been unsuccessful or the workers prefer to use some method which is more suitable to their own physical strength and physical anthropology.

Damkot et al. (1984) reported that the severe pain group had much more bending of legs and less lifting with bent back than no pain and moderate pain groups. Stubbs et al. (1983) observed that the low-back pain rates for nurses remained very high even though all of them had participated in a mandatory training program. Dehlin et al. (1981), Snook et al. (1978) and Venning et al. (1987) concluded that lifting instructions and choice of lifting technique did not affect the occurrence of low-back pain symptoms. Based on a study of nurses in a hospital, Wood (1987) suggests that experienced workers will not benefit from training programs as most of them have learned the basic safety elements of the job.

In summary, although instructions on manual handling and lifting are fairly widely believed to have some prophylactic value, there is no scientific evidence that these are, in fact, effective in reducing the frequency or severity of musculoskeletal injuries and, in particular, back pain. As stated by Stubbs et al. (1983), "if the work is intrinsically unsafe, then no amount of training can correct the situation." Clearly, it is not the lifting technique that has a major impact on the relative risk of back injury. It is the job that puts the worker at risk (Venning et al., 1987).

Preemployment Strength Testing

Studies of low-back pain and other musculoskeletal injuries in relation to isometric strength show some predictive value (Chaffin and Park, 1973; Chaffin, 1974; Chaffin et al., 1978; Keyserling et al., 1980, a,b; Cady et al., 1979; Karvonen et al., 1980; Anderson and Catterall, 1987). These studies have demonstrated that both a worker's likelihood of sustaining contact, musculoskeletal and back injuries and severity of injuries increase when job lifting requirements approach or exceed the strength capability demonstrated by the individual on an isometric simulation of the job (Figure 2.6). Similar, observations have been reported by Ayoub et al. (1983) using psychophysically determined maximum acceptable weights (Figure 2.7). The basic premise for preemployment strength testing is that most of the musculoskeletal and back injuries are caused by overexertion due to a mismatch between worker's strength and job strength requirements. In other words, the job physical requirements exceed the physical strength capability of the worker.

Magora (1974) reported that when a job exceeded the lifting capability of the worker, symptomatic low-back pain was more likely to develop. Poulsen and Jorgensen (1971) and Poulsen (1981) proposed that the weight limits should be based on isometric back muscle strength. Chaffin and Park (1973) and Chaffin (1974) reported a sharp increase in the mean low-back pain incidence rates (by a factor of 3:1) for those jobs where the job strength requirements exceeded the lifting strength of the workers. In a subsequent study, Chaffin et al. (1978) confirmed that as the job strength requirements approached or exceeded the demonstrated isometric strength of workers on the job, the mean incident and severity rates increased at a ratio of about 3:1 (Figure 2.6). Keyserling et al. (1980a) supported these findings and concluded that the medical incidence rate of employees who were selected using the strength tests was approximately one-third that of employees selected using the traditional medical criteria. In a subsequent study, Keyserling et al. (1980b) reaffirmed the earlier findings and found significant relationships among job strength requirements, worker strengths and medical incidents. The study concluded that the workers with strength abilities less than job strength requirements suffered a higher rate of medical incidents than workers whose strength abilities matched or exceeded job demands. Recently, Anderson and Catterall (1987) concluded that isometric strength testing by itself can be very effective in reducing contact, musculoskeletal and back injuries. Also, a test of endurance along with strength testing can enhance the effectiveness of a screening battery.

Ayoub et al. (1983) proposed the use of a job severity index (JSI) as a tool for job design and employee placement. The authors showed that the ratio of job physical demand to the capacity of the worker (psychophysically determined maximum acceptable weight) was related to the frequency and severity of back injuries suffered during manual materials handling jobs (Figure 2.7).

It is clear from the above studies that the inability to demonstrate a lifting strength equal to that required on the job is a significant risk factor. However, it can not be stated that physical ability and/or endurance testing will always be effective. Strength testing does not account for hazardous

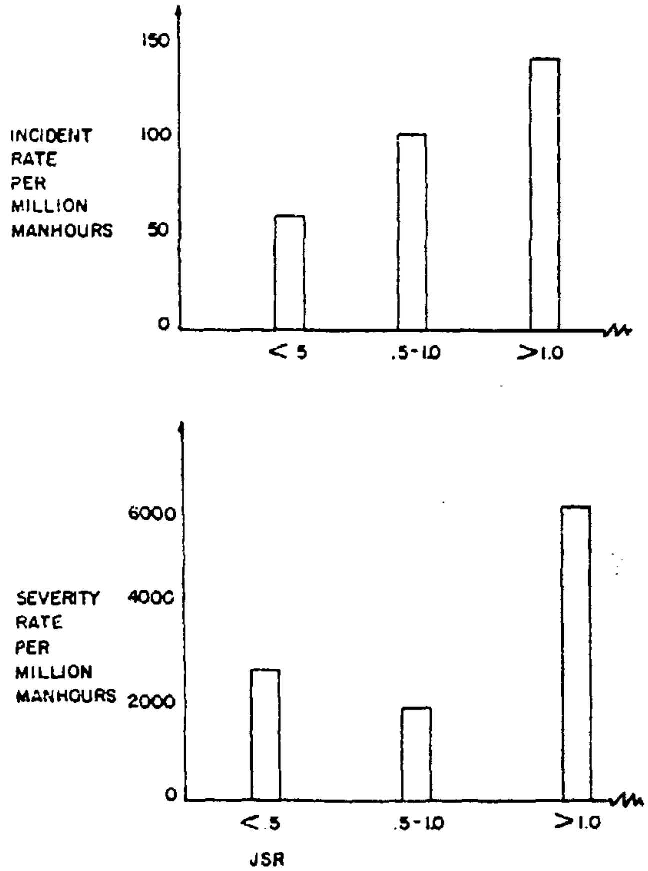

Figure 2.6: Back injuries vs. job strength ratings (Chaffin et al., 1978).

levels of stress to the spinal structure such as high compressive and shear forces. In spite of these concerns, strength testing can be used to identify workers who would be at an increased risk of suffering medical incidents if placed on jobs which exceed their strength capability. Thus, it can be effectively used to minimize overexertion types of musculoskeletal and back injuries such as muscle strains and sprains. In this regard, the preemployment strength testing test should be safe, reliable, related to specific job requirements, practical and should predict risk of future injury or illness.

Ergonomic Job Design

Job design is an ergonomic approach which attempts to fit the job to the worker. As far as manual materials handling is concerned, the objective is to design the job so that (i) physical requirements will not exceed strength and endurance capabilities of a large percentage of workers, (ii) it would not produce undue

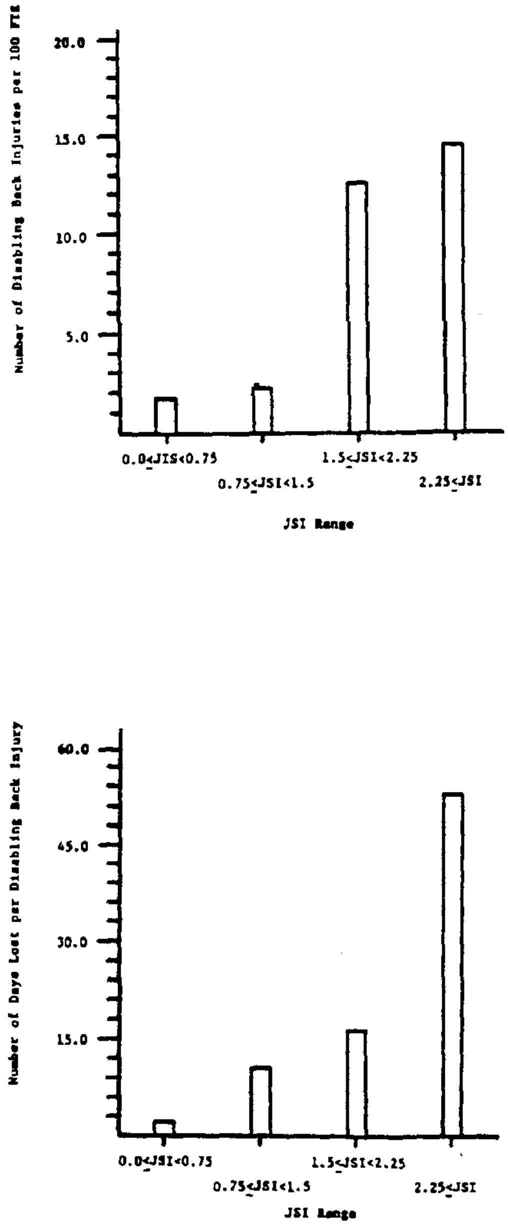

Figure 2.7: Incidence and severity of disabling back injuries caused by lifting versus job severity index (JSI) (Ayoub et al., 1983).

stresses to the spine and other body joints, and (iii) significant workplace risk factors are minimized. The basic premise is that both the frequency and severity of musculoskeletal and back injuries can be minimized if the job is not hazardous to a large percentage of the worker population.

It is widely believed that the most effective control for musculoskeletal injuries, and low-back injuries in particular, is the ergonomic job design (Chaffin and Park, 1973; Snook et al., 1978; Rowe, 1983; Ayoub et al., 1983; Liles et al., 1984; Herrin et al., 1986). Snook et al. (1978) reported that a worker was three times more susceptible to low-back injury if the worker was performing a job which less than 75% of the working population could perform without overexertion. The authors suggested that the ergonomic approach would be more effective if the jobs were designed so that they were within the physical capability of 90% of the working population. Liles et al. (1984) also reported that the disabling back injury rate (worker missed at least one day) increased with an increase in the percentage of overstressed workers (Figure 2.8). Ayoub et al. (1983) also reported a relationship between the job severity index (JSI) and the frequency and severity of back injuries (Figure 2.7).

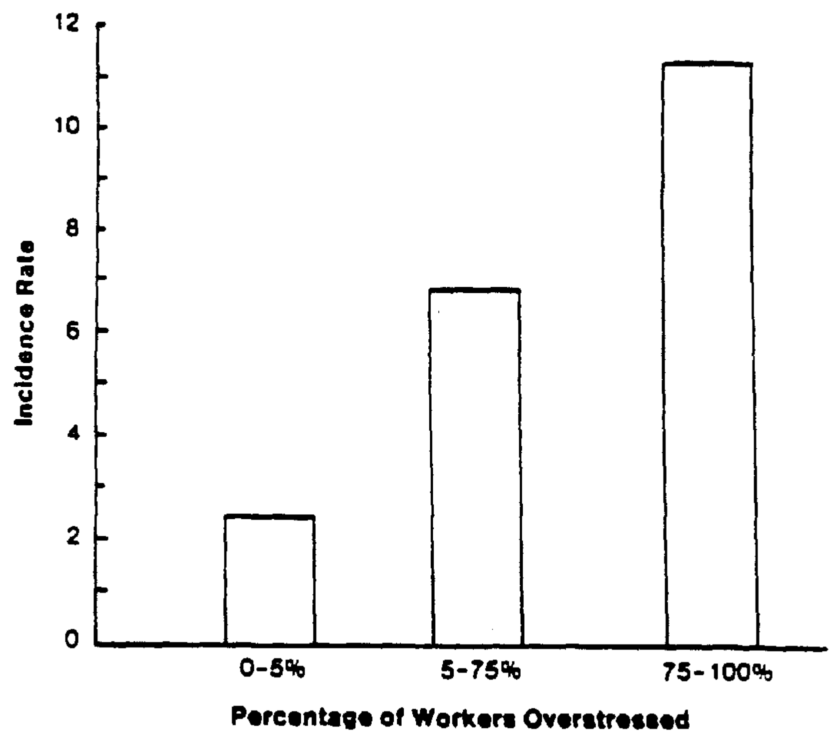

Figure 2.8: Incidence rates of back complaints (per 100 full-time employees) versus percentage of employees overstressed (from Jensen, 1988 based on data from Liles et al., 1984).

Chaffin and Park (1973), based on data involving 103 jobs in five manufacturing plants, reported that a job with even one highly back-stressing lifting task could appreciably increase the risk of back pain complaints (Figure 2.3). The authors also found a correlation between the compressive force on the L_5/S_1 disc and the incidence rate of low-back pain. Jobs with a compressive force over 6236 N (636 kg) had an 8 times greater low-back pain incidence rate than jobs having values below 2673 N (273 kg). Herrin et al. (1986) based on a study involving fifty-five industrial jobs in five industries showed a consistent increase in low-back incidence rate with an increase in compressive force on the L_5/S_1 disc (Figure 2.9). The jobs were classified only on the basis of the most stressful task. The study reported similar findings when the jobs were evaluated using strength requirements instead of compressive force. The study concluded that overexertion injuries can be related to physical job stress and that, in addition to compressive force, the percentage of the population capable of performing the most stressful element of the job is perhaps the best single index. This index can be based upon either isometric strength or psychophysical strength (maximum acceptable weights and forces).

Rowe (1983) believes that the real objective is to minimize disability, and ergonomic job design can significantly reduce

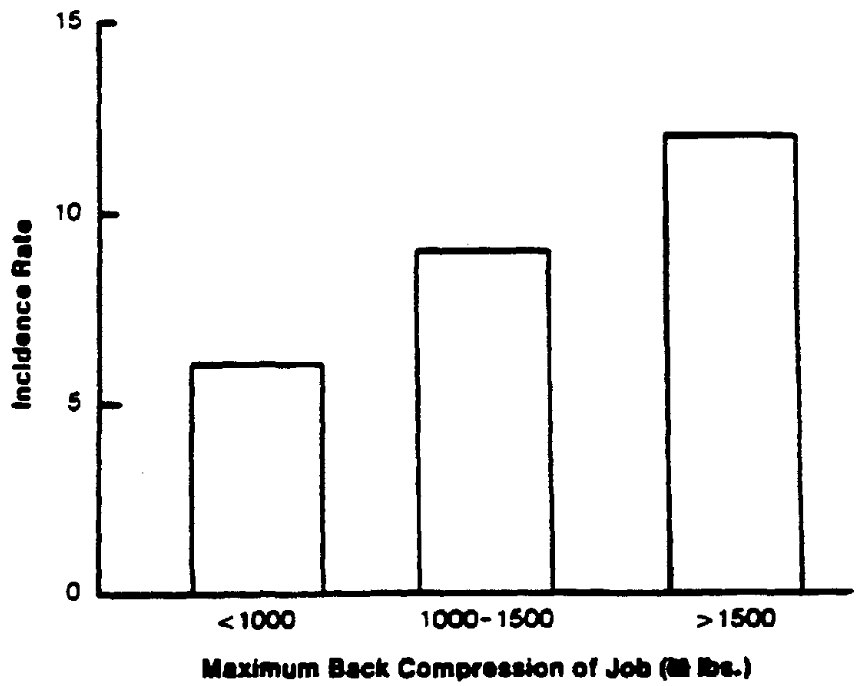

Figure 2.9: Incidence rates of back complaints (per 200,000 hours) versus compressive force on the lower back (from Jensen, 1988 based on data from Herrin et al., 1986).

disability. Adequate job design so that all work falls within the physical capabilities of the majority of workers may allow the workers to continue to work regularly with backache because it would have the same effect as placement in lighter work (Rowe, 1983).

SUMMARY

Low-back pain and back injuries are of such a complex nature that any one criterion cannot be applied by itself to give a valid assessment of the risk associated with manual materials handling jobs. There is no question that low-back pain is an extremely significant cause of disability and has a major socioeconomic impact. Many different personal and job factors are associated with the incidence and prevalence of low-back complaints. There is a need for ongoing systematic investigations of the multiple risk factors that may be causally related to low-back pain and may possibly be preventable. Knowledge of workplace and individual risk factors is far from complete. Prospective studies are needed so that factors contributing to the development of low-back pain can be separated from factors resulting from low-back pain.

It is difficult to relate low-back pain to the workplace because it is found quite often in workers employed in sedentary occupations. However, the incidence, severity and potential for disability are all related to the physical demands of the job. In this regard, jobs involving lifting, lowering, pushing, pulling, carrying and holding; body movements such as frequent bending, twisting and sudden movements; and working in bent-over postures appear to have a significant potential for producing low-back pain. A combination of lifting, bending and twisting appears to be the most hazardous. It is concluded that heavy load lifting contributes to the increased frequency and severity rates for low-back pain. This is true regardless of whether the lifting is performed over a short period or throughout the day and whether it is performed a few times per day or repetitively. If, however, such lifting is performed repetitively, the medical hazard extends beyond low-back problems to other musculoskeletal strain/sprain injuries and fatigue related injuries, particularly for weaker workers.

In this latter regard, gender, age, anthropometry and previous history of back pain are known to modify these risks for populations of workers. The inherent variability between workers and within any worker over time preclude the use of such factors to assign risk to any particular individual. Strength testing, however, is supported as one means for identifying high risk workers who need to perform manual materials handling. Studies are needed to carefully validate the effectiveness of this form of selection procedure. At present, ergonomic job design offers the most potential for preventing low-back pain and other musculoskeletal injuries.

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Biomechanical Basis for Manual Lifting Guidelines

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CHAPTER 3

BASIS FOR GUIDE: BIOMECHANICAL APPROACH

Arun Garg

Biomechanics deals with the laws of physics and engineering concepts applied to the human body to determine motions of body segments and the forces acting on various parts of the body (muscles, ligaments, joints, etc.). It is an attempt to combine physics and engineering with anatomy and physiology. Thus, biomechanics is a multidisciplinary activity. Occupational biomechanics is an applied discipline in the general field of biomechanics. According to Chaffin and Andersson (1984), "occupational biomechanics can be defined as the study of the physical interaction of workers with their tools, machines, and materials so as to enhance the worker's performance while minimizing the risk of future musculoskeletal disorders."

Since back pain has a multifactorial etiology, its prevention requires a biomechanical approach which is equally broad. In addition to engineering and life sciences, occupational biomechanics must include epidemiology, behavioral sciences and psychophysical factors (Troup, 1979). Occupational biomechanics deals with those human disorders and performance limitations which are either produced or aggravated by the mismatch between the human physical capacities and human performance requirements (job requirements) (Chaffin and Andersson, 1984).

Occupational biomechanics is extremely useful in (i) quantifying stresses on various body parts (musculoskeletal system) from manual handling of loads, (ii) determining the risk of an injury from these stresses, especially when combined with epidemiological studies, and (iii) evaluating alternative designs and methods to prevent potential injuries. Knowledge about mechanical and physiological functions of the spine is useful in determining: (i) etiologies of low-back pain syndromes, (ii) quantifying stresses on the spine due to maintenance of body posture and external forces, and (iii) methods to prevent potential back injuries. Additionally, biomechanics plays an important role in determining treatment and care programs for the already injured. This chapter concentrates on the biomechanics of the low back as a basis for a load handling limit.

OCCUPATIONAL BIOMECHANICS OF LOAD LIFTING

It is a well established fact that the stresses induced at the low back during manual materials handling are due to a combination of the weight lifted and the person's method of handling the load. The internal reaction forces needed to equilibrate the body segment weights and external forces (such as weight of the load being lifted) are supplied by muscle contractions, ligaments and body joints. More importantly, the human body acts as a lever system. Specifically, the external forces applied with the hands as well as the body segment weights create rotational moments or torques at various body joints. The skeletal muscles are positioned to exert forces at those joints in such a manner that they counteract the moments due to the load and body segment weights. Since the moment arms of the muscles (and ligaments) are much smaller than the moment arms of the external forces and body segment weights, small external forces produce large muscle, ligament and joint forces. However, the advantage is that the muscles can produce large motions with small degrees of shortening.

For example, consider the task of holding a load, L_h, in both hands with the forearm-hand segments held horizontally and the upper arms held vertically (Figure 3.1). Under static equilibrium conditions:

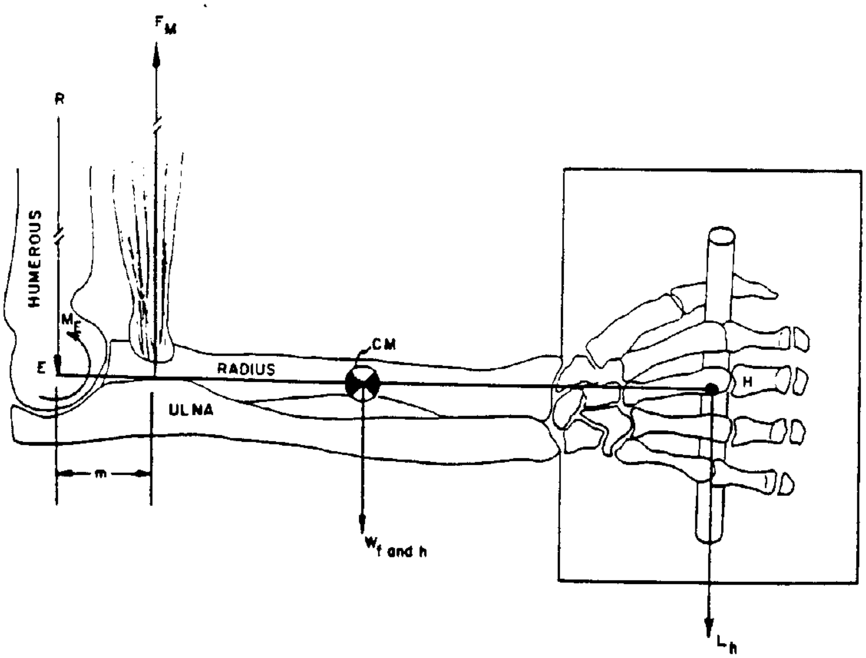

Figure 3.1: Analysis of internal muscle force F_M and joint reaction force R created by weight of forearm-hand $W_{f\&h}$ and load L_h held horizontal. (Chaffin and Andersson, 1984)

$$M_E = 0$$

$$- M_{load} - M_w + M_m = 0$$

where M_{load}, M_W and M_m are moments at the elbow joint due to weight of the load, weight of the lower arm and muscle force. M_E is the net moment at the elbow joint. If it is assumed that the primary muscle action is provided by the biceps brachii and its moment arm is 5 cm from the elbow center of rotation, then for an average male holding a 10 kg mass (98 N load) in both hands (49 N load in each hand):

$$35.5 \text{ cm } (-\ 49 \text{ N}) + 17.2 \text{ cm } (-\ 15.8 \text{ N}) + 5 \text{ cm } (F_M) = 0$$

$$F_M = 402 \text{ N}$$

Thus, holding a load of 49 N (5 kg mass) in each hand creates an internal muscle force requirement about eight times greater (402 N). This mechanical disadvantage of muscles due to their small moment arms can produce high stresses in muscles in certain body postures, even when lifting relatively light loads.

The elbow joint reactive force, R_E, acting on the distal trochlea of the humerus can be determined by balancing the external and internal forces along the vertical axis:

$$F_E = 0$$

$$R_E + F_m - W_{f\&h} - L_h = 0$$

$$R_E + 402 - 15.8 - 49 = 0$$

$$R_E = -\ 337 \text{ (downward)}$$

where $W_{f\&h}$, L_h and F_E are weight of the forearm and hand, weight of the load, and net reactive force at the elbow joint in the vertical direction.

This shows that the high forces created by muscles during a voluntary exertion produce equally large forces on adjoining skeletal structures. This concept of muscles loading skeletal structures is extremely important in the biomechanics of low-back injuries as handling of light loads in certain postures can create large compressive loads on the lumbar spine structures.

One of the assumptions in the above analysis of internal forces is that a single muscular action accounts for the internal force. Often, several muscles share the moment requirement at a joint. For example, if two muscles flex the elbow--the brachialis and the biceps brachii--then there are four unknowns (F_{m1}, F_{m2}, $_3$ and R) and three independent equations ($M_E = 0$, $F_x = 0$, and $F_y = 0$) in Figure 3.2.

Thus, a unique solution is not possible without certain assumptions, as the system is statically indeterminate. Unfortunately, it is not clear which particular biomechanical objective is dominant during the performance of a manual task. Further, subtle changes in body posture may shift load from one muscle group to another and there are wide variations in individual motor behavior patterns. Details of this can be found in Chaffin and Andersson (1984).

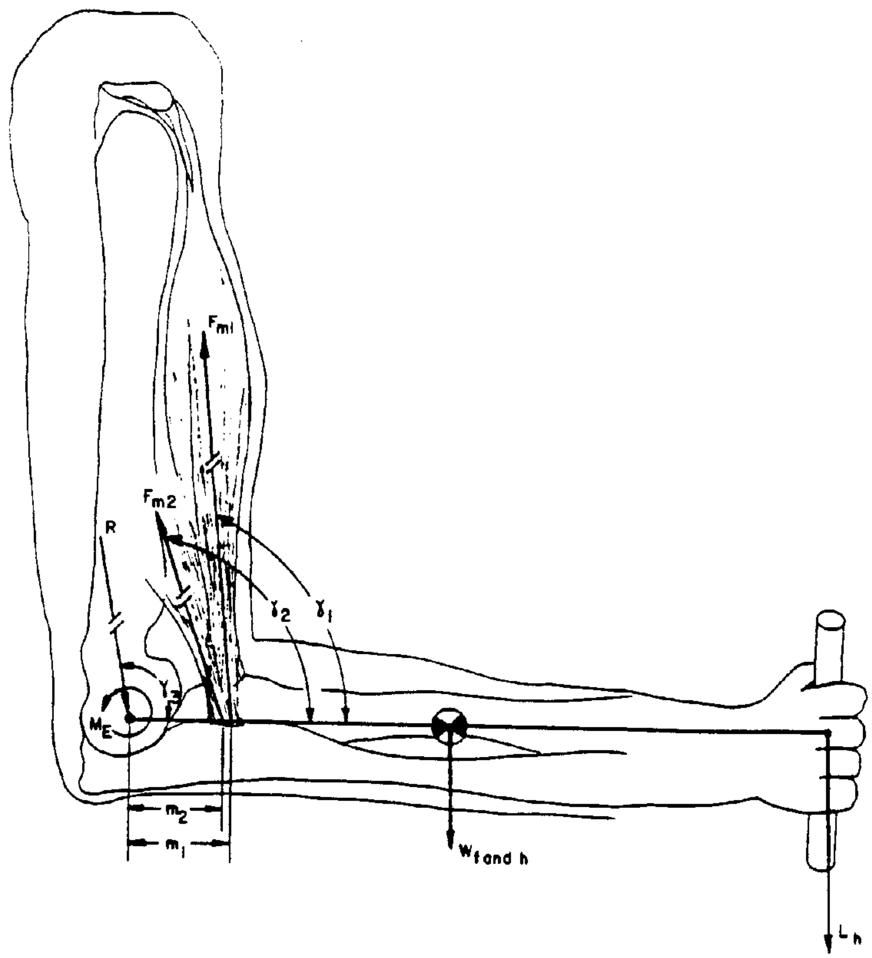

Figure 3.2: Two-muscle system for elbow flexion. (Chaffin and Andersson, 1984)

The second major assumption in the model of the elbow was that there was no antagonistic activity, i.e., elbow extensors were silent. When analyzing the lower back this may be a reasonable assumption when there is no lateral bending and/or axial rotation of the spine involved (Bean et al., 1988). Several studies have shown the presence of antagonistic activity, especially when the trunk is laterally bent and/or axially rotated (Portnoy and Morin, 1956; Andersson et al., 1977; Ortengren and Andersson, 1977; Zetterberg et al. 1987; Pope et al., 1987; Schultz et al., 1987). Biomechanically, the presence of antagonistic muscle activity should result in greater compressive force on the spine.

Lastly, it was assumed in the elbow example that all restorative moment was provided by the muscles. It appears that under certain load lifting conditions, such as for some strenuous tasks, the ligamentous tissues of the lumbar spine may passively provide significant resistance (restorative moment) to external moments (Gracovetsky et al., 1981: Gracovetsky et al., 1985; Anderson et al., 1985; Schultz et al., 1987). This would reduce the muscle contraction forces required to develop necessary restorative moment. At present, it is not clear under what conditions antagonistic muscles and ligaments play an important role, the extent of their involvement and the biomechanical objective function that the body attempts to minimize.

BIOMECHANICAL BASIS FOR BACK INJURY

Injury of the lumbar spine occurs as the limits of maximum stress or strain of the tissues are exceeded. This may happen due to a single strenuous effort or due to repeated loadings. In one case a truly accidental event leads to trauma. More often it is a situation in which there is no disruption in the normal pattern of work, but only an unexpected onset of pain during an everyday task. In the later case it might be assumed that local degenerative changes have increased the susceptibility to a sudden onset of symptoms.

One of the difficulties in analyzing the cause of a back injury is that it can take place without pain because neither the facets of the apophyseal joints (synovial membrane has nerve endings) nor the intervertebral discs receive a nerve supply (Troup, 1979). Thus, two major load bearing tissues of the spine can be injured without pain. "Evidence of old, stable fractures is common in people with no history of injury and there are innumerable cases in which the onset of pain was delayed for 24 hours or more after the injury." (Troup, 1979). If the intervertebral discs and/or apophyseal joints are repeatedly injured, degenerative changes may set in; though radiographic evidence of degeneration is equally prevalent in those with or without low-back pain (Pope et al., 1984). It is generally believed that the low-back pain from occupational and non-occupational physical stresses may be the culmination of a series of truly accidental, but at the time painless, injuries (Troup, 1979). Irreversible mechanical derangement of the intervertebral joint (for example, a decrease in disc height, changes in relative position of the apophyseal joints) may produce clinical symptoms long after the acute phase of injury (Brinckmann et al., 1988). To what extent the intervertebral disc is a source of pathology is not clear, but disc degeneration is often linked to low-back disorders. It appears that chronic low-back pain is often the result of degeneration of the disc (Morris et al., 1961; Armstrong, 1965; Rowe, 1971).

The compressive strength of the lumbar vertebral bodies and intervertebral discs has been the focus of many studies because of clinical interest in disc diseases and their causes. In the healthy spine, the disc is stronger than the vertebral bodies (Roaf, 1960). Cadaver studies show that the cartilage end plates that distribute the compression loads to the bodies of vertebral segments fail (Roaf, 1960; Armstrong, 1965; Hutton and Adams, 1982). A person can sustain a compression injury without a radiographic visible fracture. End-plate fracture may result in intracorporeal nuclear protrusion and loss of disc turgor (Roaf, 1960). Loss of nuclear turgor can cause abnormal mobility between the vertebral bodies and the disc is now vulnerable. Later a relatively minor injury (such as compression or flexion movement) can cause a severe and incapacitating annular prolapse (Roaf, 1960).

The large variations in strength of the cadaver columns may indicate that the cartilage end plates of some people were already weakened by prior stresses, with resulting microfractures and scarring. If true, this would contribute to the disc degeneration that now is acknowledged as being necessary before the more common and most serious discogenic low-back problems can develop. In other words, evidence indicates that large spinal-disc compression forces can be produced by muscular exertion, especially when lifting (Chaffin and Andersson, 1984). These repeated compressive stresses can be sufficient to cause microfractures in the cartilage end plates and subchondral bone of the vertebral bodies. It is believed that repeated microfractures and bone scarring of the cartilage end plate leads to a weakening of the annulus fibrosus of the disc, which thus protrudes into the spinal canal, as shown in extreme form in Figure 3.3 (Chaffin and Anderson, 1984). End plate fractures are always accompanied by an irreversible decrease in disc height and a permanent increase of the radial disc bulge (Brinckmann and Horst, 1985). Bulging or rupture of annulus fibrosus can cause nerve root compression or distortion of the ligaments around the disc or at the posterior facet joints.

It is believed by Rowe (1969) that 70-80% of all chronic low-back pain will be diagnosed as discogenic after a period of repeated episodes. At the very least, degeneration and the narrowing of the disc that results from it will contribute to a more unstable spinal structure. In this regard, Fiorini and McCammond (1976) state: "Many damaged discs showing radiographical narrowing may not cause discogenic back pain at all if there is no disc herniation, but may cause facetogenic back pain by causing subluxation and malapposition of the interarticular joints."

Some evidence that disc degeneration is accelerated by physical stresses has been developed by Hult (1954). He reported that narrowing and osteophyte developments of the discs and adjacent vertebral bodies was 1-1/2 times greater in those people engaged in heavy physical labor than in sedentary workers. In summary, although several low-back injury mechanisms have been proposed (Farfan et al., 1970), disc compression has been named as an important measure of low-back stress causing end plate fracture, disc herniation and nerve irritation.

The above disc degeneration theory implies that assigning a cause for low-back pain cannot be based simply on the immediate circumstances at the time when the pain first developed. In fact, most low-back episodes do not suddenly start with a "jabbing pain," although these cases are easily remembered and reported. Rather the symptoms more often are slow to develop, with stiffness, dull aching pain and, finally, incapacitating discomfort, which occurs possibly hours or even days later.

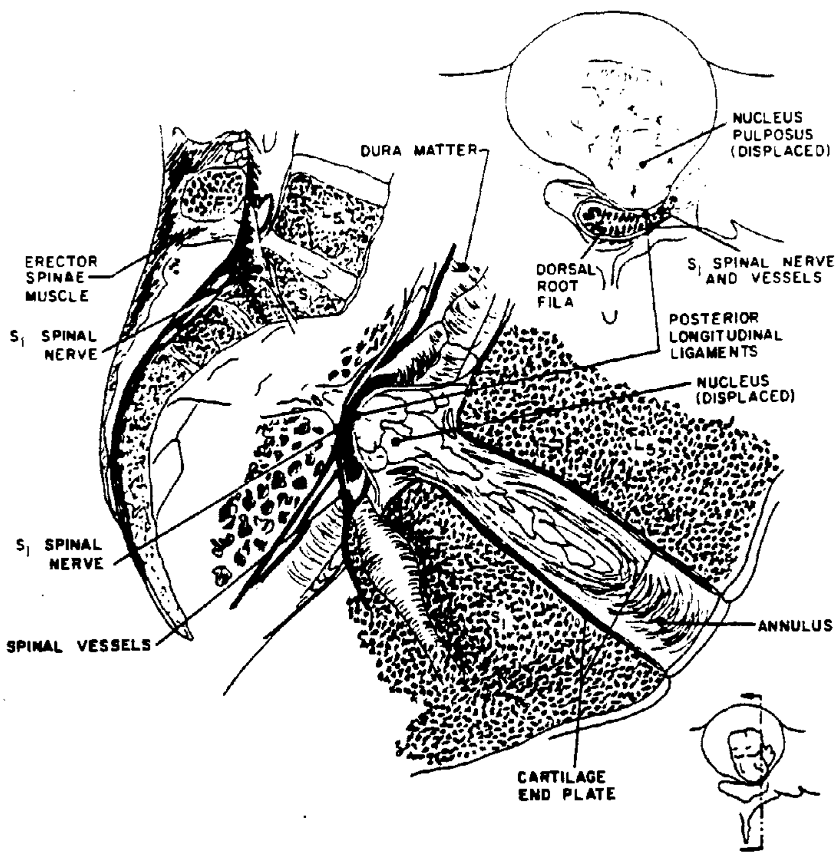

Figure 3.3: Example of L_5/S_1 disc herniation resulting in spinal nerve root compression. (Chaffin and Andersson, 1984)

The disc shear forces, experienced in flexion, extension, lateral flexion and axial rotation, also need some attention. These shear forces are resisted primarily by the posterior facet joints in the lumbar spine and the annulus fibrosus of the disc. Under normal physiological conditions, the facets can resist shear forces (Fiorini and McCammond, 1976). However, the limit to such forces is not well documented (Schultz et al., 1979). Cyron et al. (as stated in Troup, 1977), Lamy et al. (1975) and Farfan et al. (1976) reported about 2,000 to 3,000 N of shear forces as the failure limits for the articular facets. If a disc space is narrowed by degeneration, it may result in abnormally high stresses on the facet joints (Fiorini and McCammond, 1976). These authors also suggest that interarticular facets, being unstable, are more vulnerable to injury and, with their rich blood supply and nerve endings (in synovial membrane), are likely to cause considerable pain. Further, facet joints may be injured simultaneously whenever there is a disc injury or may be injured exclusively without a disc injury.

Virgin (1951), Markolf and Morris (1974), Gracovetsky and Farfan (1986) and Gracovetsky (1986) proposed that instead of intradiscal pressure (nucleus), the annulus is the main load transmission structure. Further, the load transmission capacities of the disc are time dependent because the annulus is made of viscoelastic collagen fibers. Therefore, the amount of load that may be safely lifted depends on time, i.e., heavy loads must be lifted quickly because the amount of load that the annulus can transmit decreases with time. However, Anderson et al. (1985) concluded that annulus rupture due directly to strain on the tissue appeared unlikely, though it could be a problem indirectly via disc degeneration. Hickey and Hukins (1980) concluded that compression was likely to cause end-plate failure rather than the annular failure. According to Roaf (1960), the pressure is mainly transmitted through the annulus only if the nucleus is no longer fluid (for example, older subjects). Roaf (1960) reported that compression of specimens from older subjects in which the nucleus was no longer fluid resulted in either tearing of annulus, general collapse of the vertebrae or a marginal plateau fracture. Nachemson and Morris (1964) suggested that high intradiscal pressure could cause high tangential stress (tensile forces) in the posterior part of the annulus. Thus, high intradiscal pressure could contribute to low-back pain by rupture of the fibers of the annulus, especially in those whom this structure is weakened. Also, a degenerated disc would considerably increase the vertical load on the annulus.

Some researchers (Farfan et al., 1970; Hickey and Hukins, 1980; Farfan and Gracovetsky, 1984; Farfan, 1985; Gracovetsky and Farfan, 1986; Gracovetsky, 1986) believe that torsion injuries are more frequent and more damaging than compression injuries. Torsion injuries involve peripheral damage to both the disc and the facet joints. These and other issues are discussed later under biomechanical models and asymmetric lifting.

The following studies and others mentioned in the next subsection provide additional support for using compressive force as one of the criteria in developing "safe" load limits.

Krämer and Gritz (1980) reported that body stature underwent a normal dirunal shrinkage of the order of 1.1% attributable to loss of disc height due to the cumulative effects of loading during the day. Fitzgerald (1972) demonstrated losses in overall stature in healthy young adult males with the shoulder load of 88 N (erect posture) for 20 minutes and recovery took about 10 minutes. Eklund and Corlett (1984) reported that shrinkage rates were closely related to the calculated levels of spinal compression at the level of L_3.

Whenever a compressive load produces a tissue pressure which is greater than the osmotic pressure, fluid is expelled from the disc (called creep effect, (Kazarian, 1975)). When the fluid is expelled from the disc, it narrows and this affects the dynamics of the intervertebral joint. The area of contact between the bearing surfaces of the apophyseal joints changes as these are compressed and strained and the intervertebral joint becomes stiffer. Thus, under the load, the capacity of the tissues to dissipate energy and their ultimate strength are reduced (Kazarian, 1975).

COMPRESSIVE STRENGTH OF LUMBAR SPINAL COLUMN

The maximal amount of compression that can be tolerated by the lumbar spinal column has been estimated from axial compression loading tests on cadaver columns. Load to failure performed in a single test determines the ultimate strength of a structure. The ultimate compressive strength of human lumbar vertebrae is presented in Figure 3.4. In general, the ultimate compressive strength varies between approximately 3 kN and 12 kN (Jäger, 1987). The mean value of lumbar compressive strength from the 283 experiments shown in Figure 3.4 was calculated as 5.1 $\pm$ 2.3 kN (Jäger, 1987). Bartelink (1957) found that discs were destroyed by forces ranging from 1.56 kN to 6.68 kN with a mean of 3.12 kN. Recently, Brinckmann et al. (1988) data showed ultimate compressive strength ranging from 2.1 kN to 8.8 kN (with the exception of one cadaver column). Also, an analysis of their data showed that about 30% of cadaver spinal columns fractured at loads below 4 kN and about 63% of cadaver spines had the ultimate compressive strength of 6 kN or less. Large variability in measured compressive strength within a study and between different studies makes it difficult to provide a single value of spinal compressive strength that would be valid for all persons.

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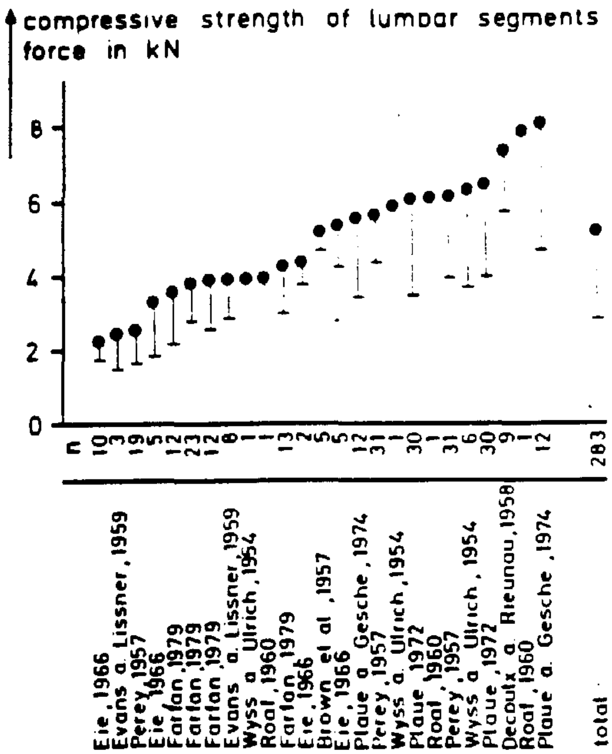

Figure 3.4: Morphological studies to determine the fracture load of lumbar segments of various length. (Jäger, 1987)

The strength of vertebral bone is primarily related to its mineral content (Hansson, 1977), bone material properties (Brinckmann et al., 1988), bone dimensions and experimental techniques (Brinckmann et al., 1988). Compressive strength of vertebral bodies varies with duration of applied stress (Perey, 1957), i.e., the longer the spine is subjected to a given compressive load, the greater the likelihood of damage. It also depends upon strain rate (Hutton et al., 1979; Troup and Edwards, 1985), i.e., how quickly the loading is applied. Hutton et al. (1979) reported a significant increase in breaking load at the faster strain rate due to viscoelastic properties of the bone. It also depends upon existing degenerative changes (Hansson and Roos, 1981). When degenerative changes have set in the spine becomes more susceptible to non-bony injury (Troup, 1979).

The disc is the strongest in young adults and weakens slowly with age (Perey, 1957; Hutton and Adams, 1982). Figure 3.5 illustrates data from Evans (1959) and Sonoda (1962) by age group. In general, the data from male cadavers disclose a mean of about 6.6 kN (675 kg) for those under 40 years of age and 2.4 kN (250 kg) for those over 60 years of age before the cartilage end plates begin to exhibit microfractures.

Sonoda (1962) estimates that the female's spinal compression tolerance is about 17% less than the male's. This would be consistent with the smaller force-bearing area of the vertebral bodies in a woman's spine.

The vertebrae are also subject to fatigue failure owing to repeated loading (Troup, 1977; Brinckmann et al., 1988). Under repeated loading by a compressive force, the height of a motion segment specimen (two vertebrae with intervening disc) decreases slowly due to viscoelastic deformation and water loss of the disc. A sudden irreversible height loss is interpreted as a compressive fracture (fatigue fracture). Brinckmann et al., (1988) showed that the probability of encountering a fatigue fracture increased both with the number of load cycles and the magnitude of relative cycle load (% of ultimate compressive strength). "At loads below 30% of compressive strength, practically no fractures were observed up to 5000 load cycles. At loads above 70%, specimens will sustain only a few cycles to fracture," (Brinckmann et al., 1988). Results of this study are presented in Figure 3.6. It was stipulated by Brinckmann et al. (1988) that fatigue fractures of lumbar vertebrae would occur in vivo. However, such issues as time interval for load cycles, periods of rest, strain rate, maximum load in consecutive load cycles, etc., need to be addressed before these results can be applied. Further in vivo effects of tissue repair are not clearly understood.

This is an important finding and shows that the compressive strength is significantly lower under repeated loading of spine. This conclusion is also indirectly supported by Chaffin and Park (1973), who found increased risk of back pain in persons performing more that 150 lifts per day. Secondly, since strength of vertebral bodies decreases substantially with age, very low cyclic loads might induce fatigue fractures in the spine of older workers. However, from in vitro experiments, no direct conclusions can be drawn whether or not clinical symptoms originate in vivo from end plate fractures. This is a topic which needs to be further investigated.

Though several researchers have developed various biomechanical models to study compressive and shear forces on low back from manual materials handling tasks, only a few studies have been reported on the relationship between the estimated compressive force and the observed incidence rates of low-back pain. Chaffin and Park (1973) reported that incidence rates for

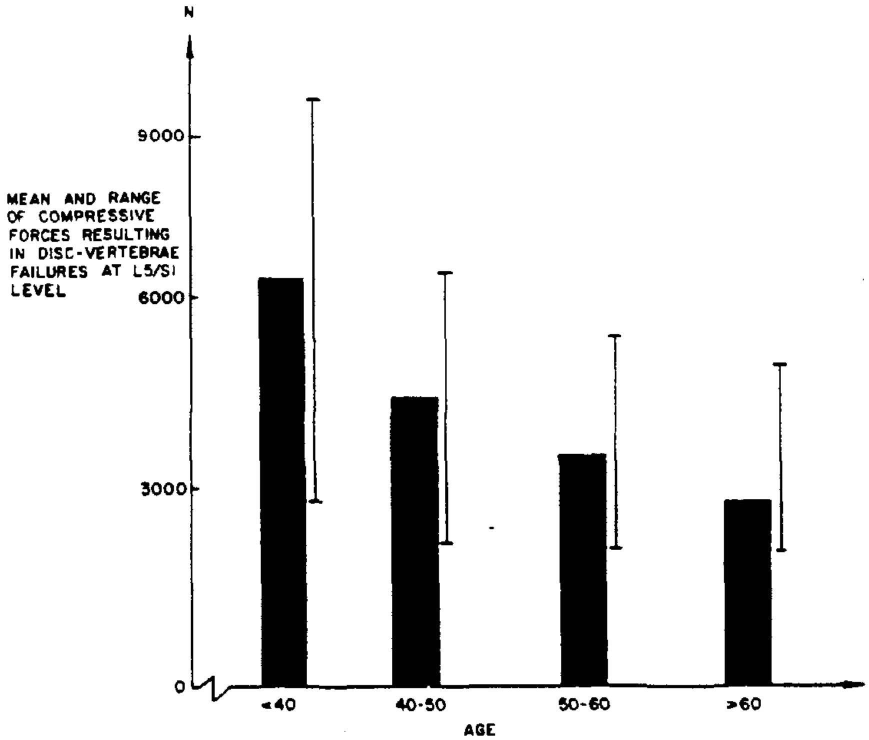

Figure 3.5: Composite of compression failure values obtained from cadavers of different ages. (Evans, 1959; and Sonoda, 1962)

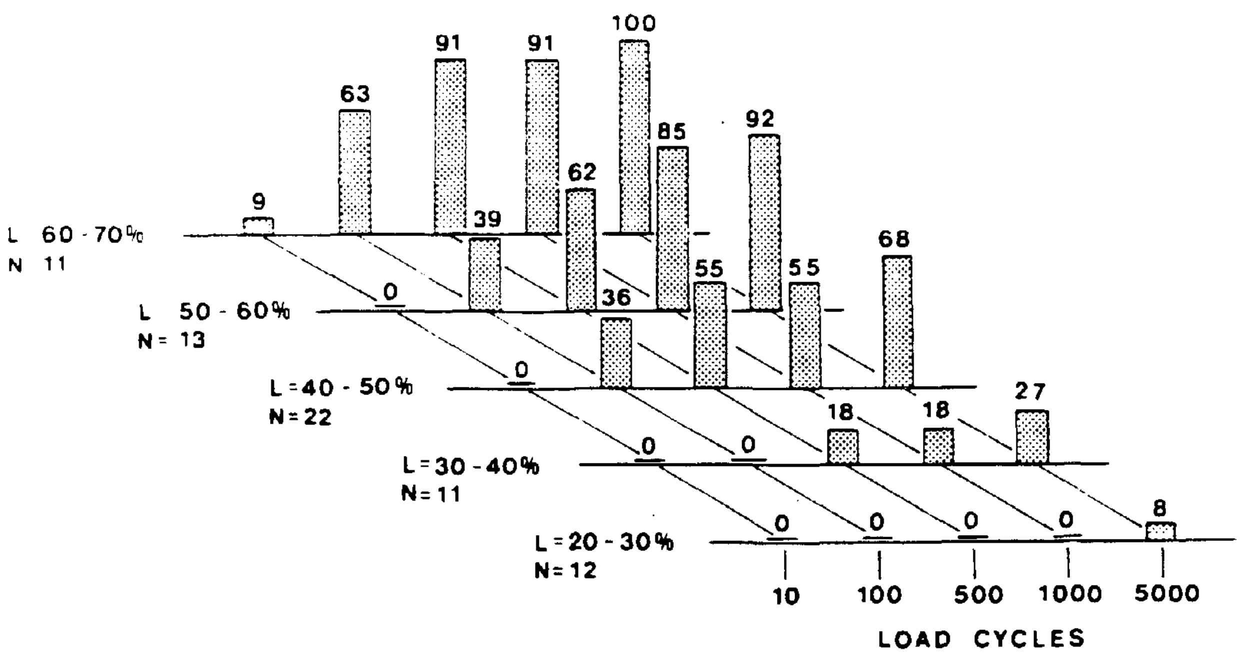

Figure 3.6: Probability of a motion segment to be fractured in dependence on the load range and the number of load cycles. (Brinckmann et al., 1988)

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low-back pain were related to compressive forces on the L_5/S_1 disc (Figure 3.7). Further, the low-back pain incidence rates were significantly higher when the predicted compressive forces were greater than 6.37 kN (650 kg) (Figure 3.7). Bringham and Garg (1983) analyzed 109 cases of overexertion injuries over a period of three years in one company. There were ten cases of back injuries (including both muscular strains and disc injuries). In eight out of ten cases where muscular strains occurred, the average estimated compressive force was 5.34 kN. In two cases where disc injuries occurred, the average compressive force was 7.97 kN. Anderson (1983) reported a 40% increase in incidence rates for jobs requiring male compressive forces above 3.4 kN vs. below that level. Based on a study of 6912 incumbent workers in 55 industrial jobs in five industries, Herrin et al. (1986) concluded that "the biomechanical criterion of maximal back compression appears to be a good predictor not only of risk of back incidents but of overexertion injuries in general."

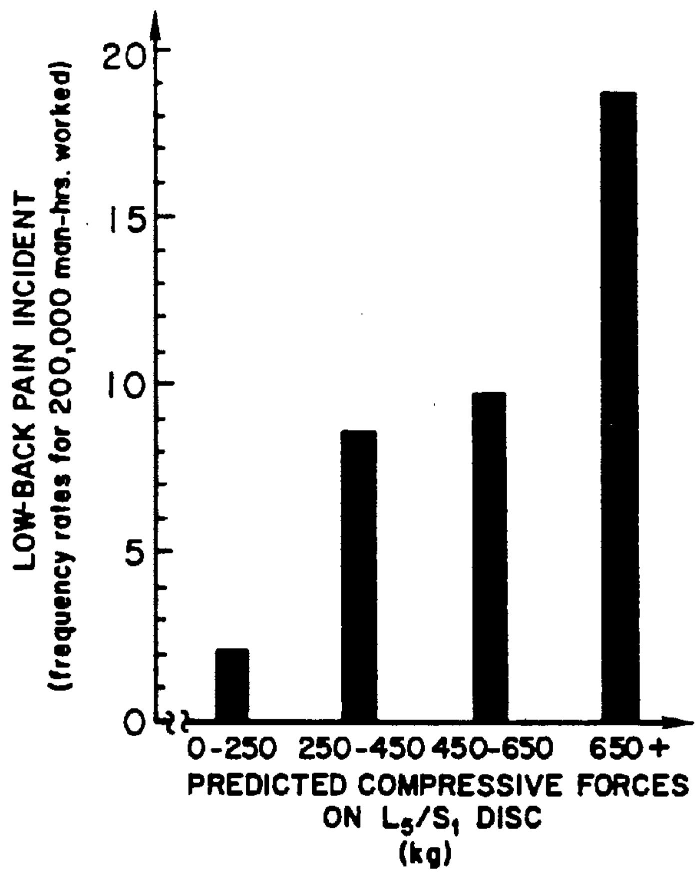

Figure 3.7: Relation between LBP and compressive Force. (Chaffin and Park, 1973)

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Once again, from the above discussion it appears that it is difficult to provide a single value of spinal compressive strength that would be valid for all workers and for different work practices. However, it is apparent from Figures 3.4, 3.5 and 3.7 that jobs which place more than about 6.37 kN (650 kg) of compressive force on the low back are hazardous to all but the healthiest of workers. Only three out of twenty-five studies (or 12%) in Figure 3.4 reported mean fracture load greater than 6.4 kN. Similarly, an analysis of Brinckmann et al. (1988) data showed that only six out of thirty-five (or 17%) cadaver spinal columns had ultimate compressive strength of more than 6.4 kN under static load. Therefore, in terms of a specification for design, a much lower level should be recommended. It is clear from Figure 3.4 that only 12% of the studies have reported a mean compressive strength of less than 3.43 kN (350 kg). Brinckmann's et al. (1988) data showed that about 20% of the cadaver spinal columns had an ultimate compressive strength of less than 3.4 kN. Thus, a value of 3.4 kN may not be protective for certain individuals, especially for those over 60 years of age (Figure 3.5) or for those suffering from degenerative changes. Also, breaking strength under a given compressive load may be lower when the spine is subjected to additional shearing and rotational forces (Troup and Edwards, 1985). However, it is difficult to support a lower limit for ultimate compressive strength at this time, based on current knowledge of spinal compressive strength, recognizing in vitro limits may not be exactly applicable to in vivo, and given that several low-back injury mechanisms have been proposed. For repetitive lifting, those values may be lowered in the future as more knowledge is gained regarding fatigue fracture of the spine.

BIOMECHANICAL MODELS

From a biomechanics point of view, "safe" weight of a load depends upon: (i) capacity of muscles to develop appropriate tension (muscle strength), (ii) postural stability of the body (body balance), and (iii) compressive and shear forces on the spine assuming that stresses on ligaments and other musculoskeletal structures are not excessive. For example, the maximal weight for symmetric sagittal plane manual lifts in the erect standing posture usually depends upon the strength of the elbow and shoulder flexors even though the compressive forces on the spine may be small and one may have strong back and lower extremity muscles. Similarly, when lifting loads near the floor level or when lifting large objects away from the body, one may have sufficient muscle strength, but compressive forces on the lumbar spine are generally fairly high. When working in constrained work spaces or when the spine is laterally flexed, axially rotated or flexed (to reach for objects away from the body or grasp large objects), postural stability becomes a major problem in addition to compressive and shear forces and muscle strength requirements. Postural stability is also a major concern in those work situations where the foot traction is not sufficient.

Although intradiscal pressures (in the nucleus of the intervertebral disc) have been measured by Nachemson and Morris (1964), Nachemson (1965), Nachemson and Elfstom (1970), Andersson et al. (1977), Nachemson (1981) and Schultz et al. (1982) in laboratory studies under controlled conditions, such measurements are not recommended due to safety requirements and probably are not feasible in field studies. Most often, one has to simulate a given manual handling task using a biomechanical model to determine all three requirements of the task and, in particular, compressive force on the lumbar spine.

Several two and three-dimensional static and dynamic biomechanical models have been developed to determine stresses from manual handling tasks. Some of the static models include Chaffin (1969), Martin and Chaffin (1972), Garg and Chaffin (1975) and Anderson et al. (1985) and dynamic models include Grieve (1974), Troup (1977), Ayoub and El-Bassoussi (1978), Ekholm et al. (1982), Garg et al. (1982), Leskinen et al. (1983), Bejjani et al. (1984), Freivalds et al. (1984), McGill and Norman (1985) and Hall (1985), etc. However, most of these models used a single muscle equivalent to account for internal trunk muscle forces and resulting compressive and shear forces. The two-dimensional models appear to be satisfactory in analyzing two-handed symmetric sagittal plane exertions. Recent model validations of Garg and Chaffin's (1975) model showed a high correlation between the measured and the predicted strength--r^2 between 0.85 and 0.88 (Chaffin et al., 1987). However, for two-handed asymmetric exertion results were not as good--r^2 between 0.54 and 0.74 (Chaffin et al., 1987). The contemporary three-dimensional models of the trunk also showed that when the external moment is purely flexion (such as in symmetrical sagittal plane exertions), only the erector spinae muscles were active (Bean et al., 1988; Schultz et al., 1982). On the other hand, tasks involving extension, lateral bending and twisting moments tend to recruit many of the lumbar trunk muscles. Also, erector spinae muscles can be represented more easily by a single muscle equivalent than latissimus dorsi or the oblique abdominal muscles (Schultz et al., 1982).

More contemporary models of back include Schultz and Andersson (1981), Gracovetsky et al. (1981), Schultz et al. (1982), McGill and Norman (1986), Jäger (1987), Bean et al. (1988), Chen and Ayoub (1988), etc. These are three-dimensional biomechanical models of the lumbar back based on several muscle groups to more accurately reflect the muscle activities and compression and shear loads on the spine. Examples of typical simple coplanar and three-dimensional models of the trunk are shown in Figures 3.8 and 3.9. As stated earlier, more unknown internal forces and fewer equations of equilibrium make the three-dimensional models of the trunk statically indeterminate. Major assumptions are made in the estimation of internal muscle forces and these assumptions need to be validated against experimental measurements (such as myoelectric activity, intradiscal pressure, etc.). Among other assumptions, these models include a biomechanical objective function such as minimization of compressive force, shear force, contraction intensity in any muscle, higher muscle contraction intensity, etc., or a combination of these variables. At present, individual muscle models are of limited practical value due to mechanically indeterminate systems and because the precise relation between the mechanical and electrical output of a muscle is uncertain (Ortengran and Andersson, 1977).

The model by Schultz and Andersson (1981) has been validated against myoelectric activity, intradiscal pressure and intra-abdominal pressure. Validation studies by Schultz and Andersson (1981) and Schultz et al. (1982a, b) for light to moderate exertions reported a correlation coefficient of 0.91 to 0.98 between mean intradiscal pressure and mean spinal compression. For less strenuous tasks, these studies and Schultz et al. (1987) reported correlation coefficients between myoelectric activities and muscle contraction forces of 0.6 to 0.99 for erector spinae, 0.70 to 0.97 for rectus abdominis and 0.34 to 0.93 for abdominal oblique muscles. The correlation coefficient between the measured intra-abdominal and the measured disc pressure was rather low (0.36; Schultz et al., 1982). For more strenuous tasks, Schultz et al. (1987) concluded that the model predictions were inadequate. The study concluded that during strenuous exertions: (i) substantial antagonistic muscle contractions sometimes occurred, (ii) intra-abdominal pressurization might sometimes have contributed substantially to the maintenance of structural equilibrium, and (iii) the ligamentous tissues of the trunk seemed sometimes to develop substantial passive resistances to bending and twisting moments.

Most biomechanical models assume negligible antagonistic activity either directly or indirectly through choice of an objective function. The model by Bean et al. (1988) accounted for antagonistic muscle activity by using a double linear programming approach. However, their model needs to be validated against indirectly measured internal forces (intradiscal pressure and myoelectric activity) for different levels of physical exertions and body postures. Bean et al. (1988) suggests that the antagonistic muscle activity cannot be assumed to be zero if more than one external moment is present since the antagonistic activity may be agonist in resisting some other moment. Electromyographic studies have also confirmed that there is a significant antagonistic muscle activity present in certain exertions (Portnoy and Morin, 1956; Morris et al., 1962; Ortengren and Andersson, 1977; Pope et al., 1987; Zetterberg et al., 1987; Schultz et al., 1987).

Farfan (1973), Gracovetsky et al. (1981), Gracovetsky et al. (1985), Gracovetsky and Farfan (1986) suggest that the posterior ligamentous system plays an important role in reducing

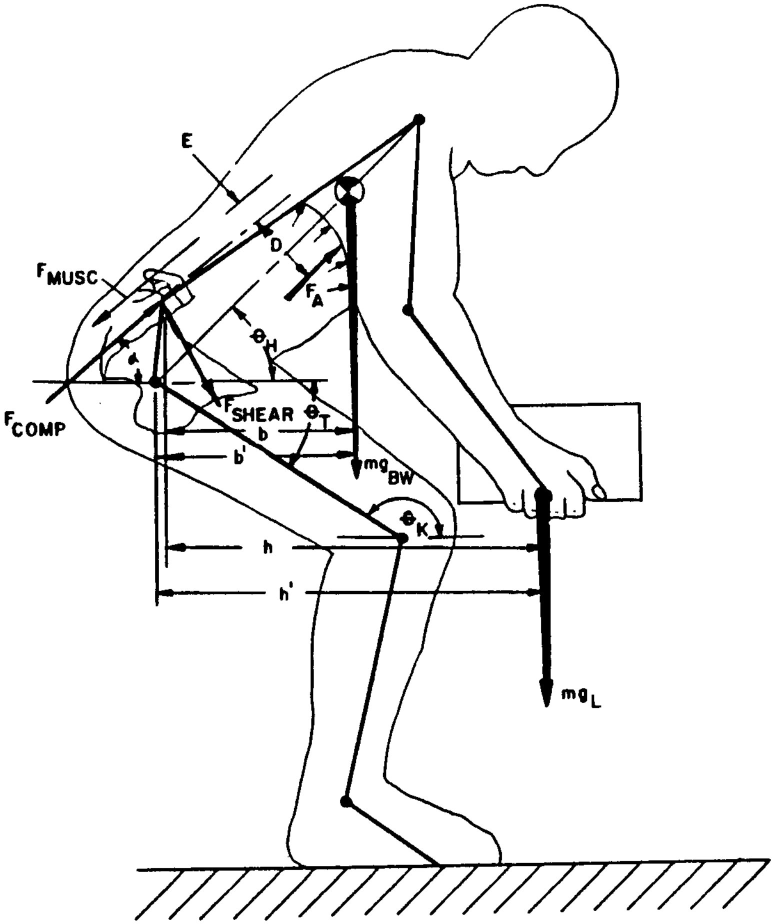

Figure 3.8: Simple low-back model of lifting as adapted by Chaffin (1975) for static coplanar lifting analyses.

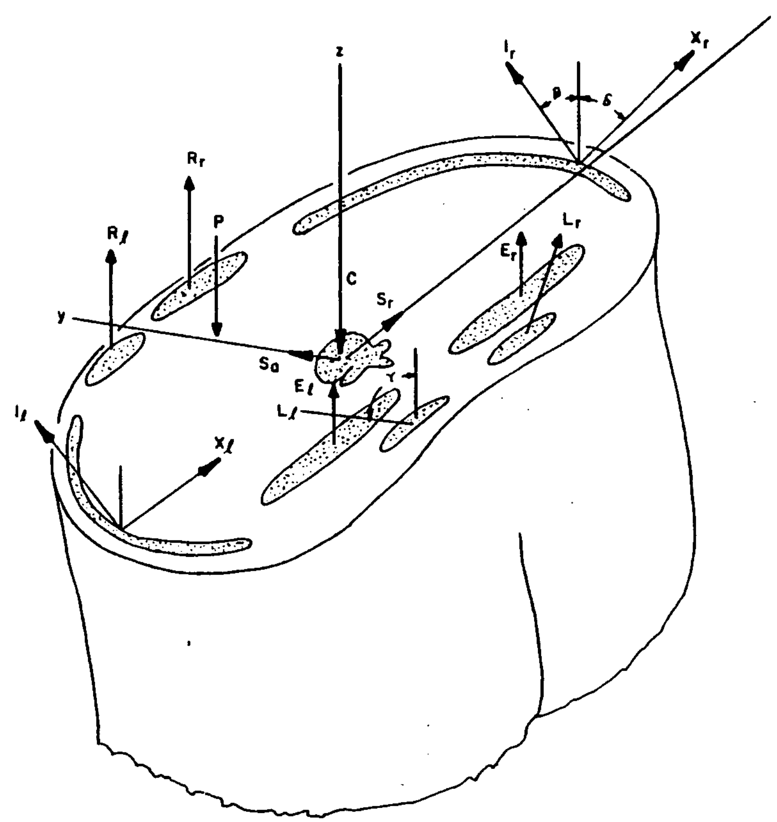

Figure 3.9: Schematic diagram of the model trunk cross section at the third lumbar level. The biomechanical analysis of the internal forces requires that the six components of the net reaction and the intra-abdominal pressure force (P) be known from experimental measurements. The ten unknown muscle forces are computed to provide the three net reaction moment components and the minimum spine compression force. Knowledge of the two remaining net force components is then used to compute the two motion-segment shear forces. (Schultz et al., 1982)

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compression at the intervertebral joint because of the angled attachment and larger moment arm. Theses authors suggest that it is important to take advantage of the capability of ligaments to partially relieve the trunk musculature of their role in counteracting the moment on intervertebral joint, especially when the lift is performed at speed with flexed back (slightly rounded spine). Using a mathematical model, Gracovetsky et al. (1981) showed that a given task could be performed by utilizing any number of combinations of muscle power and ligament tension and when support of the external load was shifted from muscle to ligament, there was a decrease in compression load at the disc (Gracovetsky et al., 1985; Gracovetsky and Farfan, 1986). However, Tesh et al. (1977) showed that the stabilization action of thoracolumbar fascia was relatively small in a fully flexed position. McGill and Norman (1986) found that ligaments played a very minor role in the lifts studied and their study could not confirm the hypothesis advanced by Gracovetsky et al. (1981, 1985). These authors concluded that posterior ligaments are not a significant component of the lifting spinal mechanism during stressful, sagittal plane lifting. Anderson et al. (1985) found that for sagittal plane two-handed lifting, the restorative moment due to ligament resistance was fairly small as compared with those due to muscle contraction and abdominal pressure. Moreover, under a 500 N load the ligaments played a much smaller role than under the no-load condition. The study concluded that typical lifting tasks could lead to excessive disc compressive forces, muscle moment generation requirements, and possibly lumbodorsal fascia strains. Adams and Hutton (1980), based on a cadaver study, concluded that the posterior ligaments (supraspinous, interspinous, capsular ligaments and ligament flavum) could resist less than half of the weight of the trunk in full flexion. The rest of the moment would be balanced by the passive resistance offered by the lumbodorsal fascia and extensor muscles of the spine. In this regard, though it has been shown that erector spinae may be electrically silent in full flexion (Floyd and Silver, 1955), they could still provide tension passively.

In summary, detailed three-dimensional biomechanical models of the trunk, as compared to simple models, provide more accurate representation of trunk musculature and more accurate prediction of muscle contraction and compressive and shear forces on the lumbar spine, especially for tasks involving axial rotation and/or lateral flexion. However, under what conditions antagonistic muscle activity and ligamentous tissue play an important role and what is the extent of their contribution to restorative moments and spinal compressive forces are not fully understood. In addition to these two, there are other issues which should be considered in interpreting predictions from biomechanical models. Generally, the model validations have been performed in a laboratory under carefully controlled body postures, such as strapping the pelvis to a support board to stabilize the lower body segments (Schultz et al., 1982a, b;

Ortengren et al., 1981). When applying these models to manual tasks in industry, it is probably not possible to control the body posture precisely and it may be difficult to obtain precise three-dimensional postural data. Also, subjects instinctively change the direction of the applied force from true vertical or horizontal in order to maximize the actual lifting, pushing, or pulling force (Garg et al., 1983; Grieve and Pheasant, 1981). Ortengren et al. (1981) showed that such variables as lifting method, height, and symmetric vs. asymmetric loading body postures, etc., might affect the relationship between intradiscal pressure, myoelectric activity and intra-abdominal pressure. Moreover, muscle recruitment patterns may vary from person to person and from time to time in any one person (Donisch and Basmajian, Ortengren et al., 1977; Schultz et al., 1982). Therefore, detailed biomechanical model validations are needed. In spite of these reservations, for the present it is believed that the biomechanical models are very useful in determining the etiology of low-back pain and in quantifying stresses on various parts of the body and, in particular, on the lumbar spine. This is an important topic which needs to be further investigated.

EFFECT OF DYNAMIC FACTORS ON SPINAL STRESSES

One criticism of static biomechanical models is that lifting is a dynamic activity. Static models tend to underestimate forces and moments because the inertial loads imposed by dynamic actions are ignored. For example, Garg et al. (1982) reported that peak compressive forces at the L_5/S_1 disc, peak dynamic moments and forces in the back muscles for lifting maximum acceptable weights (about 30 kg) were two to three times greater than those based on the static biomechanical simulation. Also, the study reported that the peak compressive forces occurred at about 0.225 to 0.628 S from the beginning of lift (Figure 3.10). Leskinen et al. (1983) reported that when lifting a 15 kg box from 10 cm off the floor the predicted forces on the lumbar spine were 33 to 60% higher with the dynamic model depending on which lifting technique was used (Figure 3.11). McGill and Norman (1985) reported 19% greater moment with the dynamic model as compared to the static model for lifting an 18 kg load. Freivalds et al. (1984) concluded that dynamic effects increased the effect of static load by as much as 40%. These and other studies (Troup et al., 1983; Hall, 1985; Bush-Joseph et al., 1988; etc.) have shown that dynamic factors significantly increase the stresses on the spine when lifting a load. Definitely, the difference between the static and the dynamic analysis will depend upon the acceleration of the load being lifted, the upper limbs and the trunk. Differences are smaller with slower lifts.

Clearly, inclusion of dynamic factors in biomechanical models is necessary to more accurately estimate the moments and forces on various body joints, including the low back. However, at

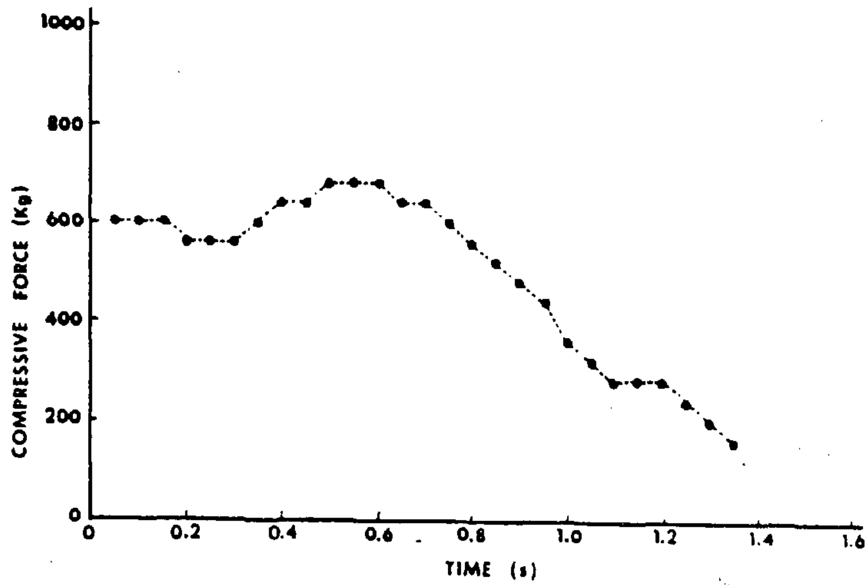

Figure 3.10: Estimated compressive forces at the L_5/S_1 disc from a dynamic biomechanical simulation of lifting a 38 cm box with handles for a typical subject versus time into lift. (Garg et al., 1982)

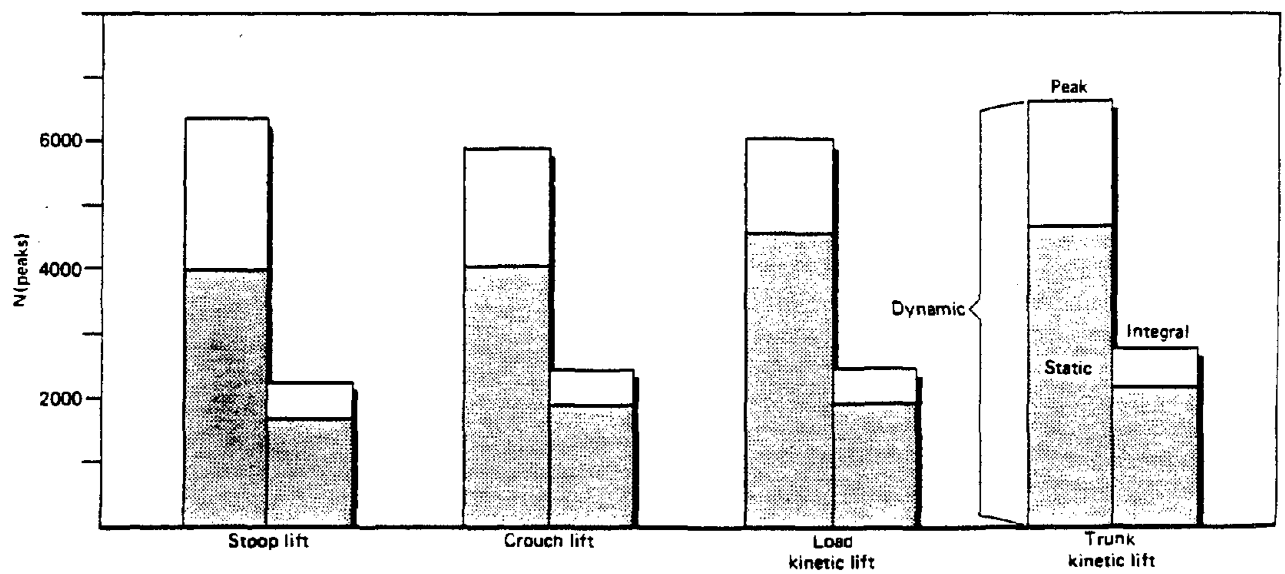

Figure 3.11: Mean peak lumbosacral compressions (N) and mean compression-time integrals (Ns) for 20 males lifting a 15-kg box, comparing calculations based on static and dynamic models, the latter taking inertial factors into account. (Leskinen et al., 1983b)

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present dynamic biomechanical models are of limited practical use in analyzing stresses from manual handling jobs and in designing workplaces. Ultimate compressive strengths of lumbar vertebral bodies, such as those presented in Figures 3.4 and 3.5, are not available under different dynamic loading conditions. Volitional muscle strengths (muscle moment capacities) and tissue limits for various body joints have not been systematically studied as a function of angular velocity and acceleration. Thus, at present it is not possible to compare the task produced moments and forces with the allowable muscle moment capacities and compressive forces. To some extent, predictions of compressive forces on the lumbar spine, even under static loading conditions, depend on the assumptions made in determining internal forces in muscles and ligaments, etc. Inclusion of dynamic factors may compound these errors. Also, it is difficult to obtain postural data in three dimensions as a function of time, especially in an industrial setting. These issues need to be better understood before workplace guidelines can be proposed based on a dynamic analysis. It is concluded that for the present one has to rely on static biomechanical analyses to determine manual materials handling guidelines.

INTRA-ABDOMINAL PRESSURE

It is common at the start of a manual handling activity to hold the breath and close the glottis. The muscles of the abdominal wall and pelvic floor contract and pressure increases in both thoracic and abdominal cavities. Increased pressure in the thorax stiffens the rib cage, provides a stable base for the activity of the upper limbs and supplements the thoracic erector spinae musculature (Davis and Troup, 1964; 1966). It is believed that a pressure increase in the abdominal cavity (intra-abdominal pressure) appears to supplement the lumbar extensor mechanism, particularly when the spine is flexed (Figures 3.8 and 3.12). An increase in intra-abdominal pressure creates a force tending to extend the spine.

The possible effects of intra-abdominal pressure in reducing the compressive force are not clear due to current controversy surrounding this mechanism (Gracovetsky et al., 1981; Schultz et al., 1982; Bogduk and McIntosh, 1984; Pope et al., 1984; Marras et al., 1984). Gracovetsky et al. (1985) believe that the primary purpose of abdominal pressurization is to ensure the proper shape (for maximum efficiency of lumbodorsal fascia) and to support the hoop tension generated by the contraction of internal abdominis and transverse abdominis muscles. The rectus abdominis counterbalances the action of intra-abdominal pressure on the diaphragm and the pelvic floor. They conclude that, "... it is apparent that any direct relief of the pressure of the disc by intra-abdominal pressure per se is negligible." Pope et al. (1984) state that reduction of muscle extension moment and compressive force by intra-abdominal pressure is controversial

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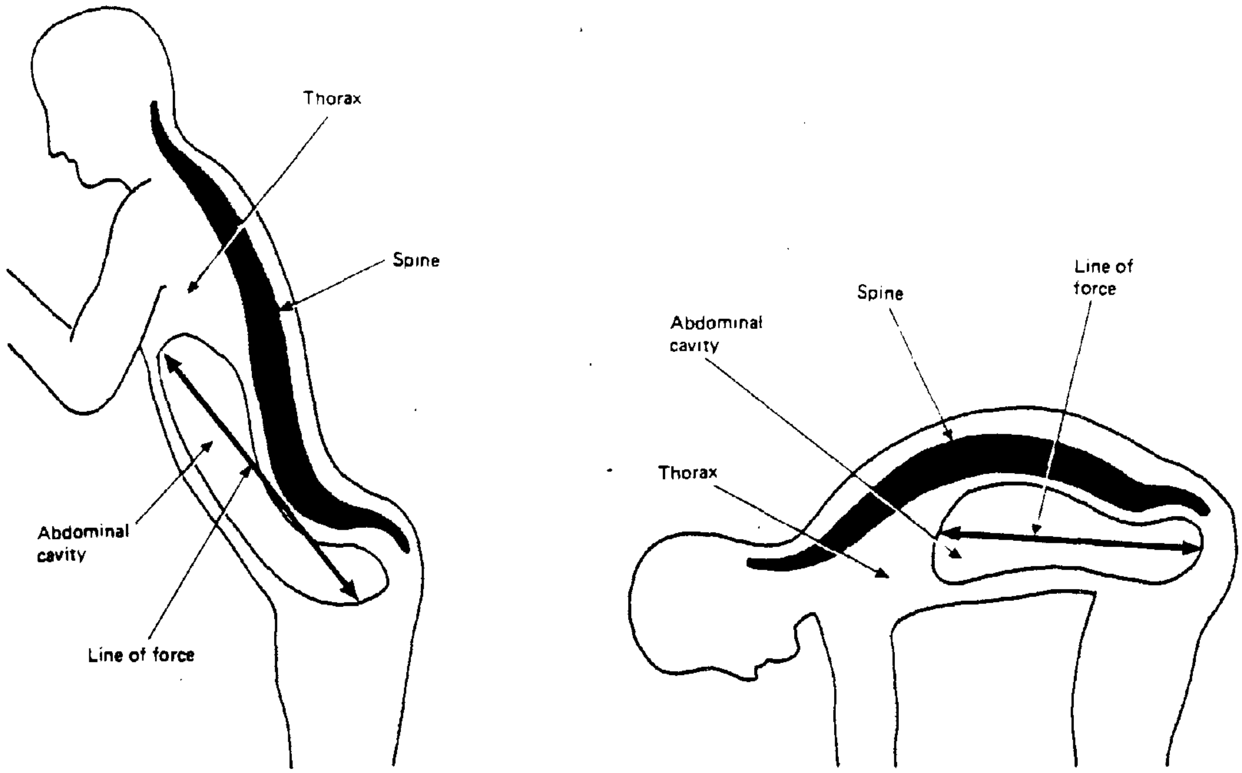

Figure 3.12: Lines of force of IAP in flexed and extended positions. (Troup, 1965)

since the abdominal muscles must contract to produce the intra-abdominal pressure and this would produce a flexion moment. McGill and Norman (1986) found that the extensor force and moment created from intra-abdominal pressure did not offset the compression force generated by necessary abdominal activation. Troup (1979) believes that the oblique muscles are more axially oriented and may to some extent oppose the effect of intra-abdominal pressure increase. Gilberton et al. (1983) showed that an increase in intra-abdominal pressure might not decrease the activity of the dorsal musculature in flexed or axially rotated position. As stated in Chaffin and Andersson (1984), asymmetric loading of the trunk can create large stresses on the lumbar spine without simultaneously increasing intra-abdominal pressure.

Marras et al. (1984) found substantial activity in the internal oblique, external oblique and rectus abdominis muscles under both static and isokinetic conditions but no relationship between the intra-abdominal pressure and the abdominal musculature. Moreover, they reported that in many high velocity

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isokinetic tests, there was an onset of delay in the production of intra-abdominal pressure and muscle moment, and this lag increased with increasing velocity. In many high velocity lifting tasks, the intra-abdominal pressure terminated before the moment production began. Marras et al. (1984) concluded that intra-abdominal pressure might not possess any load relieving capabilities. Legg (1981) found that the intra-abdominal pressures developed in the submaximal lifting were not influenced by fatigue or training of the abdominal muscles. Thus, it appears that the training and fatigue of abdominal muscles do not play an important role in the risk of back injury.

Intra-abdominal pressure response to stoop lifting can be divided into an initial peak (the snatch pressure), a lower sustained pressure while the load is raised to the target level (the lift pressure), and a further peak associated with placement of load (Davis, 1959; 1981) (Figure 3.13). The peaks are believed to be associated with extra moment required to accelerate the load and the trunk at the beginning and end of lifting, and coincide with the accelerative phase (Davis and Troup, 1964). Intra-abdominal pressures increase during pushing and pulling also. Pressure increase is in proportion to the speed of lifting and the weight of the load (Davis, 1959; Davis and Troup, 1959), and, thus, is in proportion to the stress imposed on the spine (Andersson et al., 1979). Davis et al. (1964) observed that jerk movements produced higher intra-abdominal pressure than slow, smooth lifting motions. As an extensor mechanism, intra-abdominal pressure is most effective during the short periods of maximal handling effort, especially when the spine is flexed. When the spine is extended (as in lifting above the shoulder), intra-abdominal pressure is less effective due to a reduction in the length of lever arm (Davis and Troup, 1965; Figure 3.12).

Intra-abdominal pressure has been found to correlate satisfactorily with the calculated compressive forces and the moments on the lumbar spine in the sagittal plane (Davis et al., 1965; Marras et al., 1984). Andersson et al. (1977) and Ortengren et al. (1981) showed that intra-abdominal pressure was linearly related to both intradiscal pressure and the myoelectric activity of erector spinae during static exertions. However, Schultz et al. (1982) reported a correlation of 0.36 between the measured intra-abdominal pressure and measured intradiscal pressure and 0.24 between the intra-abdominal pressure and the predicted compressive force. Davis et al. (1981) stated that lifting with the spine rotated resulted in higher levels of intra-abdominal pressure. Andersson et al. (1977) reported that the intra-abdominal pressure increased when the trunk was loaded in lateral flexion as well as in rotation. Davis et al. (1983) reported higher intra-abdominal pressure with stoop lift than with crouch lift, but Troup et al. (1983) found the opposite to be true. For a given task intra-abdominal

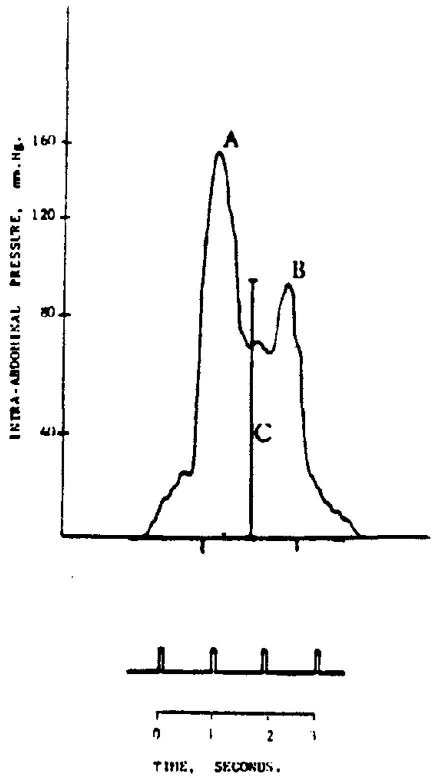
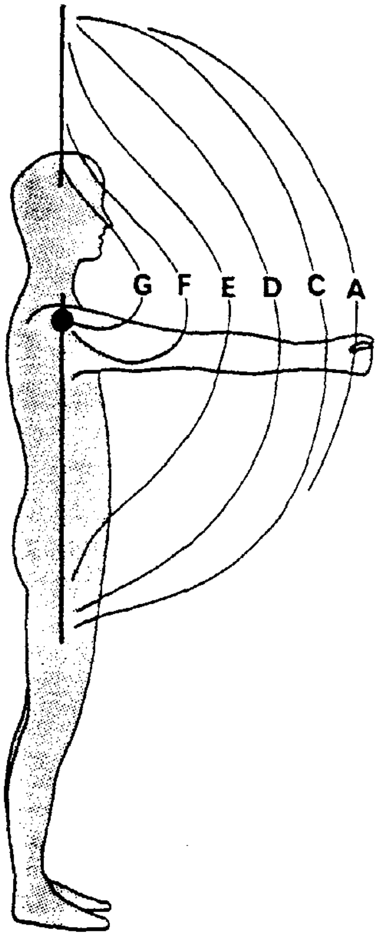


Figure 3.13: Intra-abdominal pressure record of subject lifting a load of 25 kg from ground level to 1.11 m using the straight full stoop technique. A) First peak pressure = 160 mm Hg; B) second peak pressure = 94 mm Hg; C) mean pressure = 95 mm Hg; D) pressure quotient (mean pressure x time of lift) = 170 mm Hg.sec. (Davis, 1981)

pressure is higher in older people--above 50 years of age (Davis, 1981; Davis and Stubbs, 1980)--and in those with back pain (Fairbank et al., 1980).

An association between high levels of intra-abdominal pressures (100 mm of Hg and above) and a high prevalence of back injuries at work has been established (Davis and Stubbs, 1978; Davis and Shephard, 1980; Nicholson et al., 1981). Davis and Stubbs (1980) published contour maps for acceptable levels of force without exceeding an intra-abdominal pressure of 90 mm of Hg (Figure 3.14). Coefficients of variation were also calculated from 1080 individual observations to determine the reliability of the method. The mean coefficient of variation for all activities was 32.3% (Davis, 1981) as compared to 50-100% reported by Ortengren et al. (1977). Davis (1981) concluded that intra-abdominal pressure measurements are useful determinants of spinal stress.



Force levels (kg) for different age groups

	AGE GROUPS		
	≤ 40 MALE	41–50 MALE	51–60 MALE
A	10	10	9
B	11	11	10
C	12	12	11
D	15	15	13
E	20	20	18
F	25	25	22
G	30	30	27

ONE-HANDED UPWARD, VERTICAL FORCES (INCLUDING LIFTING) when standing or squatting with the trunk reasonably upright.

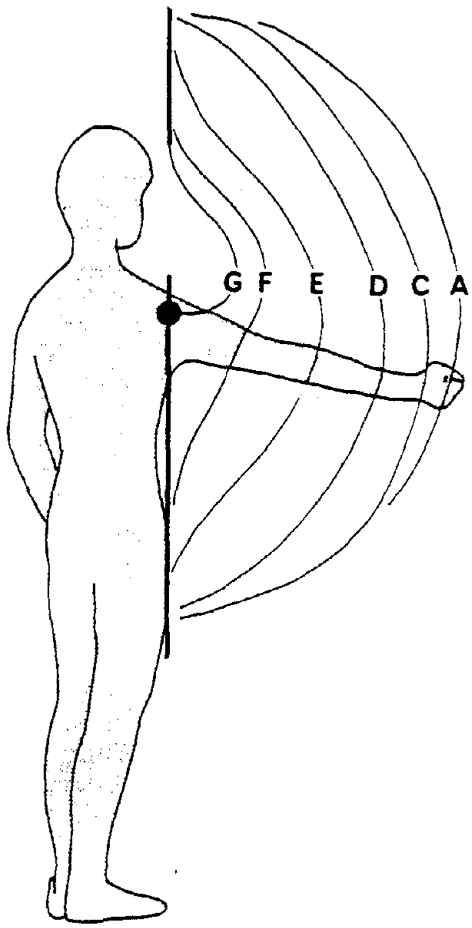


Figure 3.14: Contour maps showing the distances from the body at which acceptable levels of force can be applied in a variety of postures with the trunk erect, without exceeding IAP of 90 mm Hg. (Davis and Stubbs, 1980)

Morris et al. (1961), using a mathematical model of forces on spine, estimated that the increased intra-abdominal pressure reduced the load on the spine by 30%. Davis and Troup (1965) concluded that the intra-abdominal pressure could reduce lumbosacral compression by as much as 25-30% and Eie (1966) by as much as 40%. Subsequent studies have estimated a lower load reduction level. Thomson (1988) estimated that the intra-abdominal pressure is capable of reducing the compressive load on the lumbar spine by about 20% during heavy lifting. Chaffin (1982) concluded that when assumed to be a well developed reflex in an individual, it appeared that the intra-abdominal pressure could relieve about 15%-20% of the lumbar compression during normal weight lifting actions. Schultz et al. (1982) reported that the mean relief of compression on the spine due to intra-abdominal pressure was 14.5% (range = 4 to 35%), and this value did not show any consistent relationship with the load imposed on the spine by the task performed. The authors also concluded that the intra-abdominal pressures were not large and seldom had a major influence on the overall mechanics of the trunk. However, in a subsequent study, Schultz et al. (1987) discussed the possibility that the intra-abdominal pressurization might sometimes contribute substantially to the maintenance of structural equilibrium when performing strenuous tasks. Using a biomechanical model, Garg and Herrin (1978) reported that the intra-abdominal pressure could reduce the compressive load on the lumbar spine from 8.7% to 20.3% for stoop lift and from 2.6% to 11.3% for squat lift for lifting loads ranging from 0 to 70 kg. Recently, Anderson et al. (1985) concluded that abdominal pressure could never relieve more than about 10% of the compressive force.

In summary, at present the role of intra-abdominal pressure in relieving compression on the spine appears to be controversial. It is not quite clear under what circumstances intra-abdominal pressure plays an important role and what is the magnitude of compression relief provided by the intra-abdominal pressure. It appears that the intra-abdominal pressure may reduce about 10%-20% compressive load on the lumbar spine during strenuous exertions.

ASYMMETRIC LIFTING

Asymmetric lifting occurs when the load is lifted off the mid-sagittal plane with one or both hands, when the spine is axially rotated (twisted), or laterally flexed, or a combination of these. More often the spine is subjected to forward flexion accompanied by axial rotation and lateral flexion. It is generally believed that asymmetric lifting in more hazardous to the musculoskeletal system than symmetric lifting because of the combined effects of flexion, axial rotation and lateral bending. Unfortunately, there are only a few studies of asymmetric load handling because of experimental and biomechanical complexities associated with three-dimensional force analysis. At the same time twisting of the spine while lifting is common in workplaces where origin and destination are oriented at an angle to one another, where there is inadequate room to use a step turn, where lifting is done across the body as in swinging bags or boxes up from a low level, or where work is done in obstructed workplaces or on littered floors to maintain body balance (Rodgers, 1985). Sometimes workers prefer to twist and/or laterally flex their spines because it is faster than lifting symmetrically in the sagittal plane with turns and one or more steps involved (Garg, 1986).

Farfan (1973) showed that spinal mechanism failed either by excessive compressive load or excessive torsional load. Farfan (1985) and Kirkaldy and Farfan (1981) estimated that approximately 65% of low-back cases are from torsional injury and 35% from compression injury (based on citations in Gracovetsky, 1986). As stated in Fiorini and McCammond (1976), Ghormely (1951) arbitrarily related low-back pain to degenerative disc disease in about 22% of cases and due to degenerative changes in the synovial joints in about 26% of cases. Facet joint pain has been estimated to be a common cause for chronic low-back pain (Pope et al., 1984). Frymoyer et al. (1980) reported that patients who reported low-back pain had occupations that required more repetitive lifting, pulling and twisting.

The torsional injury is basically a rupture of ligamentous tissue, the annulus, and the associated damage to the facet (Gracovetsky, 1986). The study also states that torsional injury is by far the most damaging and the ligamentous injuries do not heal quickly. In a torsion injury, the joint never regains full strength and therefore the same joint is most likely to fail with repeated torsion (Farfan, 1985). Torsional injuries involve peripheral damage to both the disc and the facet joints occurring simultaneously (Farfan, 1985). The annulus is avulsed from the endplate and its laminae become separated while the nucleus and endplate remain intact. At a later stage, the annulus develops radial fissures and the changes in facet joints are severe and the intervertebral joint may become unstable (Farfan et al., 1970; Farfan, 1985; Gracovetsky, 1986). The torsional deformity can cause the neural elements in the intervertebral canal to displace to one side and stretch the nerve roots (Farfan, 1985). Symptoms may arise form intrusion of disc (annulus) into the canal, stretched nerve roots, constriction of neural elements by torsional deformation (stenosis) and/or instability (Farfan, 1985).

Mathematical models demonstrate that torsion produces a stress concentration at the region of posterior lateral annulus which is a common site of disc degeneration (Hickey and Hukins, 1980; Pope et al., 1984; Gracovetsky and Farfan, 1986). Based on a cadaver study, Farfan et al. (1970) estimated that about 90% of the torque strength of an intervertebral joint was provided by its disc (annulus) and the two joints between the articular process. The annulus fibrosus provided 40%-50% of the torsional resistance to twisting of the lumbar vertebrae. The nucleus being a gel, can provide little or no resistance to torsion. The authors proposed that the cohesion between the laminae gave the disc its torque strength. Therefore, damage to annulus as a result of disease, fracture or surgical assault must have serious consequences for the whole joint (Farfan et al., 1970). The authors speculated that with each successive injury, deeper and deeper annular layers might be affected, and gradually a communication between the nucleus and the outside might be

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established, forming the radial tears typical of natural disc degeneration. Further, with the loss of cohesion between the laminae, the articular facets will have to provide a greater portion of resistance to torsion. This may increase the risk of disc degeneration. Based on a study of 42 cadaver lumbar motion segments, Schultz et al. (1979) reported that the segments were least flexible in torsion (as compared to extension, lateral bending and flexion), destruction of posterior elements (facet joints and ligaments) resulted in significantly increased motions in torsion and extension (with little effect in flexion and lateral bending), intradiscal pressure increases were relatively small in torsion and extension (as compared to flexion and lateral bending) and significantly large intradiscal pressure increases occurred in torsion and extension when posterior elements were removed. In short, posterior elements of a motion segment played a significant role in torsion and extension and little or no role in flexion and lateral bending. Skipor et al. (1985) showed marked increases in rotation when posterior ligaments were severed leaving the facet joint capsule intact. Based on loading of cadaver lumbar intervertebral joints simultaneously in torsion and compression, Adams and Hutton (1981) showed that torsion of the lumbar spine was resisted primarily by the apophyseal joint that was in compression, although the intervertebral disc played a major role. They showed that the compression facet was the first structure to yield at the limit of torsion. The study suggested that a local collapse of the articular cartilage or subchondral bone of the articular facet might have occurred. Further, the intervertebral disc was subjected to relatively small stresses and strains (1/3 of its maximum angle) in the physiologic range of torsion because of the protection offered by the compression facet. The authors also suggested that torsion seemed unimportant in the etiology of disc degeneration and prolapse as rotation is produced by voluntary muscle activity. Based on biomechanical analysis, Fiorini and McCammond (1976) also supported Adams and Hutton's observations. They inferred that if a person twisted while lifting and bending, the pressure on one facet would increase considerably, while it decreased on the other. The interarticular facet joints, being small and joined together at the periphery by a very thin and delicate capsular ligament, are unstable and vulnerable to injury (Fiorini and McCammond, 1976). Since the synovial membrane of the facets is highly vascular and innervated with sensory nerves, the articular facets are likely to cause considerable pain (Fiorini and McCammond, 1976).

Farfan et al. (1970) reported that the average torque at failure for intact whole intervertebral joint was 88 Nm (range = 85 to 101 Nm) for those with the normal discs and 54 Nm (range = 33 to 68 Nm) for those with degenerated discs. The mean rotations at failure were 22° and 14° for normal and degenerated discs, respectively. However, the authors suggested that the stress-strain relationship was exponential and there was probably a change in behavior of the disc at 3 degrees of rotation. Further, the study concluded that the intervertebral joint might sustain injury at much smaller rotation of 2 to 5 degrees. This would correspond to an axial moment of 11 to 23 Nm (Farfan et al., 1970). This is consistent with the findings of Adams and Hutton (1981), who reported that most specimens reached the limit of torsion with a torque of 10 to 30 Nm and with a rotation of between 1° and 3°. However, Adams and Hutton (1981) found that the more degenerated joints had greater angles of rotation before failure (1.2° with grade 1 discs and 6.7° with grade 4 discs). Based on a mathematical model of the disc, Hickey and Hukins (1980) computed 16 Nm as the maximum torque that would not damage the annulus. This would correspond to a 3° torsion angle or 4% stretch in the annular fibers.

The intra-abdominal pressure, myoelectric activity of trunk muscles, intradiscal pressure and compressive force have also been studied for asymmetric activities. In general, high levels of antagonistic activity in both abdominal and posterior back muscles has been reported in lateral flexion and axial rotation (Andersson et al., 1977; Kumar, 1980; Ortengren et al., 1981; Schultz et al., 1982; Pope et al., 1987; Seroussi and Pope, 1987; Zetterberg et al., 1987; Schultz et al., 1987). These studies also found higher myoelectric activity on the side contralateral to the load in the lumbar region though there was significant muscle activity on the ipsilateral side. Seroussi and Pope (1987) reported high correlations between the difference of right and left erector spinae myoelectric activity and the frontal plane moment arm. Since several muscles are active under asymmetric lifting conditions, it is difficult to quantitatively compare the myoelectric activity for asymmetric exertions with those for symmetric exertions. However, Pope et al. (1987), in general, showed greater myoelectric activity at a given percentage of maximum voluntary contraction (MVC) when the trunk was rotated by 30° as compared to the neutral position. They also reported that the ability to develop maximum torque was enhanced if the subject was prerotated away from the direction in which the torque was being developed. Andersson et al. (1977) reported higher intra-abdominal pressure and myoelectric activity when the trunk was loaded in rotation than in lateral flexion.

Ortengren et al. (1981) showed higher intradiscal pressure for a given level of myoelectric activity for asymmetric loading positions than that for symmetric loading positions. Andersson et al. (1977) reported that intradiscal pressure and the intra-abdominal pressure both increased when the trunk was loaded in lateral flexion (20°) as well as in axial rotation (45°) (Figure 3.15). The measured pressures were higher when the trunk was loaded in rotation than in lateral flexion (Figure 3.15). However, it is not clear from Figure 3.15 how much increase in intradiscal pressure is due to trunk flexion and how much increase is due to axial rotation. Bean et al. (1988),

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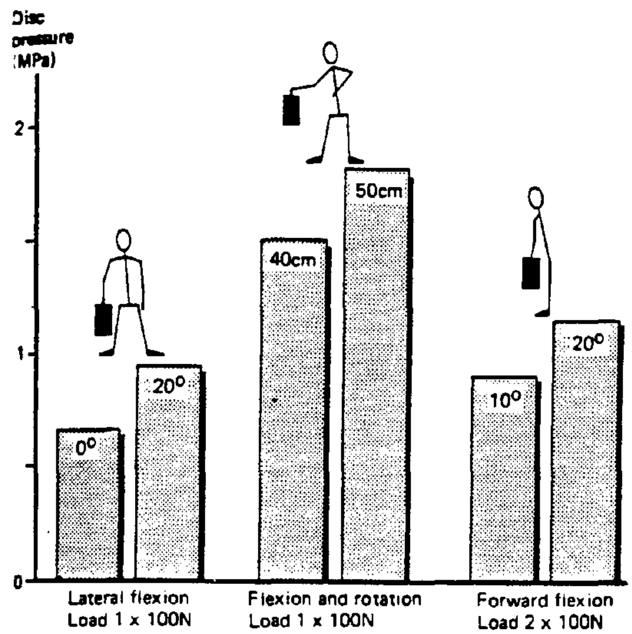

Figure 3.15: Intravital disc pressures (MPa) during static loading in left lateral flexion with a load of 100 N (10 kg) in the left hand; with combination of flexion and rotation and a load at a distance of 40 and 50 cm from the center of the body respectively; and, finally, in forward flexion with 100 N (10 kg) in each hand at 10 and 20° respectively. (Nachemson, 1980)

using a double linear programming approach, estimated compressive force for holding a 222 N weight on a circular arc of 38 cm from the L_5/S_1 disc center at 0, 30, 60, and 90° angular displacements. Estimated values from their graph showed that the compressive forces at 30, 60 and 90° were about 14%, 4% and 36% higher, respectively, than those at 0° (mid-sagittal plane). Figure 3.16 shows percentage increase in compressive force compared to 0° for lifting a load of 400 N at a vertical height of 81 cm for three different horizontal distances (Chaffin, 1989; personal communications). In each of these postures, the hand to hand separation distance was held at 51 cm and an erect torso was maintained. However, these findings are not supported by Schultz et al. (1982), who found that the tasks involving axial rotation or lateral flexion did not load the spine and trunk muscles significantly more than trunk flexion or holding of weights in front of the body. Neither the myoelectric measurements nor the model analysis (compressive, shear and trunk muscle contraction forces) could support the hypothesis that tasks involving axial rotation, lateral flexion, or a combination of these with forward flexion unduly load the lumbar structures. According to Schultz et al. (1982), it is the flexion moment (such as due to outstretched arms or trunk flexion) rather than the twist or lateral bending that is responsible for the large loads on the spine.

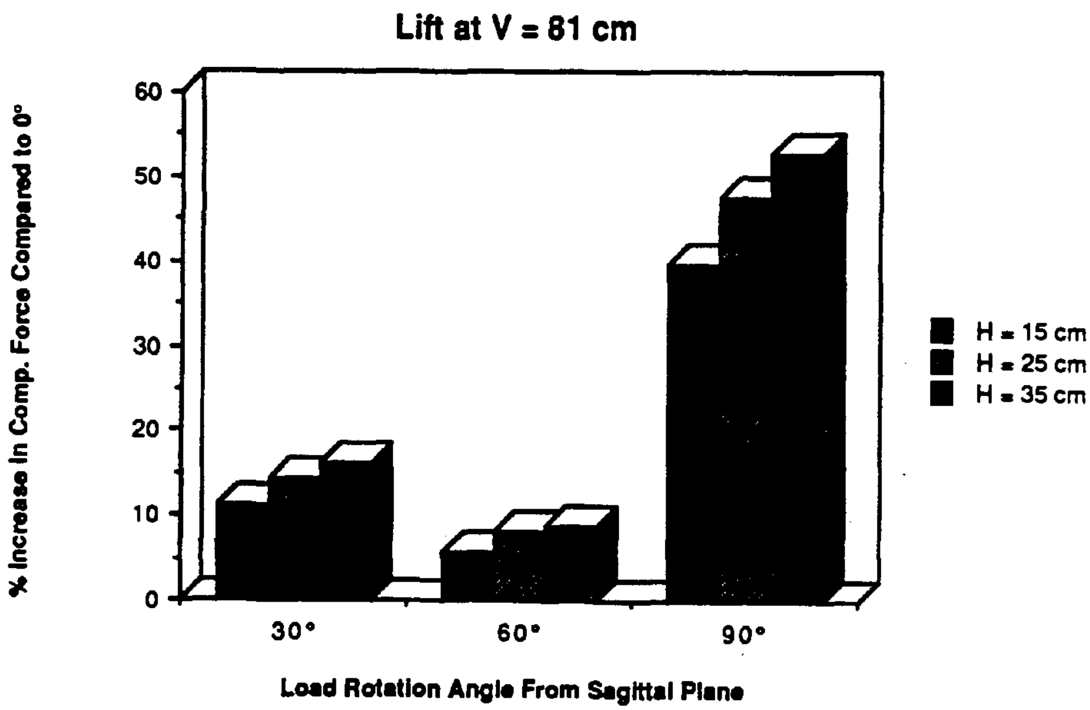

Figure 3.16: Effect of axial rotation of spine on compressive force at L_4/L_5 disc from Chaffin (personal communications).

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Predictions of trunk muscle contraction and shear and compressive forces to some extent depend upon the choice of objective function and the assumptions made in the model. For example, Bean et al. (1988) showed that for a given task there was as much as 21% difference in the model predicted compressive force due to differences in objective function.

Maximum voluntary muscle strengths for asymmetric postures have also been studied. Zetterberg et al. (1987) reported significantly higher muscle moments (muscle strength) for trunk flexion and extension than for lateral flexion. Warwick et al. (1980), Garg and Badger (1986) and Garg and Banaag (1988) reported significant and consistent decrease in static lifting strengths with an increase in axial rotation of the trunk (Figure 3.17).

In summary, it appears that asymmetric lifting can produce large and concentrated stresses on lumbar trunk structures. Asymmetric lifting can cause poor postural stability; increased and asymmetric muscle activity; and increased stresses on annulus fibrosus, ligaments and facet joints. Asymmetry in muscle activity can lead to unequal stress concentrations on different component structures of the lumbar spine. It also results in reduced maximum voluntary muscle strength and, therefore, in addition to low-back injury, risk for an overexertion injury is high. Also, injury is more likely in a muscle that is stretched due to twisting or lateral bending and then heavily contracted.

EFFECT OF TASK VARIABLES ON STRESSES TO SPINE

The "safe" weight of the load depends upon a number of task variables and work characteristics. From a biomechanical point of view, some of the task variables that determine "safe" weight of the load include size of the load, horizontal and vertical locations of the load, body posture, foot traction, adequacy of grip, stability of load (solid vs. liquid), obstructions, space constraints, speed of lift, frequency of lift, and direction of force exertion (straight vertical lift vs. pulling the load towards the body) etc. Biomechanical considerations in determining handle positions and angles are discussed in Drury and Deeb (1986). Foot traction has received attention primarily in pushing and pulling tasks (Fox, 1967; Kroemer, 1971; National Safety News, 1974; Lee, 1982). Effects of frequency (fatigue fractures) and asymmetric lifting postures were discussed earlier. Biomechanical effects of horizontal and vertical locations of the load, speed of lifting and lifting technique are briefly discussed here.

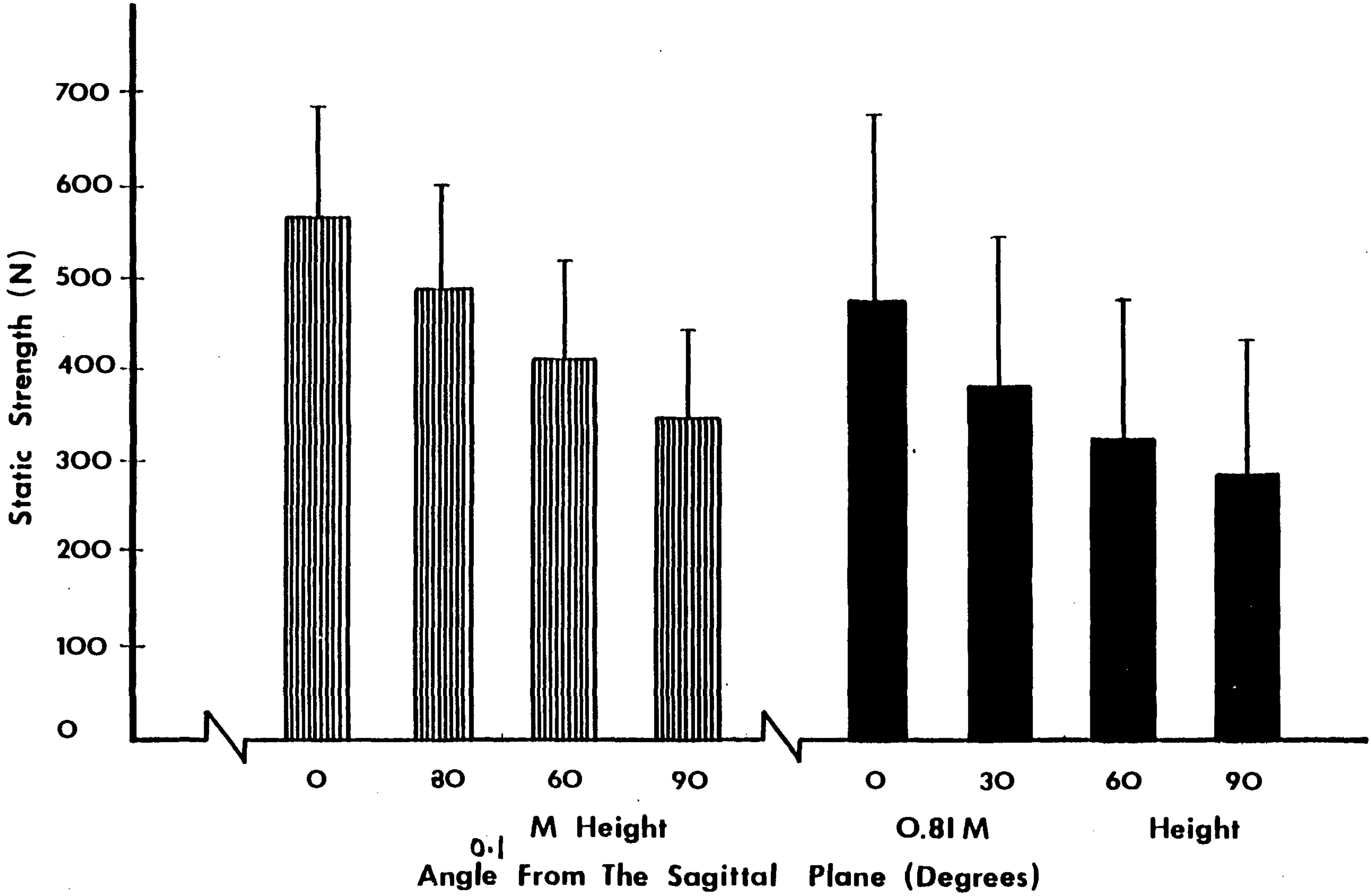

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Figure 3.17: Effect of asymmetric lifting on maximum voluntary static strength. (Garg and Banaag, 1988)

Vertical Location of Load

The flexion of the trunk increases as the vertical height of the load to be lifted is lowered from about elbow height. In general, the lower the height of the object to be lifted, the greater the trunk flexion. As the trunk inclines forward, the center of gravity of the upper limbs and torso moves more anterior to the lumbar spine, i.e., moment arm for the upper limbs and torso weight increases (Figure 3.18). This produces larger flexion moment on intervertebral joints. Muscle tension in trunk extensors increases to counterbalance the increased flexion moment. The net result is that the compressive force on lumbar intervertebral discs increases because it is the tension in the back muscles that accounts for a large proportion of spine compressive force (60% when holding a 222 N load; Bean et al., 1988). Secondly, when an object to be lifted is placed on the floor or at a lower height, in most cases it is difficult to bring the object close to the body unless one can straddle the load (keep it between the knees). Once, again, this results in a larger moment arm of the load and, therefore, in higher tension in back muscles and compressive force on the lumbar spine.

In flexed postures, the anterior annulus is under compression, where as the posterior annulus is under tension. Hutton and Adams (1982) and Hickey and Hukins (1980) suggest that the posterior annulus can be severely stretched in flexed postures and this may cause a prolapse of the intervertebral disc. The posterior annulus is also under tension through the circumferential stress generated by the compressive force on the disc (Nachemson and Morris, 1964; Adams et al., 1980). As stated in Nachemson and Morris (1964), approximately 90% of all ruptures in the lumbar discs occur in the posterior part of the annulus. Presence of nerve fibers in the outer part of the annulus can contribute to the production of low-back pain, especially in persons whom the annulus is weakened (Nachemson and Morris, 1964). Also, the rupture of the fibers of annulus could speed the degenerative process. In addition to the disc, the stresses on the posterior ligaments may be fairly high especially in hyperflexion. For example, Adams et al. (1980) reported that supraspinous and interspinous ligaments sprained first in hyperflexion because they were rather weak (tensile strength = 95 N cm^{-2}).

It is believed that a combination of trunk flexion and rotation may be more hazardous to the low back than either one of them alone. Brown et al. (1957) proposed that the disc might be sensitive to torsion and bending. These body motions can cause failure of the annulus fibrosus and hence protrusion of the nucleus pulposus (Hickey and Hukins, 1980). In this regard, Roaf (1960) believes that "a combination of rotation and compression can produce almost every variety of spinal injury."

Several studies have shown an increase in myoelectric activity of trunk muscles with an increase in trunk flexion, until full flexion is reached (Floyd and Silver, 1955; Portnoy and Morrin, 1956; Carlsoo, 1961; Morris et al., 1962; Ortengren and Andersson, 1977; Andersson and Ortengren, 1977). Ortengren et al. (1981) reported that the intradiscal pressure increased when the distance between the floor and the handle height decreased, i.e., when the angle of forward flexion increased. Nachemson (1965, 1980), based on measured intradiscal pressure, reported that the approximate load on the L_3 disc was 686 N when standing erect and 1176 N when the trunk was flexed forward by as little as 20°. Andersson et al. (1977a, 1977b) found a linear increase in intradiscal pressure, myoelectric activity and intra-abdominal pressure with an increase in trunk flexion between 10° and 50° (Figures 3.19 and 3.20).

Thus, a number of indicators of low-back stress such as compressive force (Chaffin, 1969), intradiscal pressure, myoelectric activity and intra-abdominal pressure suggest that lifting at the floor level or at lower heights can be hazardous to the low back and should be avoided through proper workplace design. On the other hand, maximum voluntary muscles strengths are higher at lower heights than at higher heights (Rodgers, 1985; Chaffin and Andersson, 1984; Garg and Banaag, 1988). It appears that the optimum height for lifting may depend on trade-off between the compressive force and muscle strength. However, epidemiological studies suggest that the risk of a back injury is higher when the loads are lifted near the floor level. In this regard, based on a case-referent study, Punnett et al. (1988) concluded that both mild and severe trunk flexions, trunk twist or lateral bending were significant risk factors for back disorders and the risk increased with trunk flexion lasting more than 10% of the work cycle. The study also concluded that the combination of mild flexion and twisting was particularly hazardous. Similarly, Snook et al. (1978) reported that 78% of lifting injuries were associated with low lifting tasks (below knuckle height, 79 cm) even though only 66% of industrial lifting tasks started below knuckle height.

<u>Horizontal Location of Load</u>

Regarding horizontal location of the load, there is almost universal agreement that the load should be kept as close to the body as possible. It is the flexion moment (the product of the weight and the distance from the spinal axis (moment arm)) rather than the weight of the load that is important in determining stresses on the lumbar spine (Figures 3.21 and 3.22). For example, both 200 N (20.4 kg) weight held at 20 cm from the spine and 100 N (10.2 kg) load held at 40 cm from the spine will produce a flexion moment of 40 Nm. However, the load held farther away from the body will require larger trunk flexion which will contribute to the total flexion moment on the lumbar spine as mentioned earlier. Also, bending forward will

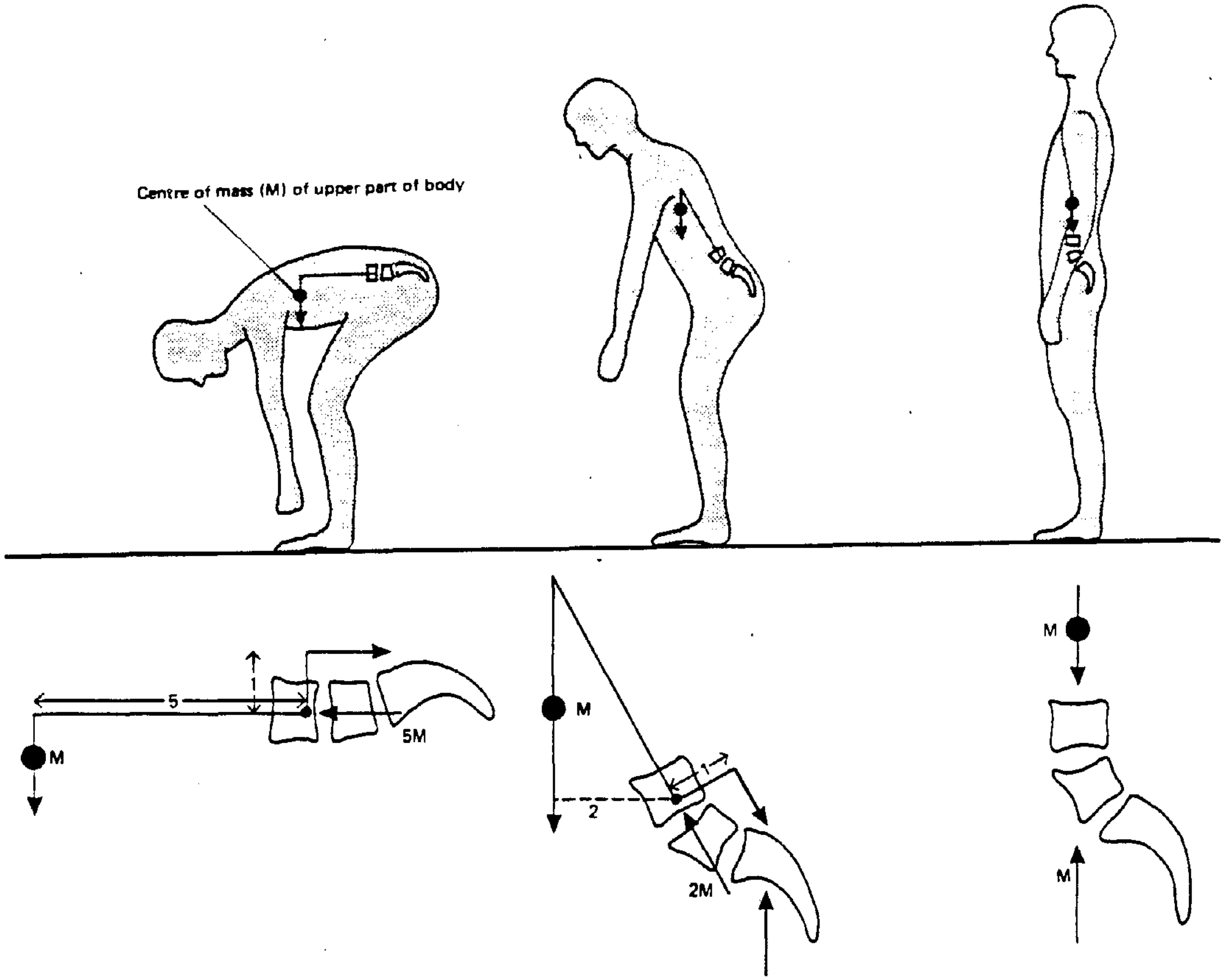

Figure 3.18: Lumbosacral compression equivalent to mass (M) of upper part of body in erect position, increasing as trunk approaches horizontal. (Troup and Edwards, 1985)

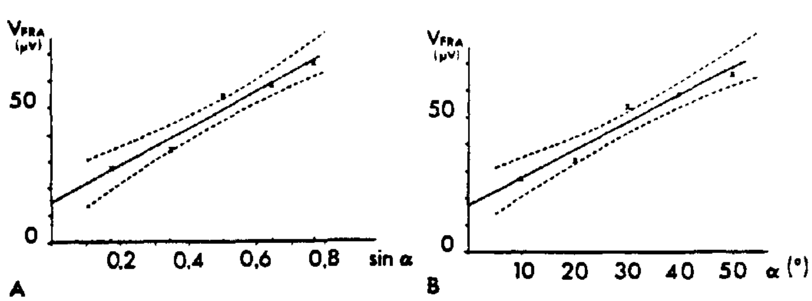

Figure 3.19: Linear regression lines for the relationship between the myoelectric activity at the L3 level, (A) the sine of the angle of forward flexion, and (B) the angle of flexion. Ninety-five per cent confidence regions are indicated. (Andersson and Ortengren, 1977)

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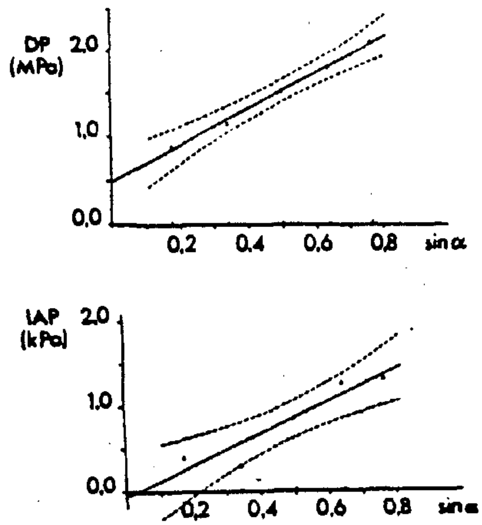

Figure 3.20: Regression analysis of relation between (A, top) disk pressure and the sine of the angle of flexion, and (B, bottom) intra-abdominal pressure and the sine of the angle of flexion. The mean values are denoted with x. The dashed lines indicate 95% confidence limits for the mean values. (Andersson and Örtengren, 1977)

change the curvature of the lumbar spine from lordosis (concave) to kyphosis (convex). Kyphotic posture is generally believed to be undesirable and results in unequal distribution of stresses on the lumbar disc (Grandjean, 1988). It appears that, as far as the low-back stresses are concerned, the flexion moment is probably the most important variable among the various task factors mentioned earlier. Indeed, Schultz et al. (1982) state that, "It can be more stressful to the spine to bend and reach in order to pick up a piece of paper than to lift a large weight held close to the trunk. This is confirmed both by myoelectric activity and the intradiscal pressure measurements."

Chaffin and Andersson (1984) showed that the predicted compression forces on the L_5/S_1 disc increased with an increase in both the weight of the load and horizontal distance of the hands from L_5/S_1 disc (Figure 3.22). Figure 3.22 reveals that an increase of 10 cm in horizontal distance amounts to about a 1000 N increase in compressive force on L_5/S_1 disc. This figure confirms the empirical rule which recommends lifting a load as close to the trunk as possible. Figure 3.23 illustrates the combinations of weight of the load and the horizontal distance from the ankles that would produce 3.43 kN (350 kg) compressive force on the L_5/S_1 disc of the average female at 50 cm vertical height from the floor. The same

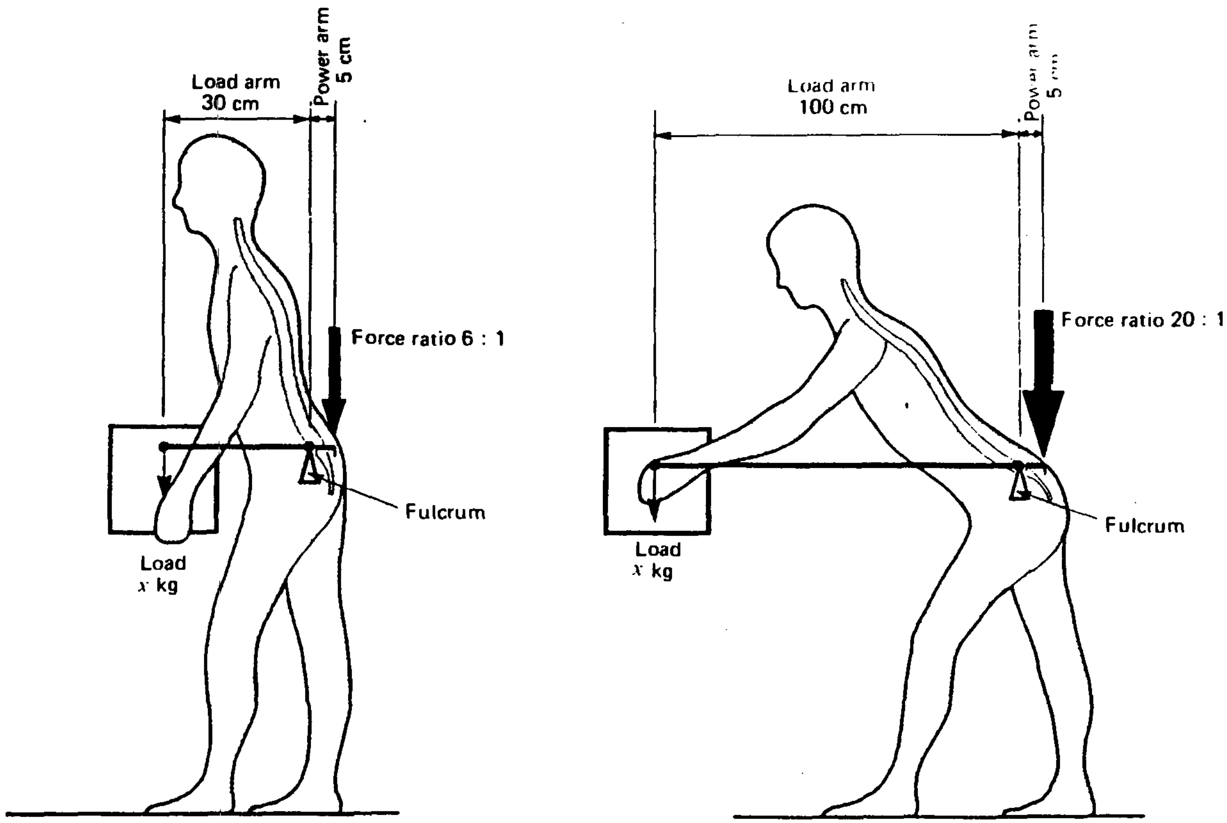

Figure 3.21: Fulcra and levers: increased force is needed to lift a given load when it is further from the body. (Troup and Edward, 1985)

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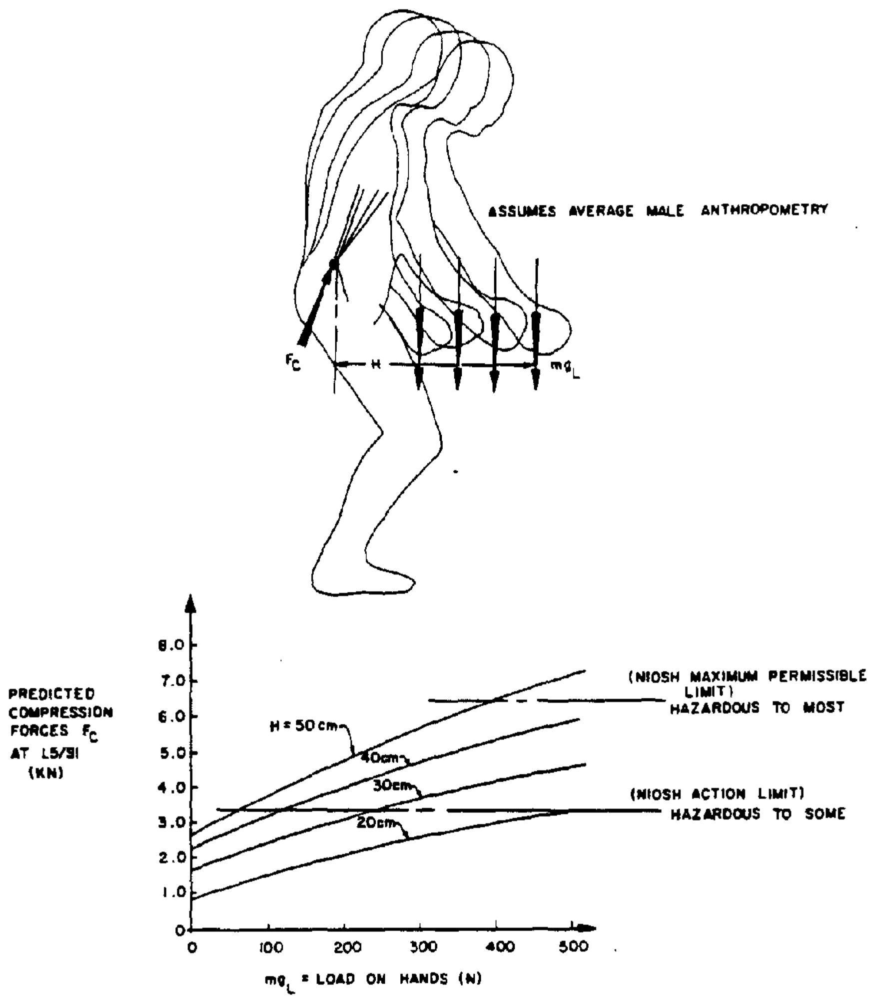

Figure 3.22: Predicted L_5/S_1 disc compression forces for varying loads lifted in four different positions from body. (Chaffin and Andersson, 1984)

combinations which would produce 6.37 kN (650 kg) compressive force on the L_5/S_1 disc of the average male are also shown in Figure 3.23. The compressive force predictions are based on a static biomechanical model (Garg and Chaffin, 1975) and the horizontal location is measured forward of the body centerline from the midpoint between the ankles.

Based on a study of three different warehouses, Garg (1986) observed that the horizontal moments arms were fairly large due to poor workplace design and this resulted in large predicted compressive forces on the L_5/S_1 disc. Based on a laboratory study, Garg (1989) reported that the untrained subjects did not

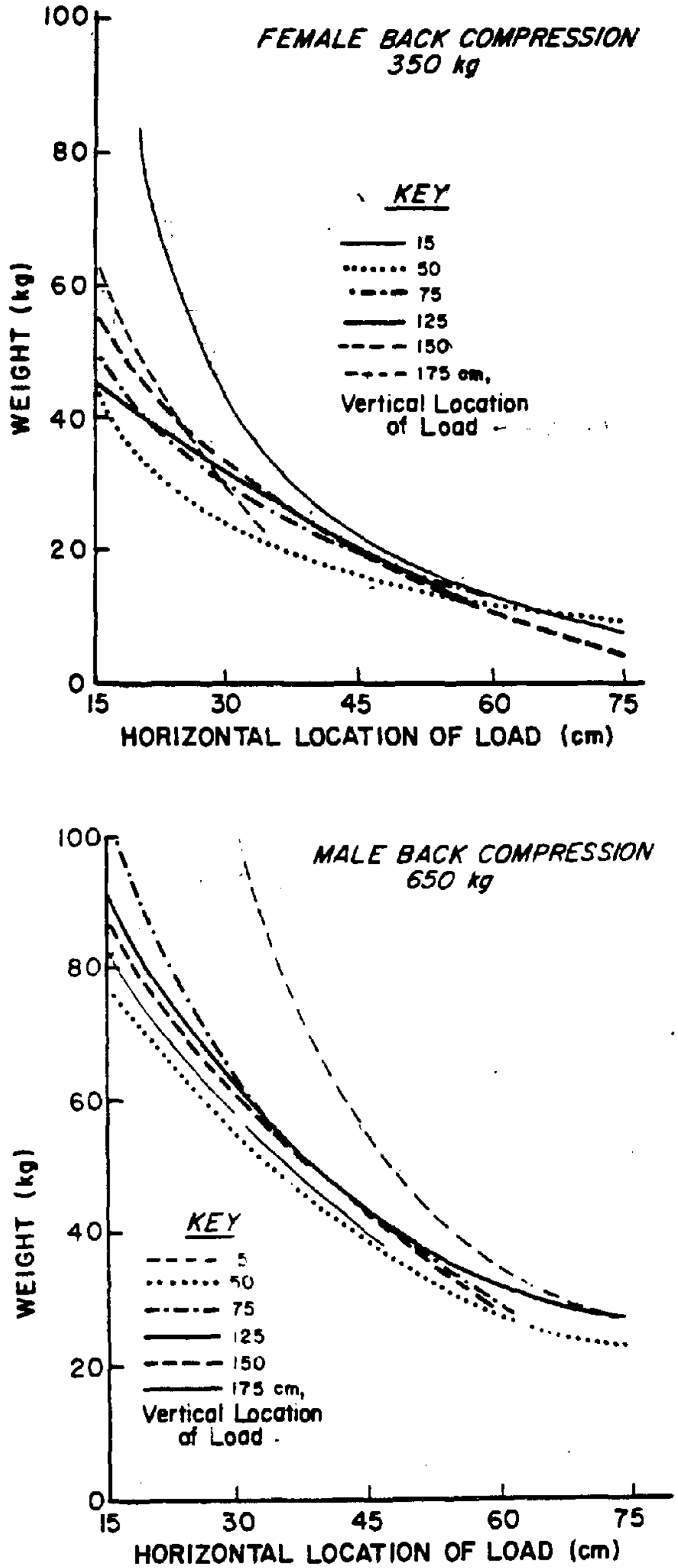

Figure 3.23: Task variables producing 350 kg female (top) and 650 kg male (bottom) back compressions. (NIOSH, 1981)

stand close to the object when lifting moderate to heavy loads from both the floor level and 0.8 m height. Moreover, there was large variation in the horizontal distance between the subjects. Therefore, the same lifting task would have produced different flexion moments and compressive forces on different subjects. Also, workers tend to avoid cardiovascular stresses at the expense of an increased musculoskeletal stress by lifting and carrying greater weight fewer times (McGill and Norman, 1985; Garg et al., 1983; Garg and Saxena, 1985). These issues need to be addressed through proper workplace design, proper work practices, education and training of workers.

<u>Speed of Lifting</u>

Grieve (1970) suggested jerking up a load with sufficient velocity at an early stage to give it energy to take it past the individual's weaker lifting levels might be advantageous, provided the compressive forces are within acceptable limits. As an example, Olympic weight lifters depend on speed and skill to avoid becoming stuck during the lift. This is sometimes justified considering the inverse relationship between the failure strength of the spine and the duration of the applied stress. Also, Gracovetsky (1986) pointed out that the load transmission capacities of the disc are time dependent. However, high speed lifting and, especially, jerking motions cannot be recommended based on the present knowledge of low-back biomechanics. It is quite possible that the inertial forces produced in jerking a load or with high speed lifting can result in momentary but potentially injurious overloads on low-back structures as mentioned earlier under dynamic factors. Sudden bending, twisting and stretching may easily tear the capsular ligaments of the facet joints (Fiorini and McCammond, 1976). With fast motions the ability of the somatic nervous system to coordinate the many muscles necessary to stabilize the spinal column is stressed. Some low-back problems are related to muscle fatigue (Brown, 1973), which further inhibits coordination of the back muscles. Also, high inertial forces associated with dynamic actions are difficult for one to control and a person may lose body balance.

Garg et al. (1982) showed that even at normal lifting speed, inertial forces increased the compressive forces on the L_5/S_1 disc considerably. The peak compressive forces were below 3.4 kN under static conditions and over 6.5 kN at normal speed. Davis et al. (1965) observed that heavier loads were lifted at slower speed. In the initial phases of a lift, inertia of weight of the load, trunk and upper limbs is overcome and acceleration is at its maximum resulting in peak compressive forces (Davis et al., 1965; Garg et al., 1982). Also, at the beginning of the lift the erector spinae muscles remain relatively silent (Floyd and Silver, 1955; Morris et al., 1962) and extension of lumbar spine is delayed, probably to protect against higher peak compressive forces (Davis et al., 1965).

Bush-Joseph et al. (1988) reported that peak moments at the L_5/S_1 joint increased with an increase in lifting speed. They recommended that excessive speed of lifting, including jerking, should be avoided. Marras et al. (1985) reported a significant decrease in torque producing capability of the trunk muscles with an increase in velocity of exertion. For example, there was an average decrease in torque production capability of 35% at only 33% of maximum velocity. Similarly, Kumar et al. (1988) reported an inverse relationship between the peak dynamic strength and the speed of motion. Therefore, it is recommended that the workers should be required to lift loads in a controlled, smooth and well-planned manner. Further, as part of this concern is the need to provide good foot traction and hand grips on such loads to avoid any possible slips and/or falls.

Lifting Straight Up

Based on chrono-cyclophotographic studies, Garg et al. (1983) and Freivalds et al. (1984) showed that the subjects pulled the loads towards the body rather than lifting them straight up vertically. A biomechanical analysis showed that the primary effect of pulling the load towards the body is to transfer stresses from the arms and torso to the legs, which have stronger muscles. Pulling the load towards the body also reduces the compressive force on the L_5/S_1 disc (Garg et al., 1983). A decrease in strength has also been reported when lifting a load straight up vertically (Garg, 1989B; Snook (Personal Communications)). This is a major concern on those jobs where a lift must be performed straight up due to obstructions, workplace constraints or inadequate room.

Lifting Technique

There is no 'natural' way of lifting which is universal. Workers typically use a combination of trunk and knee flexions when lifting an object from the floor. The degree of trunk vs. knee flexion varies from worker to worker and from object to object. Garg and Saxena (1985), based on observations of workers in three different warehouses where they were required to lift loads frequently, found that practically no workers bent their knees and kept their backs straight when lifting objects near the floor level. Other studies have also observed that the stoop lifting technique is a frequently used technique (Brown, 1971; Park, 1973; Shephard, 1974; Stubbs, 1976; Troup, 1979). Davis et al. (1965) reported that young adult untrained males when asked to lift a heavy weight by using their legs and not their backs tended to convert the bent knee lift into a straight knee lift. Many authors and most physicians and safety professionals recommend that a squat posture (straight-back, bent-knees) be assumed when lifting a load from the floor level (Asmussen et al., 1965; Adams and Hutton, 1982; Leskinen et al., 1983; Ayoub and El-Bassoussi, 1978). Squat lifting technique is said to be preferable to stoop lifting because (i) the load is closer to the body resulting in smaller moment arm (Bendix and Eid, 1983; Troup et al., 1983), (ii) it shifts the load to the legs which are stronger than the back, (iii) the low-back ligaments are exposed to a lower maximal strain (Poulsen, 1981; Anderson, 1983), (iv) it produces relatively smaller compressive force on the lumbar back (Ayoub and El-Bassoussi, 1978; Leskinen et al., 1983), and (v) the spine is kept in the sagittal plane, i.e., neither rotated nor bent sideways (Troup and Edwards, 1985). In considering the biomechanical implications of stoop vs. squat postures, often it has been assumed that the load can be brought between the knees with the squat posture and it is farther away from the body with the stoop posture (Figure 3.24). This is not always true. For example, Garg et al. (1983) reported that the horizontal distances (from ankles to the hand grips) were a little lower for the free style (stoop) postures than those for the squat postures for lifting boxes ranging in width from 25 cm to 63 cm. Biomechanical evaluations have shown that stoop lifting method is preferable in those

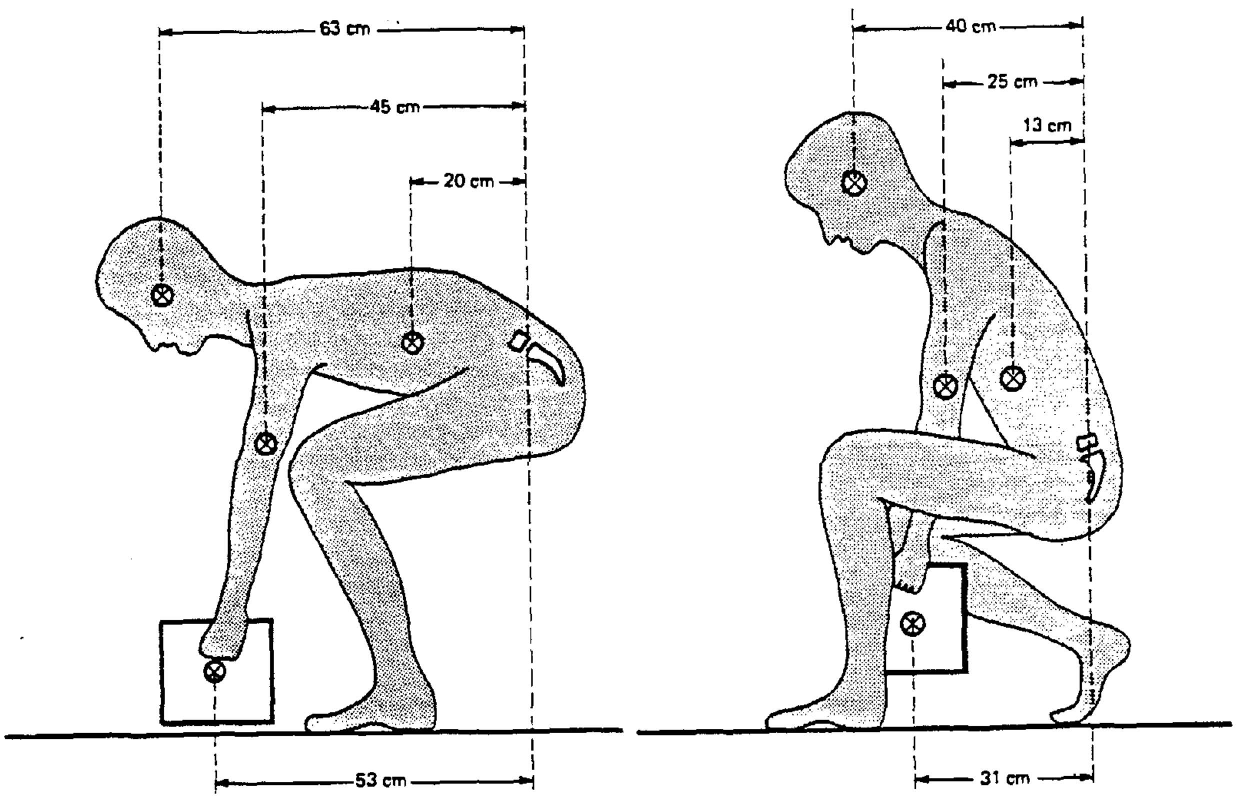

Figure 3.24: Vertical lifts from stooping position with load in front of knees (left) and from crouching posture with load between knees (right). The circled crosses indicate the centers of mass for the head, upper limbs, trunk and load: the horizontal distances from the lumbosacral disc are shown. (Troup and Edwards, 1985)

situations where the load is too wide or bulky to be placed between the knees (Park and Chaffin, 1974; Garg and Herrin, 1979; Frankel and Nordin, 1980; Troup et al., 1983). In these situations, the stoop lifting posture is preferable (Figure 3.25) because (i) the load moment arm may be smaller and (ii) the vertical components of both the body weight and load are shifted to a shearing effect when the spine is bent (Chaffin, 1975; Garg and Herrin, 1979). Of course, the shearing forces on the L_5/S_1 disc are greater when lifting with the bent spine and the articular facets and the annulus fibrosus provide the

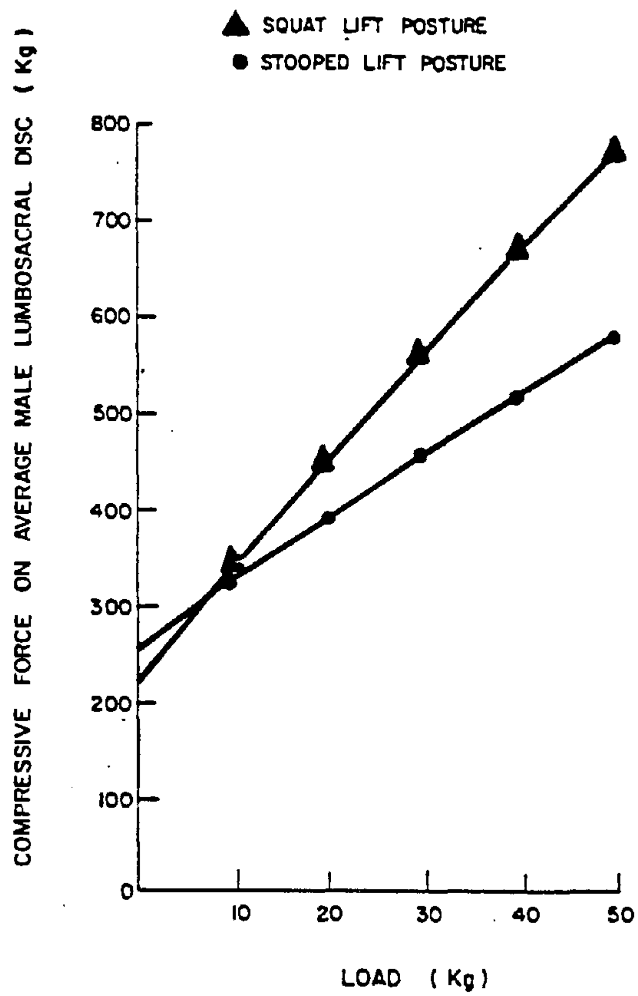

Figure 3.25: Effect of load on L_5/S_1 compressive force for large load in front of body. (Garg and Herrin, 1979)

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primary resistance to these forces. Other disadvantages of squat lifting postures are that (i) most workers' knee extensor muscles are a weak link in the lifting process (Troup and Edwards, 1985; Bejjani et al., 1984; Davis et al., 1965), (ii) the feet usually are not flat on the floor and may not be far enough apart for good stability and leverage, and (iii) the lifting strength is lower as compared to that in stoop posture (Garg et al., 1983; Marras et al., 1984). As mentioned earlier, most workers use a combination of trunk and knee flexions. This does not imply a hyperflexed back, which should be avoided as it places greater stress on the posterior ligaments and posterior annulus of the disc. Soft tissues of the trunk can be damaged if the spine were hyperflexed (Hutton and Adams, 1982).

Nachemson and Elfström (1970), based on intradiscal pressure measurements, reported compressive forces of 3330 N and 2050 N for bent-back, straight-knee and bent-knee, straight-back postures, respectively, for lifting a 20 kg load. However, Ortengren et al. (1981) found no significant difference in intradiscal pressures for the two methods of lifting.

Some authors and most back schools emphasize the importance of keeping the back flat throughout the lift (Asmussen et al., 1965; Grandjean, 1988; Anderson and Chaffin, 1986). A flat back is one in which the lumbar lordosis is maintained throughout the lift by holding the trunk rigid and forcing all torso flexion to occur at the hip joints. The flat-back configuration is recommended because it provides the greatest amount of muscle control of the trunk and minimizes strain on posterior spinal ligaments. However, others argue that the flat back would prevent midline ligament from contributing to the reduction in lumbar stresses (Farfan, 1975; Gracovetsky et al., 1981; Gracovetsky et al., 1985). These authors suggest that some flexion of the spine is advantageous as it would transfer some of the forces to the posterior ligaments. These authors recommend flexing the spine and bending the knees as it would result in the lowest possible compression stress on the spine. This recommendation is also supported by Hutton and Adams (1982), who reported that wedged lumbar intervertebral joints to simulate forward flexion resulted in greater compressive strength. These authors recommend flexing the lumbar spine and extending the thoracic spine to keep the load close to the body. Adams and Hutton (1982) recommend that it is mechanically and nutritionally advantageous to flex the lumbar spine when lifting heavy weights because it reduces the compressive stress on the posterior annulus and improves transport of metabolites in the intervertebral discs. On the other hand, based on a biomechanical evaluation of five different lifting methods, Anderson and Chaffin (1986) reported that, in general, the straddle stance with flat back produced the lowest compressive force on the L_5/S_1 disc when lifting both compact and bulky loads. They also reported that lifting methods incorporating a flat back resulted in minimum risk to lumbodorsal fascia (%

strain) and the methods involving a curved back in the maximum risk. Anderson and Chaffin (1986) concluded that a straddle-stance with a squat lift should be used so that even the bulky load could be brought close to the body and the back should be kept flat (as when standing erect).

Thus, there are differences between various techniques in terms of flat vs. curved back, bent knees vs. straight knees, placement of feet and placement of hands. Different lifting techniques may produce different compressive forces, intradiscal pressures and ligament stresses and moment producing capacities of the muscles may also be affected. At present biomechanical advantages of one lifting technique over others are not clearly established due to controversy in the literature cited. Protection of the other body segments, such as knee joints in addition to the back, must also be considered and one must maintain stability over the entire lifting activity. More research is necessary to establish the validity of any suggested method of handling loads. However, all lifting techniques agree that the load should be kept as close to the body as possible and the load should be lifted in a slow and controlled manner.

CONCLUSIONS

(1) Lifting compact objects of moderate weights close to the body could create compressive forces sufficient to cause damage to some lumbar intervertebral discs, especially to the lumbar spines of older workers. For example, lifting an object weighing less than 245 N (25 kg) within 25 cm from the ankles can create compressive forces in excess of 3.43 kN (350 kg).

(2) The compressive force is directly related to the horizontal moment arm of the load. Therefore, even light loads should be lifted close to the body through proper workplace design and education and training of workers.

(3) Both the intradiscal pressure and compressive force increase with an increase in angle of trunk flexion. When a load is lifted from the floor stresses on the low back increase due to larger moment arms of the body weight and weight of the load. Therefore, objects, especially heavy loads, should not be stored on the floor, but should be raised to about standing knuckle height (minimum 50 cm) to avoid the necessity for stooping over and lifting.

(4) Asymmetric lifting (with one hand or with both hands at the side or with torso twisted and/or laterally bent) results in significantly lower maximum voluntary muscle strength and higher compressive force, intradiscal pressure, myoelectric activity and antagonistic activity of trunk muscles. These postures can impart complex and potentially hazardous stresses to the lumbar column. Asymmetric

lifting should be avoided by proper workplace design, proper work practices, and education and training of the workers.

(5) Frequent lifting of moderate to heavy loads can lead to fatigue fracture of the lumbar intervertebral joints, in addition to cardiovascular stresses and localized muscle fatigue. Thus, repetitive lifting may cause disc degeneration in addition to low-back problems due to muscle fatigue.

(6) Rapid and/or jerking motions can impart substantially higher and potentially dangerous stresses to the low-back structures. Maximum voluntary muscle strength also decreases with an increase in speed of lifting motion. Workers should be required to lift loads in a smooth and controlled manner.

(7) Practically all lifting studies have been conducted with good foot traction. Weights should be reduced significantly and the objects should be lifted in a planned and careful manner when a low coefficient-of-friction exists in a workplace. Slips and falls can cause serious back injuries.

(8) The different lifting techniques recommended to lift loads from the floor can cause different complex stresses on different parts of the low-back structure (muscles, ligaments, disc and facet joints). Effects of different lifting techniques on stresses to low back and other parts of the body are not fully understood. Further, a safe lifting technique may depend upon such factors as leg strength, weight of the load, size and shape of the load and workplace geometry. Until such complexities are better understood, it is recommended that instructions on lifting techniques be avoided.

(9) Jobs should be designed so that the compressive forces on the L_5/S_1 disc are below 3.43 kN (350 kg) to protect most workers. This upper limit will not be protective for older workers and for those with weaker spines. Also, jobs which place more than 6.4 kN (650 kg) of compressive force on low back are hazardous to all but the healthiest of workers.

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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

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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).

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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., 1974h; 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

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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

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

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Table 2 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 s	9 s	14 s	1 min	2 min	5 min	30 min	8 h	5 s	9 s	14 s	1 min	2 min	5 min	30 min	8 h	5 s	9 s	14 s	1 min	2 min	5 min	30 min	8 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.

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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 + 10 to KL + 20	6
KL + 20	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

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Table· 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	8·85	8·50
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

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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

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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

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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

```
Cap (F-S) = 23.3 - 0.91 * (FY - 1) + 0.30 * (46 - BX)
            + Z * (6.86 - 0.24 * (FY - 1))
          = 23.3 - 0.91 * ( 2 -1 ) + 0.30 * (46 - 40.64)
            + (-1.6449) * (6.86 - 0.24 * (2 - 1))
          = 13.1 kg
```

****
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] K	$26.0^{b}FY^{-0.184697}$	1	$26.0 - 0.91(FY - 1)$	7
[illegible] S	$23.3FY^{-0.184697}$	2	$23.3 - 0.91(FY - 1)$	8
[illegible] R	$22.4FY^{-0.184697}$	3	$22.4 - 0.91(FY - 1)$	9
[illegible] S	$23.3FY^{-0.138650}$	4	$23.3 - 0.91(FY - 1)$	10
[illegible] R	$22.7FY^{-0.138650}$	5	$22.7 - 0.91(FY - 1)$	11
[illegible] R	$22.0FY^{-0.138650}$	6	$22.0 - 0.91(FY - 1)$	12
	Female Capacity			
[illegible] K	$17.0^{b}FY^{-0.187818}$	13	$17.0 - 0.5(FY - 1)$	**19**
[illegible] S	$14.1FY^{-0.187818}$	14	$14.1 - 0.5(FY - 1)$	**20**
[illegible] R	$12.8FY^{-0.187818}$	15	$12.8 - 0.5(FY - 1)$	**21**
[illegible] S	$14.0FY^{-0.156150}$	16	$14.0 - 0.5(FY - 1)$	**22**
[illegible] R	$12.4FY^{-0.156150}$	17	$12.4 - 0.5(FY - 1)$	**23**
[illegible] R	$12.0FY^{-0.156150}$	18	$12.0 - 0.5(FY - 1)$	**24**

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

[b] Mean capacity for lift based on data from Ayoub et al. (1978) and Snook (1978) for various ranges of lift for the 50th percentile and 1.0 lift/min. From: Ayoub et al. (1983). *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)[a]		
Range of **Lift**	**0.1 ≤ FY < 1.0**	**(Eq.)**	**1.0 ≤ FY ≤ 12.0**
	Male Capacity		
F-K	CAP + Z · 7.66FY$^{-0.174197}$	1	CAP + Z[7.66 − 0.27(FY − 1)]
F-S	CAP + Z · 6.86FY$^{-0.174197}$	2	CAP + Z[6.86 − 0.24(FY − 1)]
F-R	CAP + Z · 6.58FY$^{-0.174197}$	3	CAP + Z[6.58 − 0.23(FY − 1)]
K-S	CAP + Z · 6.67FY$^{-0.156162}$	4	CAP + Z[6.67 − 0.25(FY − 1)]
K-R	CAP + Z · 6.31FY$^{-0.156162}$	5	CAP + Z[6.31 − [illegible](FY − 1)]
S-R	CAP + Z · 6.11FY$^{-0.156162}$	6	CAP + Z[6.11 − 0.23(FY − 1)]
	Female Capacity		
F-K	CAP + Z · 3.12FY$^{-0.251605}$	13	CAP + Z[3.12 − 0.07(FY − 1)]
F-S	CAP + Z · 2.60FY$^{-0.251605}$	14	CAP + Z[2.60 − [illegible](FY − 1)]
F-R	CAP + Z · 2.35FY$^{-0.251605}$	15	CAP + Z[2.35 − 0.05(FY − 1)]
K-S	CAP + Z · 2.57FY$^{-0.258700}$	16	CAP + Z[2.57 − 0.05(FY − 1)]
K-R	CAP + Z · 2.28FY$^{-0.258700}$	17	CAP + Z[2.28 − 0.05(FY − 1)]
S-R	CAP + Z · 2.20FY$^{-0.258700}$	18	CAP + Z[2.20 − 0.05(FY − 1)]

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

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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

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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

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* 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

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<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.

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Insert Table 18 Testing Procedure

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Table 18

TESTING PROCEDURES

	STATIC	DYNAMIC
(I) Protocol for Measurement		
(1)	A maximum steady exertion for a total of 3 seconds should be performed.	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.	The strength score is a continuous position dependent value. Values at different angular position (or similar other identifiers) should be reported.
(3)	N/A	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.	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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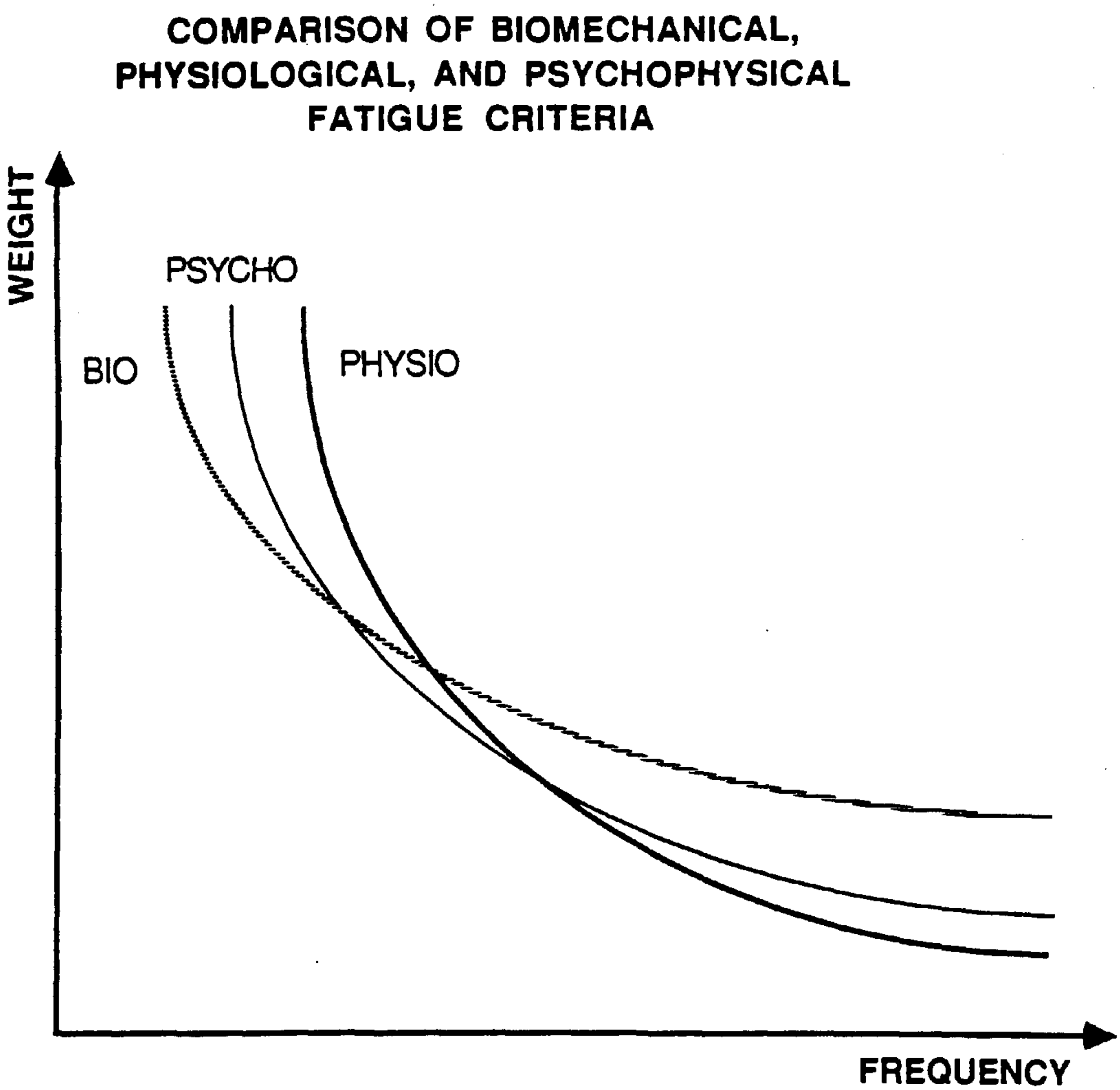
COMPARISON OF BIOMECHANICAL, PHYSIOLOGICAL, AND PSYCHOPHYSICAL FATIGUE CRITERIA
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Figure 1.

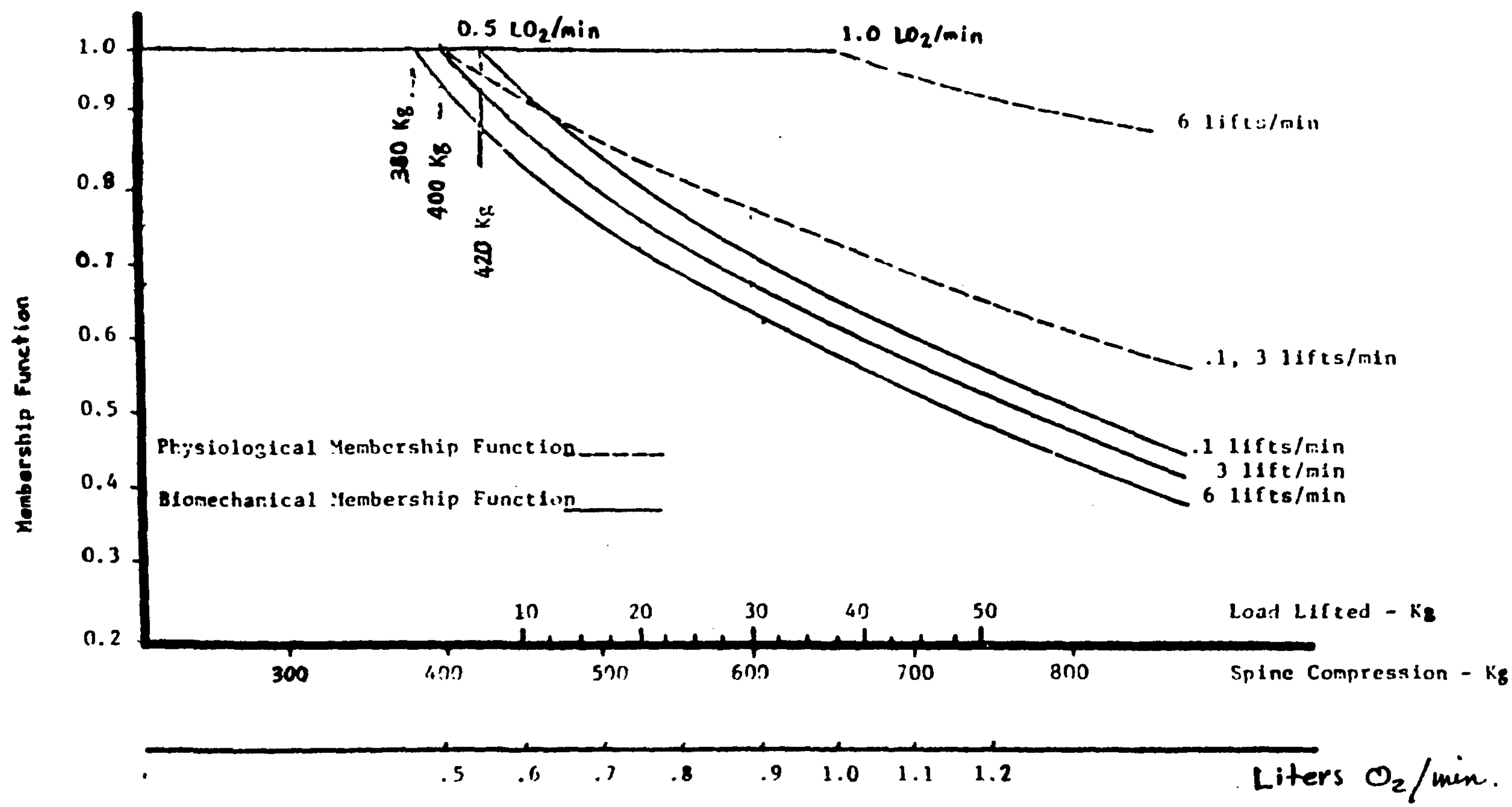

Figure 2. Biomechanical and Physiological Functions
(Ayoub and Hafez)

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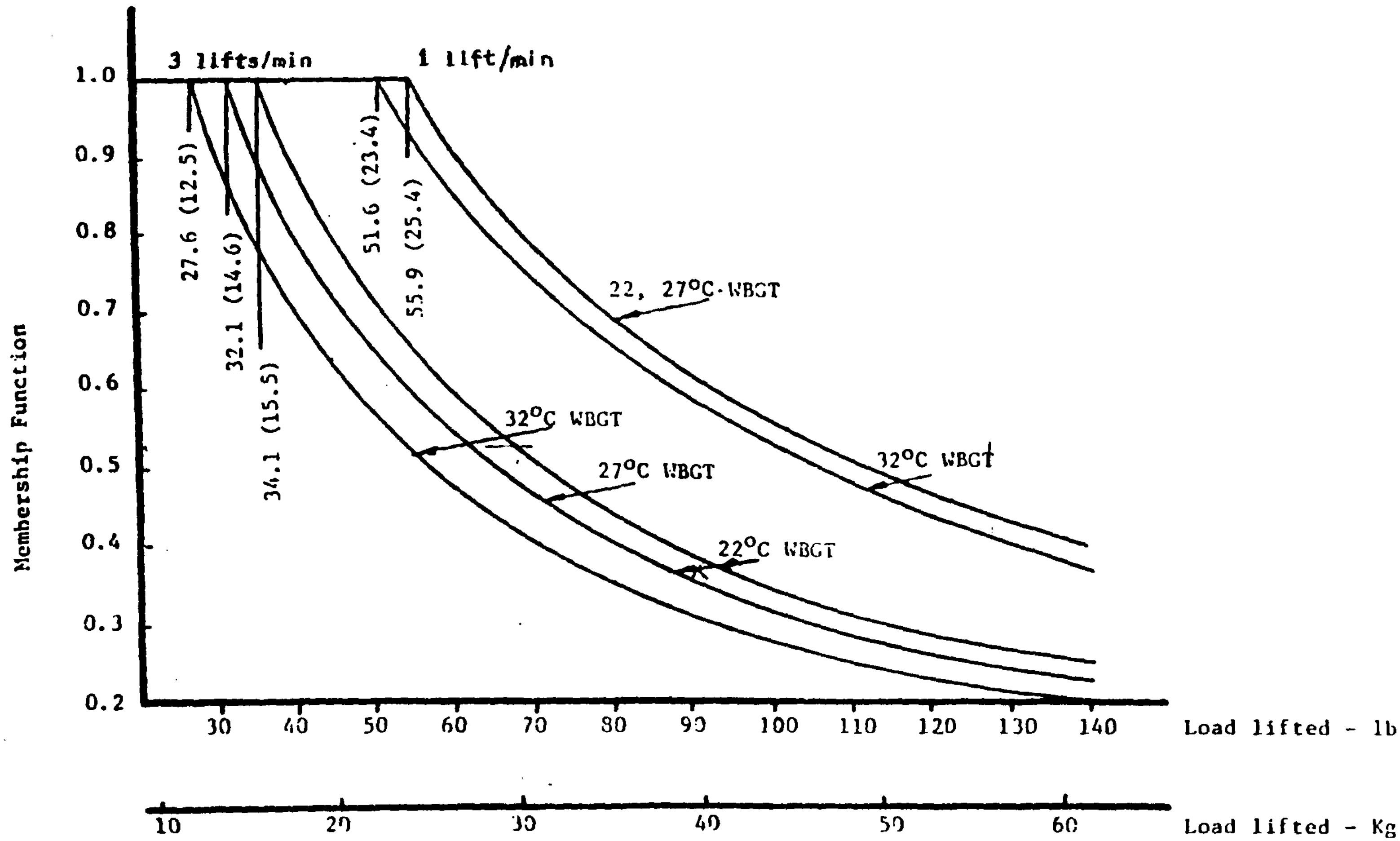

Figure 3. Psychophysical Membership Function
(Ayoub and Hafez)

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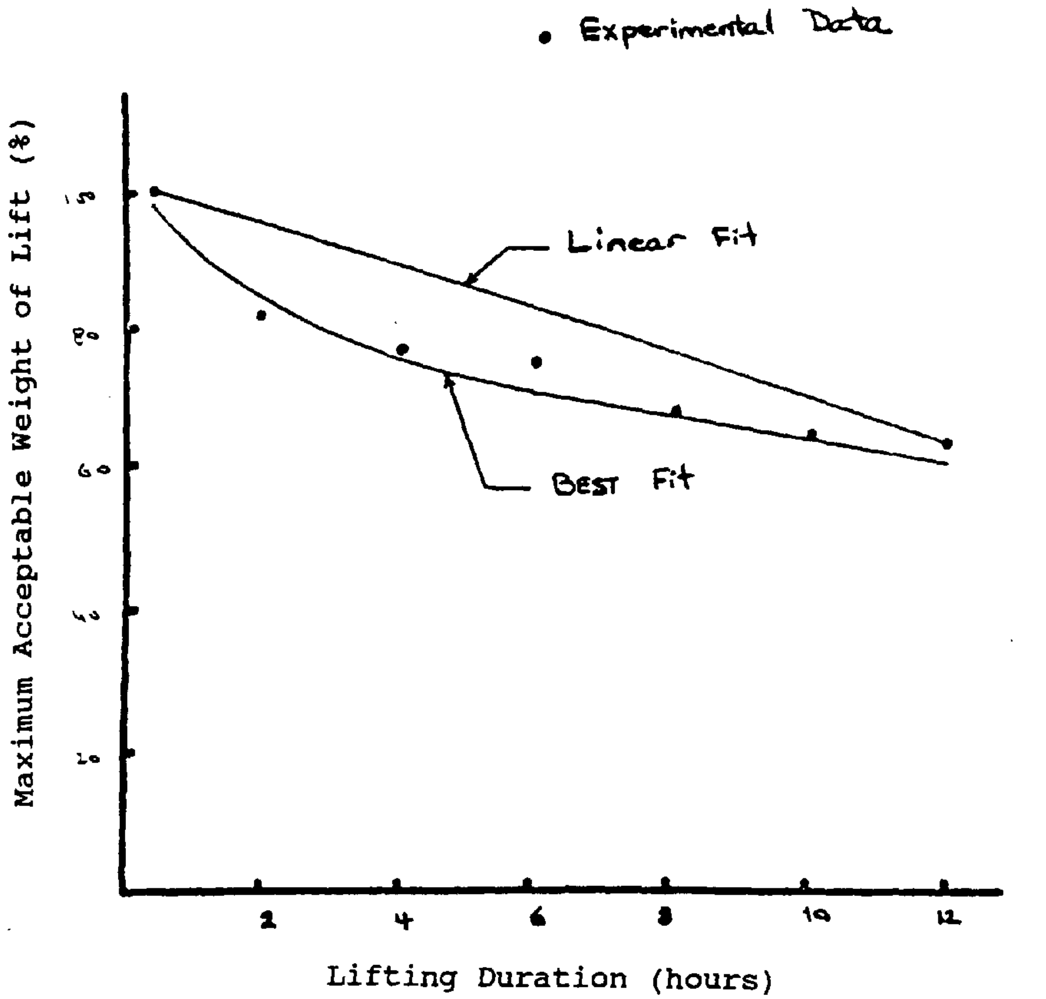

Figure 4. Change in Maximum Acceptable Weight of Lift with time for males (Mital, et al., 1986c)

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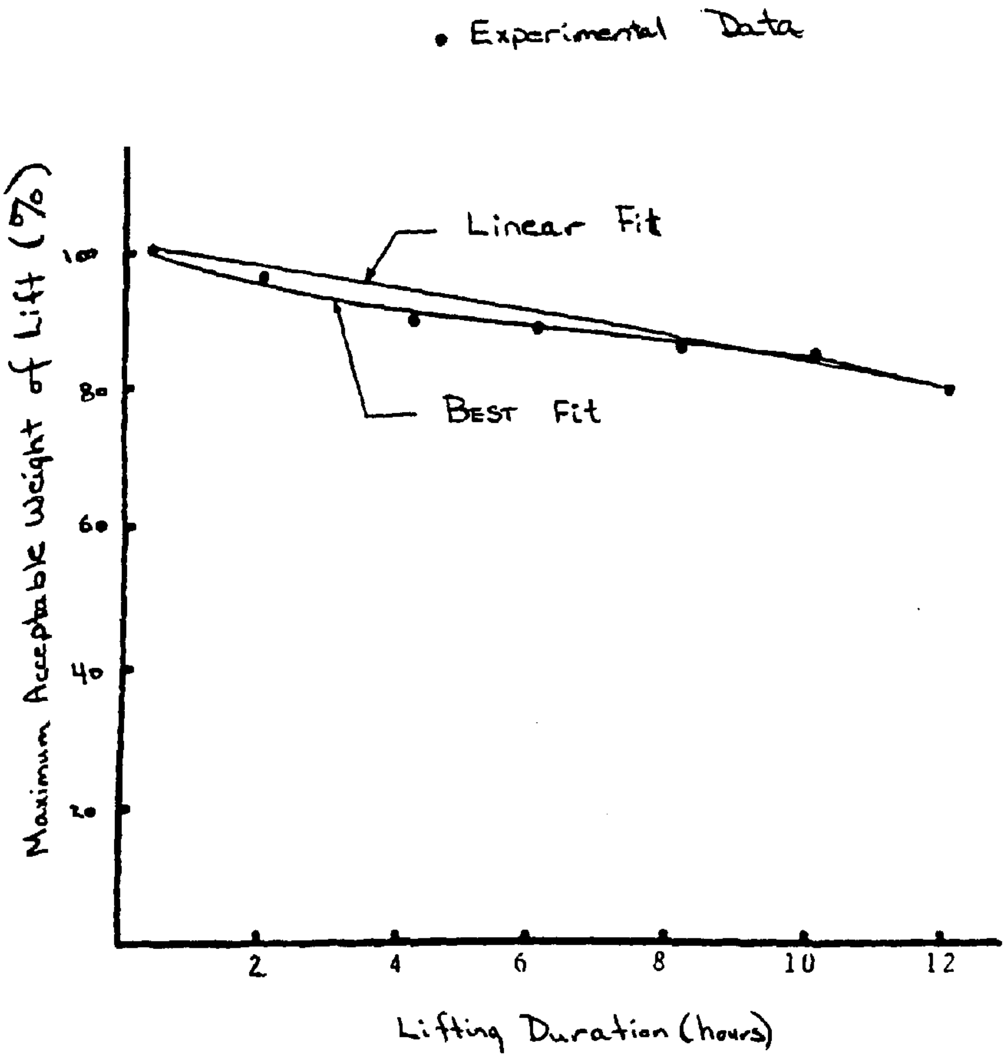

Figure 5. Change in Maximum Acceptable Weight of Lift with time for females (Mital, et al., 1986c)

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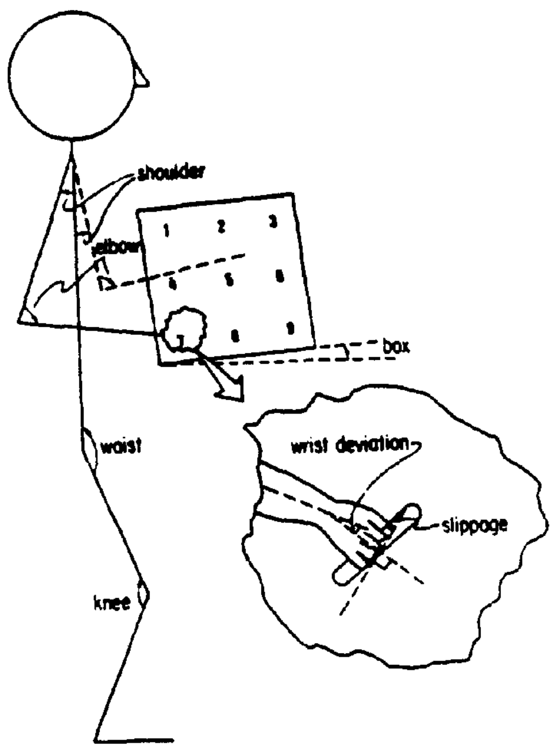

Figure 6. Definition of Handle Positions
(Drury and Deeb, 1986)

Source : Ergonomics 29(6), 1986 743-768
"Handle positions and angles in a dynamic lifting task. Part 1: Biomechanical considerations
by C.G. Drury and J.M. Deeb

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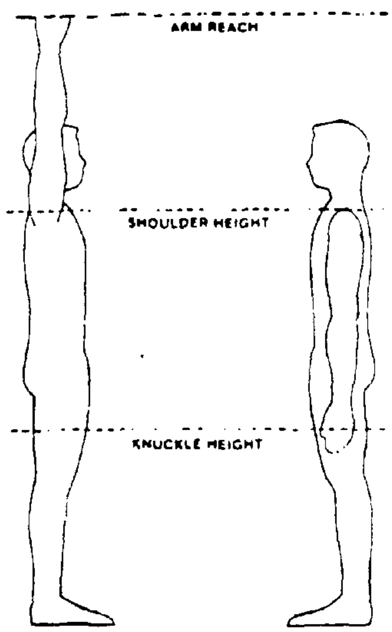

Figure 7. Classification of Lifting Height

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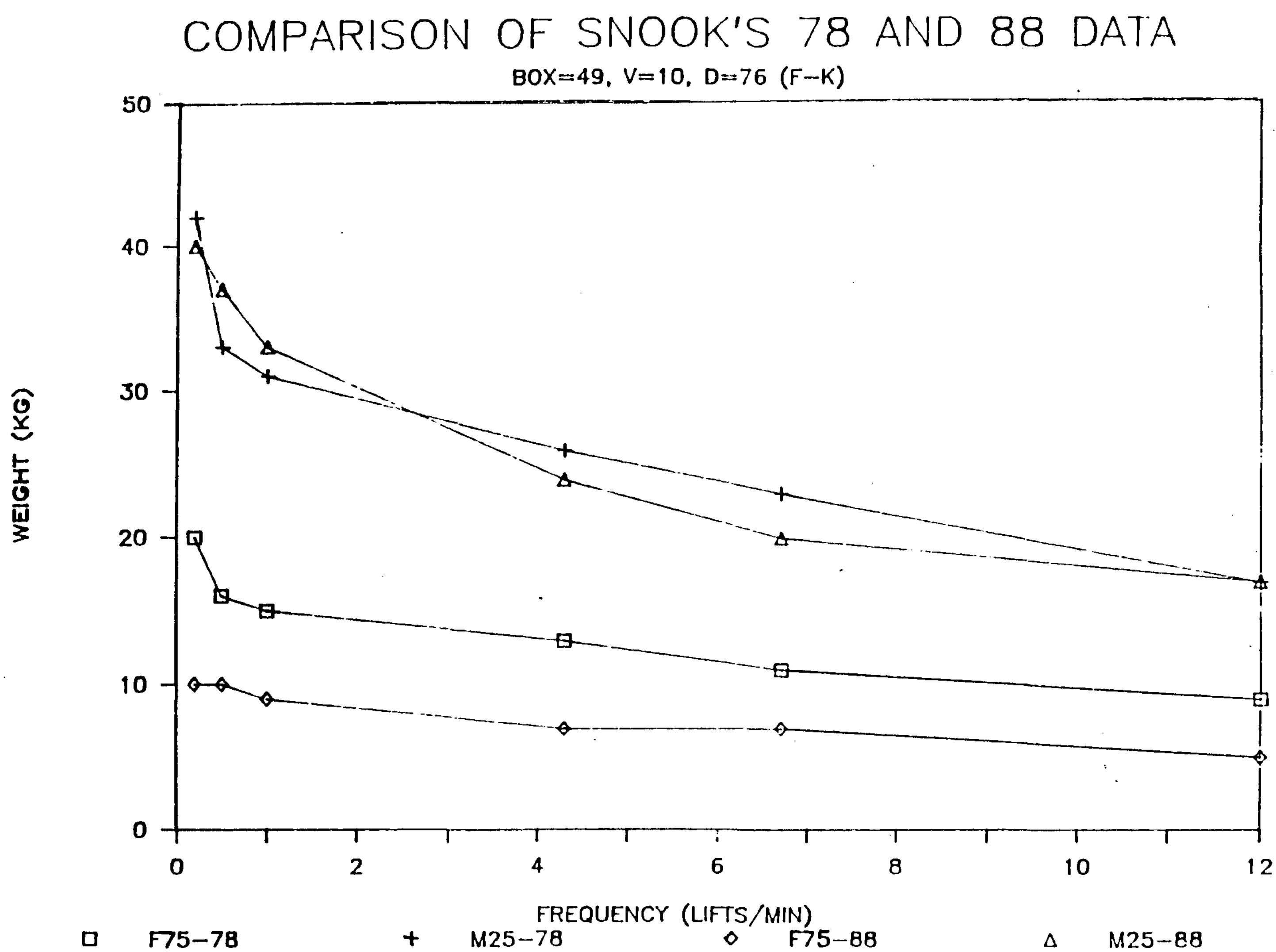

Figure 8. Comparison of Snook's 1978 and 1988 Data Bases

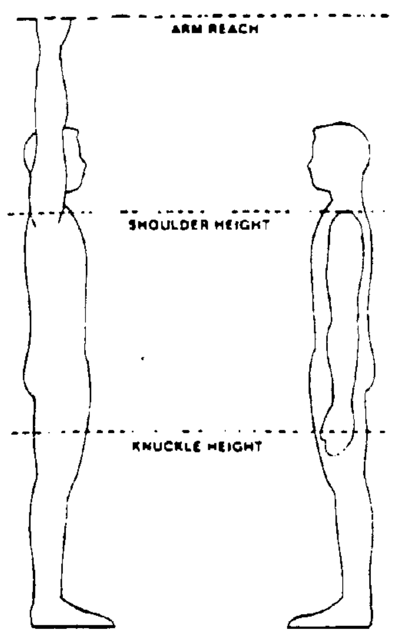

Figure 7. Classification of Lifting Height

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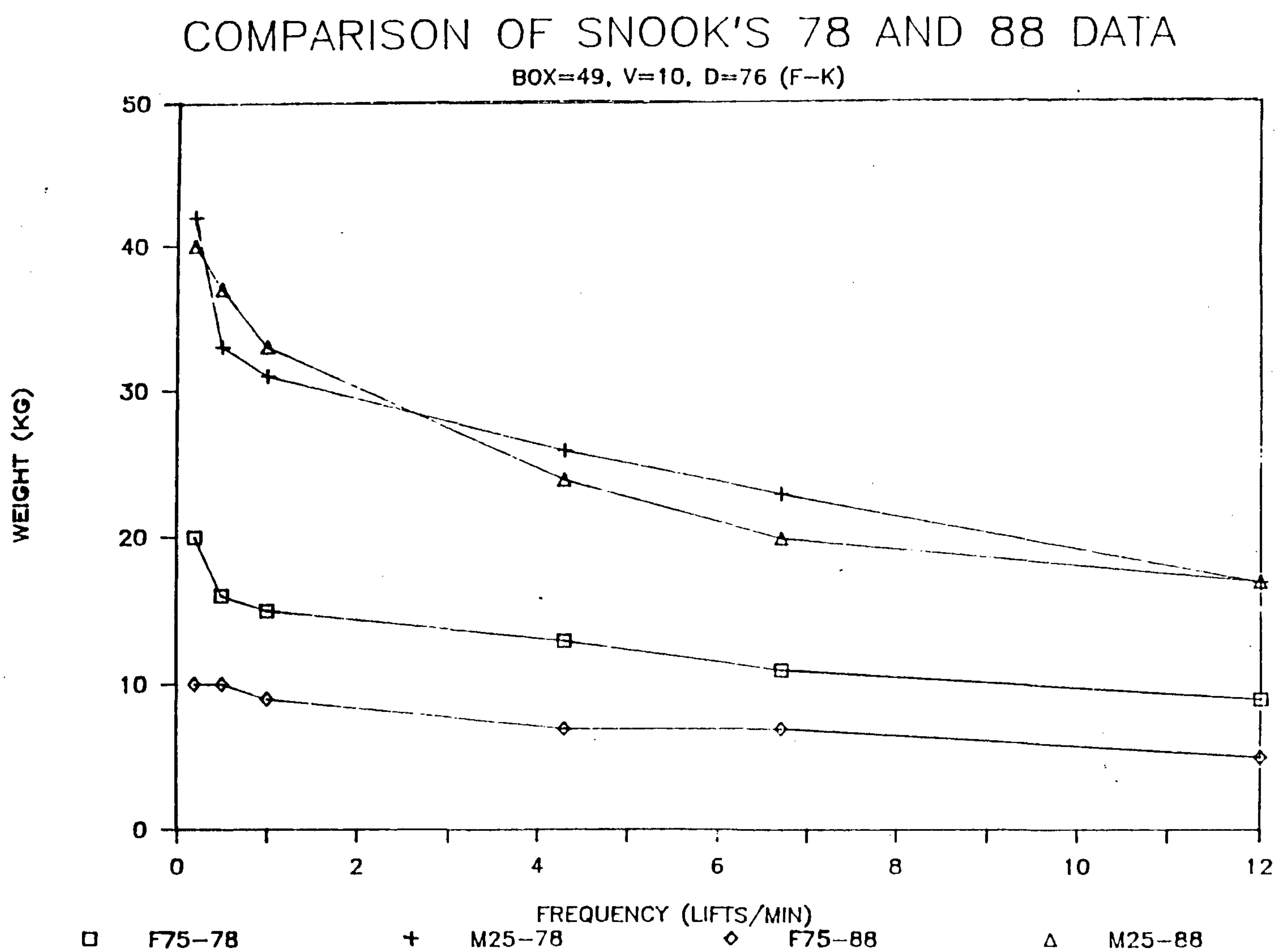

Figure 8. Comparison of Snook's 1978 and 1988 Data Bases

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