PB82-178948

WORK PRACTICES GUIDE FOR MANUAL LIFTING

(U.S.) Department of Health and Human Services
Cincinnati, OH

Mar 81

U.S. DEPARTMENT OF COMMERCE
National Technical Information Service
NTIS

CHAPTER 1

JUSTIFICATION AND SCOPE

Overexertion in the workplace accounts for a large number (and in some industries the majority) of disabling injuries. Most of these injuries involve the act of manually handling materials. This Guide summarizes research on the hazards of manual materials handling in industry, and formulates recommendations to reduce the toll of human suffering and economic burden.

JUSTIFICATION AND RATIONALE FOR THIS GUIDE

For many years manual materials handling (MMH) has been recognized as a major hazard to industrial workers by authorities in the field of occupational health and safety. A particular concern has been shown for women and children performing such acts. In fact, during the period from 1930 to 1950 almost all the states enacted laws specifically limiting the weights that women and children could handle. All of these statutes have been subsequently struck down as unconstitutional since they discriminate against employment of all women without recognition of the large variation in capabilities between women.

As late as 1962 the International Labour Organization published an Information Sheet which stated limits shown in Table 1.1. These limits were primarily based on inspection of injury and illness statistics which depicted manual materials handling as contributing to about a threefold increase in spinal, knee and shoulder injuries, a tenfold increase in elbow injuries, and about a fivefold increase in hip injuries (ILO, 1962).

Table 1.1: ILO suggested limits for occasional weight lifting (kilograms) (ILO, 1962)

Age (years)	Men	Women
14 - 16	14.6	9.8
16 - 18	18.5	11.7
18 - 20	22.6	13.7
20 - 35	24.5	14.6
35 - 50	20.6	12.7
Over 50	15.6	9.8

Despite such guidelines, gross occupational injury and illness statistics continue to dramatize the problem in the United States and elsewhere. In 1973, the State of California reported 27% of all compensable injury and illnesses were due to overexertion (National Safety Council, 1975). Worker's compensation reports for Arkansas in 1976 show the same percentage (BLS, 1978). The later study also revealed, 1) an average of almost $3,000.00 per incident was spent in lost wage compensation and medical payments, and 2) 68% of the overexertion incidents involved lifting and 20% involved pushing and pulling objects. The State of Wisconsin reported the number of overexertion injury claims doubled between 1971 and 1977, as indicated in Table 1.2. The State of California reported over 68,000 overexertion injuries in 1973 alone (National Safety Council, 1975). Though the total for the United States in 1980 is not known, it will probably exceed 500,000 injuries.

Table 1.2: Wisconsin occupational injury and illness compensation records (Workmen's Compensation Division, 1978)

Year	Total Number of Overexertion Claims
1971	7,160
1973	9,875
1975	10,795
1977	14,411

Some industries have a greater overexertion injury rate than others. Table 1.3 depicts several high injury industry groups for Arkansas (BLS, 1978). A study of back strain and sprain injuries in Wisconsin in 1973 showed similar patterns between industry groups (Taugher, 1973). This latter study also reported that 61% of the back pain cases listed overexertion as the cause of the problem, and that about 7% of the back pain cases became permanently disabling to the individual. In this regard, a recent in-depth follow-up of 549 persons classified as partially but permanently disabled due to on-the-job injuries disclosed that less than one-third of the severe cases (particularly back problems) were able to return to work at any job, and that the worker's compensation payments replaced less than one-third of the wage earning capabilities of the workers (Grinnold, 1976).

If low-back pain cases alone are used as an indication of the economics involved, a recent report by the National Safety Council estimated over $1 billion dollars was spent on worker's compensation and medical payments in the U.S. in 1974 (Hirsch, 1977). Average awards in the railroad industry, which is not covered by the worker's compensation system are 10 times those awarded under the Worker's Compensation Act in some states (Hirsch, 1977).

Table 1.3: Arkansas 1976, Supplemental Data Systems Report (BLS, 1978)

Industry	% of All Injuries Reported as Overexertion	% of All Injuries Reported as Strain/Sprain
General Manufacturing of Durable Goods:	24%	29%
Household Furniture	35%	34%
Primary Metals	29%	34%
Fabricated Metal Products	35%	37%
Fabricated Structural Metals	38%	40%
Metalworking Machinery	43%	54%
Electric & Electronic Equip.	31%	38%
Ship Building & Repair	34%	40%
General Manufacturing of Non-Durable Goods:	30%	36%
Beverages	42%	40%
Knitting Mills	50%	60%
Chemicals & Allied Products	41%	54%
Inorganic Chemicals	45%	62%
Drugs	44%	38%
Rubber & Misc. Plastics	35%	45%
Tires and Inner Tubes	43%	55%
Wholesale Trade & Distribution:	32%	37%
General Merchandising Stores:	35%	38%
Service Industries:	36%	49%
Health Services	48%	62%

Clearly, human suffering and high economic burdens are greatest in industries which require manual handling of objects. Whether such acts are the primary cause or simply aggravate a pre-existing susceptibility to injury of the musculoskeletal system is often debated. Further, how many of the medical problems are falsely reported in the worker's compensation statistics is an open question. From a labor relations standpoint, the question is irrelevant. The fact is that the physical act of manual materials handling in industry is regarded as hazardous by many workers who claim,.with regular success, that such caused harm and resulting disability. Be the harm of organic or psychological nature, the facts presented support the need to reduce the exposure to such acts as a matter of protecting worker health and well-being. Evidence of the epidemiological, biomechanical, physiological and psychophysical bases for such claims are presented in this guide to further define the exact conditions which seem to be of most concern to both scientists studying the problem and exposed workers.

EXPOSED POPULATION

A large and diverse group of industries appear to have significant overexertion injury and illness claims, as reported in Table 1.3. How many workers in these industries are actually exposed to hazardous manual materials handling is difficult to estimate. Assuming for the moment that lifting a 20 kilogram (44 pound) object once a day could be hazardous (see Table 1.1) for the occupational groups shown in Table 1.4, it is estimated that over 30 percent of the total workforce is exposed. If this mix of occupations were representative of the U.S. workforce then over 30 million workers are exposed daily. It should be noted that, with the exception of farm workers, all occupational groups listed in Table 1.4 are expected to increase in employment between 1970 and 1980 from 5% to 40% (Wisconsin Bureau of Research and Statistics, 1974).

Table 1.4: Estimated work force performing manual materials handling activities in Wisconsin (Wisconsin Bureau of Research and Statistics, 1974)

Craft Workers:	137,000 workers or 60% of total
	(especially carpenters, brick layers, plumbers, structural iron & steel, tin smiths, tool & die, mechanics, & telephone installers)
Operatives:	100,000 workers or 30% of total
	(especially press operators, packagers, sanders & buffers, welders, truck drivers, bus drivers, railroad brakemen & switchmen, delivery person)
Service Workers:	132,000 workers or 60% of total
	(especially janitors, waiters & waitresses, nurse assistants, porters, firefighters, police, housekeepers, groundskeepers)
Laborers, Except Farm:	65,000 workers or 90% of total
	(especially construction, freight handling, garbage collection, lumbering, stock handling)
Farm Owners & Laborers:	131,000 workers or 100% of total
Total Work Force in Wisconsin (1970):	1,703,810 workers
Estimated Workers Performing Manual Materials Handling:	565,000 or 32% of total

An added complexity in determining the exposed worker population stems from the continually changing mix of personal risk factors. As suggested by the ILO (Table 1.1) both gender and age of the work force modify risk. Figure 1.1 depicts the total employment by gender in the U.S. from 1966 through 1976. An analysis of such trends by the Women's Bureau of the U.S. Department of Labor (1975) stated:

> "The number of women employees increased at a much faster rate than men workers did. Women made up 39% of the total employment in 1974 compared to 34% in 1964. Most of the increase in women workers was in four major industry divisions that showed the fastest growth:
>
> Services: 2.8 million increase
> Government: 2.6 million increase
> Wholesale & Retail Trade: 2.2 million increase
> Manufacturing: 1.4 million increase"

Figure 1.1: Employment in United States by Gender, 1966-1976. (DOL, 1977).

What is disturbing in this regard in the prevalance of manual materials handling occupations in these industries, thus exposing more women to overexertion hazards. As an example, 8 out of 10 employees in the health services industry in 1974 were women (Women's Bureau, 1975). As depicted earlier in Table 1.3, this industry reported the highest proportion of overexertion injuries (48%) and the higher proportion of strains and sprains (62%). Presumably a majority of these incidents are attributed to patient handling by nurses, nurses aides and therapists.

It is clear that the number of women exposed to manual materials handling is increasing. Further, the workforce is aging. Figure 1.2 depicts this trend for women in particular for the last 30 years. The most rapid expansion of the women labor force has been in the age group 45 to 54 (Women's Bureau, 1975). The emergence of these and other susceptible groups into workplaces which were designed years ago for "strong, healthy, young males" will undoubtedly exacerbate problems of overexertion injury in the U.S. A work practices guide is needed to allow future workplaces to be designed safer and more productive for a changing workforce.

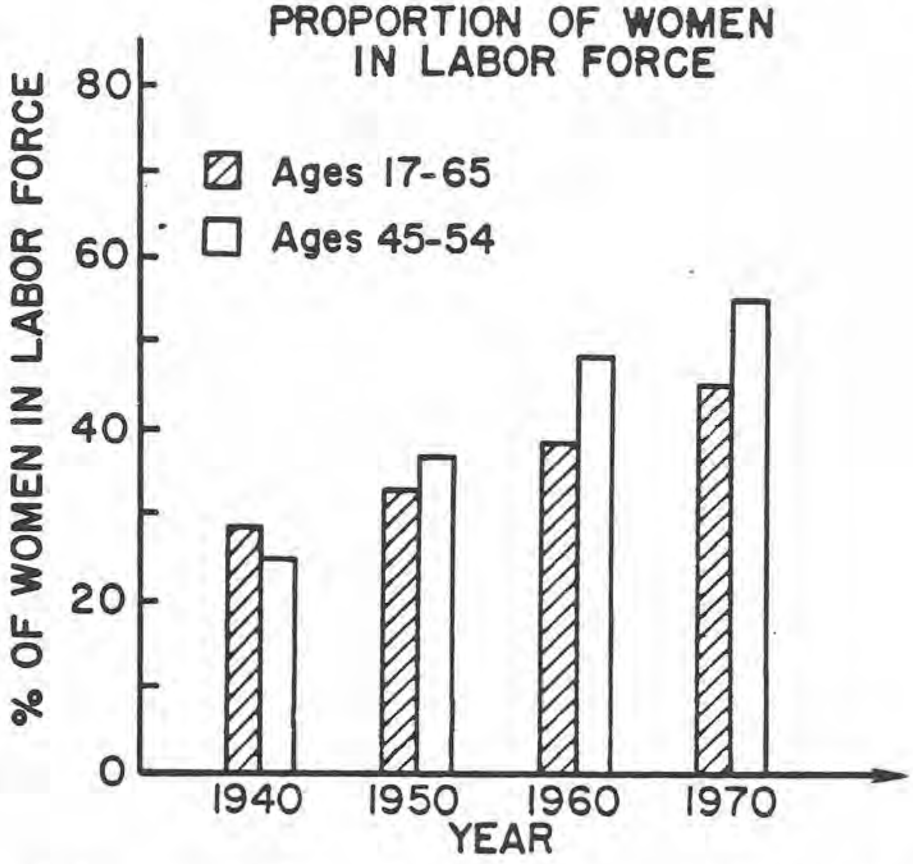

Figure 1.2: Female Labor Force as Percent of Women by Age (Women's Bureau, 1975)

SCOPE OF GUIDE

The variety of work methods, loads handled, frequency of exertions and worker characteristics which modify risk of injury in manual materials handling is virtually limitless. Careful reviews of the knowledge base regarding the hazards of manual materials handling (Herrin, et al., 1974; Drury, 1978) reveal that many facets of the problem still remain inadequately researched. The act of lifting in particular, however, has been extensively studied by many researchers (over 600 literature citations) to the extent that the hazards are reasonably well understood.

There are basically four approaches or criteria for establishing this Guide:

1. epidemiological
2. biomechanical
3. physiological, and
4. psychophysical.

In the next four chapters of this Guide each approach and the implied set of criteria are examined in detail to provide a basis for the recommendations that follow.

Epidemiology as a science is concerned with identification of the incidence, distribution, and potential controls for illness and injuries in a population. Chapter 2 surveys a number of factors identified in epidemiological studies which tend to modify risks of overexertion injuries with particular emphasis on the incidence and severity of low-back pain in industry.

Biomechanical approaches outlined in Chapter 3 show that the musculoskeletal structure (particularly the low-back) of some individuals can be overstressed when lifting compact loads of moderate magnitudes even occasionally. Further, the complex stresses to the body during manual materials handling can be predicted given a careful documentation of the specific handling task.

Physiological studies of the human body's metabolic and circulatory responses to various loads (especially with high frequency of load handling) are presented in Capter 4. Conditions which will not result in excessive physiological strain or ftaigue for a majority of workers are presented.

Psychophysical studies are designed to quantify the subjective tolerance of people to the stresses of manual materials handling. These studies, outlined in Chapter 5, indicate that a large variation exists in the working population's acceptnace of typical load handling conditions, and that combinations of certain weights and work methods are much more objectionable than others. Further, strain/sprain injuries are more prevalent for jobs requiring lifting of heavy loads. Weaker workers in terms of muscle strength (a psychophysical measure) are more susceptible to injury on these jobs than their stronger cohorts.

The large number of studies cited in this Guide indicate that a complex set of limitations exist in the working population's capability to safely handle loads of varying weights and sizes, and for various frequencies and durations during the work day.

In essence this Guide summarizes a wealth of research and presents recommendations to control the various types of hazards associated with the unaided act of symmetric (two-handed) lifting of an object of known weight and size. Quantitative recommendations regarding the safe load weight, size, location and frequency of handling are presented (Chapter 8). Factors which mitigate these recommendations are also discussed (e.g., worker training, physical fitness, strength, workplace layout, load handles, etc.). The Guide includes recommendations regarding both the selection and training of workers who must perform manual materials handling activities (Chapter 6) as well as presenting some engineering guidelines for the design of workplaces where manual materials handling is performed (Chapter 7).

CHAPTER 2

BASIS FOR GUIDE: EPIDEMIOLOGICAL APPROACH

This chapter presents a survey of recent epidemiological literature regarding short and long term health effects of MMH. Since lumbar spine disability has received much attention in research, this evidence is examined in detail. The factors which modify risk of injury are divided into job and personal risk factors. The characteristics of the job which contribute to risk are discussed in terms of weight handled, size of the load and frequency of lifting. Personal risk factors include gender, age, anthropometry, lift technique, attitude, training, and strength. The potential for preventive measures through selective matching of personal and job factors is also examined.

SHORT TERM EFFECTS OF MMH ON HEALTH

There are both short and long term health effects attributed to MMH. Short term effects include traumatic injury and fatigue. Traumatic injury to the body such as lacerations, bruising or fractures often arise during MMH due to

1. sharp or rough surfaces on the materials handled;
2. materials being dropped;
3. workers being struck by swinging loads, and other moving materials not under their control;
4. workers slipping and falling;
5. workers colliding with unseen objects;
6. mechanical stresses induced in the musculoskeletal system leading to sprained joints or torn muscles.

For injuries to the limbs and those which are superficial, the evidence is usually well documented because cause and effect are often simple to diagnose. Musculoskeletal injuries (especially to the lower back) are less clear cut and the extent of trauma is seldom defined. The interpretation of such injuries therefore depends mainly on the mechanism of injury and this (due to inexperienced, incomplete or subjective reporting) is difficult to analyze.

Traumatic back injuries may arise from the unexpected situation, the load being unexpectedly heavy or light or stuck, and from blows on the back or slips and falls (Troup, 1965; Troup, et al., 1970; Manning, 1971; Magora, 1974). In terms of the cost of medical services, productivity losses, etc., these injuries are the most serious because of the frequency with which they lead to chronic disability.

Fatigue, on the other hand, is a more prevalent short term health effect than injury in some occupations, but recovery is more rapid. Symptoms of fatigue may be respiratory, cardiovascular or muscular. Respiratory symptoms such as shortness of breath are seldom a problem in MMH except for the individual with chronic respiratory disease. In this case the worker finds it difficult to move materials in postures which restrict the movements of the rib cage.

Signs of cardiovascular stress are increased heart rate or blood pressure. Prolonged, sustained muscular activity imposes postural stresses on the muscles (particularly when bending down or carrying for any length of time) which leads to an increase in heart rate and blood pressure. High frequency, repetitive lifting elevates heart rate and blood pressure. This may be significant for the worker who suffers from the effects of hypertension or who has a cardiac disorder.

Muscular fatigue is a common cause of symptoms during and after MMH. The severity and duration of symptoms depend not only on the weight and frequency of handling but on the fitness and skill of the individual. Infrequent sessions of unaccustomed, hard work are often associated with the deposition of fibrin and a temporary peritenomyosis (Rais, 1961) which may persist for two or three days. Postural stress is also a common cause of muscular fatigue and discomfort at work (Corlett and Bishop, 1976; Wickström, et al., 1978).

LONG TERM EFFECTS OF MMH ON HEALTH

There are few epidemiological studies which relate chronic exposure to fatigue, postural stress, or musculoskeletal injury with excess morbidity or mortality. One study by Davis and Jackson (1962) identified a greater incidence of chronic bronchitis in those who regularly stooped to lift compared with those who lifted on the shoulder without flexing the trunk. Otherwise, the main long term health hazards concern the spine.

Backache due to fatigue (or postural stress), back or sciatic pain following back injury, and the early onset of degenerative disease of the spine have been cited as consequences of MMH. However, distinctions which exist between these "causes" in theory are not always distinguishable in practice. Prevention requires first, a definition of the pathological process attributable to MMH, and second the identification of the causative mechanism. The epidemiological data are at present insufficient either for a precise understanding of the pathological changes produced or to allow distinctions to be drawn even between fatigue, postural stress and injury. In practice these distinctions are difficult because:

1. There have been few attempts to analyze MMH tasks in terms of postural and handling stresses because it is a very expensive task.

2. Back pain has many possible etiologies, thus, to attribute it to a single causative factor is misleading.

3. There appear to be various "conditioning" factors (individual and environmental) which predispose a back to injury.

Not surprisingly, many authors have found it epidemiologically expedient to lump together all reported episodes of back pain attributable to work irrespective of diagnosis or cause.

BACK PAIN

Back pain can be defined as primary or secondary (Wyke, 1976). Primary back pain arises directly from the tissues of the back which are in a state of neurological, mechanical or biochemical irritation because of fatigue, postural stress, injury or local pathological change such as degeneration. It can arise from any of the tissues supplied by nociceptor afferents (i.e., practically every tissue except for the intervertebral disc and the facets of the apophyseal joints). Back muscles and fascia, vertebral ligaments, apophyseal joint capsules, the spinal dura and dural root sleeves, the adventitia of blood vessels and the periosteum all receive a nerve supply and may become primary sites for back pain. The cartilaginous facets of the apophyseal joints, the end-plates, the nucleus pulposus or the annulus fibrosus (except where it is in contact with the longitudinal ligament or periosteum) are not primary sites.

Secondary back pain is caused by a lesion which affects the nerve supply to the tissues of the back. Thus a mechanical derangement of the spine (for example, any of the degenerative processes affecting the disc or apophyseal joints) which leads to irritation or ischaemia of the posterior primary ramus or nerve degeneration in its fibers may be an indirect or secondary cause of back pain. This is analogous to the derangement of the lumbar spine (such as a prolapsed intervertebral disc) which mechanically compromises a nerve root by stretching it or angulating it from its normal path and which may cause pain, weakness or numbness in the lower limb in the area of distribution of that nerve root (Murphy, 1977; Marshall, et al., 1977).

Back pain is seldom well localized. When severe, it may be referred down the buttocks and thighs without actual root involvement (Mooney and Robertson, 1976; McCall, et al., 1978). It cannot be measured since the severity of pain actually experienced has no direct relationship either to the intensity of nociceptor activity or to the underlying pathological process (Wyke, 1976).

A truly accurate identification of the site and origin of back pain is seldom easy. The tissues concerned are usually deep from the skin surface. The quantity of pain felt and the sites from which it may arise are not closely related. And because of the absence of a nerve supply, the disc and the joint-facets may be injured without causing pain. Often the pain after back injury only begins after the secondary effects of the injury and the ensuing irritative state spread to neighboring structures.

The radiological appearance is seldom of great help in identifying the site and origin of pain. Any observed abnormality such as disc degeneration, a congenital defect or any other structural derangement is likely to be present both before the onset of pain and after its relief. Such changes have frequently been seen in people who have never had back pain.

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. It is misleading to select a single factor for the etiology of back pain. Many possible contributory factors must be borne in mind, for example:

1. fatigue
2. postural stress
3. trauma
4. socio-economic and emotional stresses
5. personality
6. degenerative changes
7. congenital defects
8. reduction in the size and shape of the spinal canal and intervertebral foramina
9. genetic factors
10. stretching, angulation, compression or adhesion of nerve roots
11. neurological dysfunction
12. the duration of symptoms
13. physical fitness
14. body-awareness

This list is far from complete. Further, it does not fully convey the complexity of the problem which is compounded by the way in which these contributory factors interact. Another problem in applying epidemiological data obtained from medical clinics is the knowledge that the patients who are seen in practice only represent a small fraction of the affected population (Westrin, 1973).

With regard to the "conditioning" factors which predispose the back to injury, mention has been made of environmental and individual factors; the latter include the psychosocial stresses associated with accidents at work (Hirschfeld and Behan, 1963). This is a subject to which scientific attention has only recently been turned. It concerns the mechanical and pathological factors which affect the dynamic response-characteristics of the spine and thus its capacity to withstand trauma. The strength of the tissues of the spine is inversely related to the duration of applied stress (Pery, 1957; Kazarian, 1972; Kazarian and Graves, 1977; Lamy, 1978). The dynamic response-characteristics vary with time, partly due to the "creep-effects" which take place whenever the compressive loading exceeds the osmotic pressure in the tissue. For example, a shoulder load of as little as 9 kg (20 lbs.) on healthy young adults caused measurable losses of vertebral height within 20 minutes, the loss of height being greater in the morning than in the evening. Recovery of height on removal of the load took about 10 minutes (Fitzgerald, 1972).

A similar effect is produced by vibration, "vibrocreep" being an acceleration by vibratory stress of the creep effect induced by static loading (Kazarian, 1972). Prolonged loading of the spine due to postural or vibratory stresses leads first to a reduction in height of the vertebral column; to a consequent change in the dynamics and kinetics of the apophyseal joints and of the ligaments and muscles which control them; to a reduction in the compliance of the spinal unit (Kazarian, 1975); and to changes in the transmissibility of stresses along the spine (Mertens, 1978). These changes alter the susceptibility to injury which accordingly varies throughout the working day in a way which depends on the pattern of spinal stress to which the worker is exposed.

The presence of degenerative changes in the disc affects its deformation under load (Rolander, 1966). The rate of creep depends on the grade of degeneration. Degenerated discs display a higher creep rate and a greater deformation which reaches a state of equilibrium more rapidly (Kazarian, 1975). However, there is no way in which the onset of disc degeneration can be detected in the living. It is only visible radiologically at a comparatively late stage. Though the process is usually symptom-free, its presence (with the associated changes in dynamic response to loading) must be accepted as a potential but unseen "conditioning" factor which alters susceptibility to injury. Kazarian (1975) found that recovery from creep-effect was inversely related to the duration of loading, taking as long as 20 hours. With a more rapid creep rate and greater deformation in the degenerated spinal unit, it could be deduced that for a given loading duration the degenerated segment takes longer to recover. It must therefore be concluded that some levels of postural stress may have a chronic, cumulative effect. Likewise exposure to vibration and other forms of kinetic stress while under static load may not allow a full recovery overnight.

One of the most common types of reported back injury is of sudden back pain while stooped to lift. In such cases there is no way to distinguish the long term effects of MMH from the short term effects of postural stress of injury, given our present knowledge.

JOB RISK FACTORS

Many aspects of the physical act of manually lifting a load have been identified as potentially hazardous to a person's musculo-skeletal system. Among those cited in a review of the literature by Herrin, et al., (1974) are:

1. Weight - force required

2. Location/Site - postiion of the load center of gravity with respect to the worker

3. Frequency/Duration/Pace - temporal aspects of the task in terms of repetitiveness of handling

4. Stability - consistency in location of load center of gravity as in handling bulky or liquid materials

5. Coupling - texture, handle size and location, shape, color, etc.

6. Workplace Geometry - spatial aspects of the task in terms of movement distance, direction, obstacles, postural constraints, etc.

7. Environment - factors such as temperature, humidity, illumination, noise, vibration, frictional stability of the foot, etc.

To date only the first three aspects have received sufficient attention in lifting injury research to form a strong basis for guidance.

Weight Lifted

The weight of the material handled is perhaps the most obvious factor which modifies risk of injury. Hult (1974), Kosiak (1968), Lawrence (1969), Magora (1969, 1970) and Rowe (1969, 1971) are but a few of the authors who have found that the frequency of low back injuries is greater in "heavy" than in "light" industries. Many of these injuries occur when individuals lift objects which are familiar in size, shape and weight (Herndon, 1927; Brown, 1958). This is one reason some researchers believe the expenditure of time and effort in the training and education of industrial workers in good lifting technique has been to little or no avail in back injury abatement (Brown, 1972; Snook, 1978).

In most previous studies, jobs have been simply classified as heavy, medium or light work. When referring to low back stresses, a job classified as light or sedentary by traditional criteria (i.e., caloric costs to perform the job) still may require the person to lift 30 to 50 kilograms a few times during a work shift. Depending on the size of the object and body postures assumed, these infrequent acts could produce injurious mechanical stresses on the low back.

Studies by Chaffin and coworkers confirm the relation between weight handled on a job and musculoskeletal injuries. The first study (Chaffin and Park, 1973) monitored 400 workers for a one-year period. It was 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 pounds (9 kg) between 25 and 35 inches (64 and 89 cm) in front of the body, would be potentially hazardous for some people."

This conclusion was based on both on-the-job and off-the-job low-back pain incidence rates.

In a follow-on study (Chaffin, et al., 1977) of 550 workers for a two-year period it was found that heavier jobs (in terms of maximum load lifted) also resulted in increased severity of injuries in terms of total lost workdays or medical work restriction days. In general, load handling of less than about 20 kilograms resulted in relatively few incidents of a severe strain or sprain diagnosis, but the heavier load handling jobs were associated with more severe sprains, joint dislocations and bone fractures.

Ayoub, et al., (1978) established job severity indices for workers based upon job demands which include weight handled, box size and frequency of lift. In a study of 220 males and 24 females employed on 63 lifting jobs, they found an increase in the incidence and severity of musculoskeletal disorders as these job severity indices increased.

Location/Size of Load

The physical dimensions of the load handled are important from a biomechanical, physiological, and psychophysical point of view. In studies referred to above, Chaffin and co-workers combined the weight, horizontal and vertical location of the object handled into an index of job stress referred to as a "lift strength rating." The value of this rating ranged from zero, when little or no lifting was involved, to 1.0 where the lifting was such that only a very strong person could perform the job due to excessive weight or awkward posture.

In the first study, the incidence rate of low-back pain was strongly correlated with the lift strength rating. In the moderate-strength-requiring jobs, where a potential hazard first appeared to exist, weight lifting was an equally serious hazard for both men and women. In the follow-on study (Chaffin, et al., 1977), it was observed 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."

The etiological basis for these findings will be discussed in Chapter 3.

Frequency

The relation of frequency, duration and pace of lifting to back injury potential was also studied by Chaffin, et al., (1977). High frequency load lifting was related to increased injury rates. In particular,

> "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."

These results suggest

1. a greater exposure to physical stresses during repetitive lifting which could accelerate "wear and tear" in connective tissues,

2. a greater potential for muscle fatigue with repetitive lifting, and

3. a greater probability of an uncoordinated muscle action during a lift.

The physiological and psychophysical implications of these results are discussed in detail in Chapters 4 and 5.

PERSONAL RISK FACTORS

The capacity to perform the physical act of lifting 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. Understanding the relationship of these characteristics to the resulting risk of injury to the worker is prerequisite to the development of schemes for placing people in jobs which do not compromise their health and safety.

Gender

The literature reveals that the gender of a worker may be related to the risk of overexertion injury. As mentioned in Chapter 1, both the ILO (1967) and more recently the U.S. Department of Labor (1970) recommended that women not lift as much as men. It appears to be accepted that, on the average, a woman's lifting strengths (primarily arms and torso strengths) are about 60% of a man's according to Asmussen and Heeboll-Neilson (1962), Chaffin (1974), Snook and Ciriello (1974b) and Petrofsky and Lind (1974). Furthermore, the biomechanical linkage mechanism (while lifting) may differ between males and females with respect to the lever systems employed, as reported by Tichauer (1973). Hence, if asked to handle a given load, the average women is more highly stressed than the average man relative to their strengths. However, the range in the strength of males and the strength of females is very large. Gender, thus, becomes secondary to the strength factor per se. Strength as a risk factor will be discussed later.

Brown (1974), in a survey of industrial workers, reports that women appear to have larger relative numbers of complaints than men when required to perform heavy, physical jobs. Magora (1970) reports a similar result. In a test of this, Chaffin and Park (1973) studied both men and women performing equally demanding, light-to-moderate load handling jobs and reported equal incidence of low-back pain cases. However, the women in this study who performed moderate materials handling jobs were stronger than the women on the lighter jobs (i.e., an unknown selection process was operating).

Age

As with gender, age has often been considered before placing people on jobs requiring the manual handling of materials. In practice, advanced age if often used in restricting a person from load handling jobs. In fact, this is mainly based on speculation, namely that older workers have diminished capacity to withstand physical stresses (Aberg, 1961). The literature indicates the greatest incidence of low-back pain (LBP) occurs in the 30 to 50 year old group (Herndon, 1927; Hult, 1954; Kosiak, et al., 1968, Magora and Taustein, 1969; Rowe, 1969 and Brown, 1973). Whether this is because older workers are not as likely to be exposed to the 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. It appears, however, that heavy physical work, even when performed in the twenties, can cause accelerated rates of injury (Blow and Jackson, 1971). Clearly, age and aging have a complex effect on many attributes necessary for workers to safely handle heavy loads.

It seems likely that the younger person may not have developed the requisite abilities to recognize and control the hazards of manual materials handling as has the older worker. He may be overly stressing his body, yet may have the strength to withstand the rigor of the job. On the other hand, the older individual, while having perfected his skills in handling heavy or cumbersome loads, is likely to have some diminished physical capabilities. Age must, therefore, be viewed as a potential risk factor but the exact form of this risk is not yet fully understood.

Anthropometry

Body weight and stature are two anthropometric attributes with potentially complex effects on an individual's risk of injury during manual materials handling. It is generally accepted that body weight has a direct effect on the metabolic energy expenditure rate of a person while lifting and carrying loads (Kamon and Belding, 1971; Garg, et al., 1978. Thus, a heavier person would have a greater metabolic rate and concomitant circulatory load, which could lead to earlier fatigue (Petrofsky and Lind, 1974), or cardiovascular problems if the person were so predisposed. On the other hand, a heavier person 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, 1969 and Konz et al., 1973). Also, Ayoub et al. (1978) found that there appears to be a relationship between body size and ability to lift. No direct link between back pain or overexertion injuries and worker body weight has been drawn.

Tauber (1970) indicated that taller people have more low-back pain incidents than shorter people. Three separate epidemiologically oriented studies by Hult (1954), Rowe (1971), and Chaffin and Park (1973) have not been able to support the notion that either fat or thin or tall or short people are at a significantly higher risk of low-back injury.

In brief, the selection of people for materials handling jobs based on their anthropometry is not well justified in terms of reducing low-back pain incidence rates. There is, however, the need to specifically consider a person's anthropometry in relation to the physical characteristics of the prospective workplace in terms of reach and mobility. All jobs that do not allow for a large range of anthropometric variation in the population, as stated in reference books such as VanCott and Kinkade (1972) and Damon, et al., (1966), should be identified and those specific function limiting dimensions should be stated in the job descriptions.

Lift Technique

A substantial amount of literature has been published on lift technique as an individual worker skill for minimizing injury. Unfortunately, no controlled epidemiological study has validated any of the contemporary theories on the subject. Proponents of the erect back, squat lift posture predicate their views on a simplistic mechanical logic; namely that this posture allows the load to be held close to the torso and, therefore, the spinal bending moment and compression forces on the back will be small. In addition, the stresses on the vertebrae will be better distributed, e.g., Floyd (1958), Davis (1959), Muchinger (1962), Himbury (1967), Anderson (1970) and Nachemson (1971). In such analyses, little concern is shown for the dynamic loadings on both the back and the knees during the lifting sequence, not withstanding the practical fact that many heavy objects are too large to be lifted between the knees, as is required by the squat lift method.

Research by Clark and Russek (1958), Brown (1973), Jorgensen and Poulsen (1974), and Garg (1976) disclose that leg lifting from a squat position is metabolically more demanding, thus possibly leading to more fatigue related injuries (e.g., slips and falls, or dropping of object). Chaffin (1969) found that the location of the load relative to the back is more important than the lifting posture in generating high compressive forces in the spine.

Confounding the issue of which posture is the safest for lifting is the realization that low-back pain can occur due to sudden slips and the resulting postural corrections necessary to regain balance (Hult, 1954; Brown, 1958). Therefore, to protect the back as well as other body segments, one must maintain a posture which assures a maximum stability over the period of the activity. Toward this end, the National Safety Council (1971) and the International Labor Office (1967) have chosen to emphasize the kinetic method of lifting, which is based upon the squat lift approach and the efficient use of body weight. However, Anderson (1970), the original developer of the kinetic method, believes that

> "it is safer to allow workers to use their own common sense and muscle sense than to teach them new drills in performing certain jobs in which a series of predetermined positions must be consciously assumed."

Observations of workers experienced in the handling of heavy loads show that the squat lifting posture is rarely used (Shephard, 1974). Davis, et al., (1965) suggested this is because the method is impractical. The leverage exerted by the quadriceps muscle in this posture is ineffective and the average worker cannot develop sufficient force to raise heavy loads. For loads away from the body, Park and Chaffin (1974) have shown that forces on the erector spinae muscles and the lumbosacral disc can be as much as 50% higher when using the recommended squat posture compared to the stooped posture. However, for compact objects close to the body, they recommend the squat method based upon a shorter moment arm for the body weight and the load acting at the lumbosacral L_5/S_1 disc.

Attitude

The characteristics of a worker's personality which may increase susceptibility to the hazards of manual materials handling are not easily measured or interpreted. Studies by Blow and Jackson (1971), Magora (1969, 1970) and White (1966) conclude that the psychosomatic aspects of low-back pain cases need further research study. Unfortunately, personality characteristics are often confounded with other demographic or anthropometric variables such as age, training, or experience. Clear evidence of how worker values and job satisfaction contribute to risk does not exist.

Training

The importance of training and work experience in reducing hazard is generally accepted in the literature. The lacking ingredient is largely a definition of what the training should be and how this early experience can be given to the naive worker without harm. Lacking strong epidemiological support at the present time, this topic is deferred to Chapter 6 where the criteria for improved training are addressed in detail.

Strength

Over the last few decades a large amount of strength data has been gathered on various populations from Olympic athletes to infant toddlers. There has also developed an awareness that strength assessments could be useful in determining personal risk of injury to a person assigned to materials handling activities. Kraus (1967) believed that strength tests should be an essential part of pre-employment examinations. Such a policy has also been advocated by Hanman (1958), Koyl and Hanson (1969), Kelly (1975) and Chaffin, et al., (1978).

Epidemiological support for strength testing as means of matching worker capabilities and job demands is provided from several studies.

Rowe (1971) found that abdominal weakness correlated with increased incidence of low-back pain. From the biomechanical point of view (Chapter 3) abdominal strength is a major factor in reducing the compressive forces acting on the lumbar spine during lifting (Davis, 1959; Bartelink, 1957; Alston, et al., 1966; and Morris, et al., 1961). Further, Troup and Chapman (1969) and Poulsen and Jorgenson (1971) believe the strength of the back extensors are of primary importance in protecting the back during manual materials handling.

A study by Chaffin and Park (1973) monitored 400 newly hired employees to determine whether medical incidence rates were related to the relative match of job requirements to strength ability. Volunteer new hires participated (anonymously) in a battery of isometric strength tests and were then monitored for one year for all medical injury experiences. A sharp increase in the mean low back pain incidence rates (by a factor of 3:1) was observed for those jobs populated by individuals who had not demonstrated strengths equal to or exceeding that required by their jobs.

Because of the importance of this result, a second longitudinal study (Chaffin, et al., 1977), was undertaken to determine if the results were reproducible. This study included another 550 workers in both light and heavy industries. All persons were strength tested as described earlier before being placed on their jobs.

Again, the incidence rate of back pain episodes was found to be almost three times higher in the overstressed group than in the understressed. For strains, sprains, dislocations, and fractures involving other than the back, strength alone did not correlate well. However, for frequent lifting an increased incident rate and severity rate resulted. Furthermore, contact type incidences such as lacerations, bruises, and abrasions of a traumatic nature increased in frequency and severity for weaker workers placed on high strength demanding jobs. It was concluded that

> "overstressing a person beyond their demonstrated strengths cannot be tolerated by a person's musculoskeletal system, especially when such exertions are performed more often than about 100 times each week. This appears true whether the medical costs are measured in terms of back injuries or more generally in terms of musculoskeletal or trauma related injuries."

Snook (1978) surveyed the strength requirements on Liberty Mutual Insurance Company policyholder jobs. From a sample of 191 compensable low-back injury claims, it was revealed that

> "...approximately one-quarter of policyholder jobs involve manual handling tasks that are acceptable to less than 75% of the workers (in terms of strength required); however, one-half of the low back injuries were associated with these jobs. This indicates that a worker is three times more susceptible to low back injury if performing a manual handling task that is acceptable to less than 75% of the working population. This also indicates that, at best, two out of every three low back injuries associated with heavy manual handling tasks can be prevented if the tasks are designed to fit at least 75% of the population. The third injury will occur anyway, regardless of the job. The other low back injuries not associated with heavy manual handling tasks will also occur. Therefore, it can be concluded that the proper design of manual handling tasks can reduce up to one-third of industrial back injuries."

The study also examined worker selection and training practices and concluded

> "No significant reduction in low back injuries was found in employers who used medical histories, medical examinations, or low back x-rays in selecting the worker for the job. Similarly, no significant reduction in low back injuries was found in employers who trained their workers to lift properly."

The topic of muscle strength and capacity is thus an important one. Chapter 5 is devoted to a detailed discussion of worker strength capability as a basis for job design.

SUMMARY

A wealth of literature can be identified which relates manual materials handling to musculoskeletal injuries in the workplace. With particular reference to low-back pain, this chapter presents an overview of but a few studies. More extensive bibliographies can be found in Brown (1972), Herrin, et al., (1974), and Drury (1978).

Due to the problems of measurement and interpretation of the "low back pain syndrome" it is recognized that longitudinal studies provide the most reliable estimates of hazard and risk. It is concluded from recent longitudinal studies that heavy load lifting contributes to increased frequency and severity rates for low-back pain. This is true regardless of the repetitive or dynamic nature of the lifting. If, however, such lifting is performed repetitively, the medical hazard extends beyond low-back problems to other musculoskeletal strain/sprain injury risk, particularly for weaker workers.

In this latter regard, gender, age, and anthropometry 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 to carefully document the effectiveness of this form of selection procedure, however, are still needed.

CHAPTER 3

BASIS FOR GUIDE: BIOMECHANICAL APPROACH

The general concern in occupational biomechanics is to determine with given precision what a person can physically (mechanically) do. This concern leads one to ask more basic questions regarding the individual's health status (i.e., history of injury, disease, nutrition, etc.) and what specific tasks the person is required to physically perform in a job. In the industrial setting, this means that the person's physical capabilities must be assessed along with the physical demands of a prospective job. In addition to the simple ability to perform, biomechanics is concerned with those physical attributes of the individual and job that have been found to produce potential harm to the musculoskeletal system. As discussed in the first two chapters of this Guide, injury statistics have resulted in a major research emphasis being placed on understanding how the act of lifting loads adversely affects the health of a person's low back. This chapter, therefore, concentrates on the biomechanics of the low-back as a basis for a load handling limit.

OCCUPATIONAL BIOMECHANICS OF LOAD HANDLING

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 for handling the load. Specifically, the load held in the hands as well as the person's body masses (when acted on by gravity) create rotational moments or torques at the various joints of the body. The skeletal muscles are positioned to exert forces at these joints in such a manner that they counteract the moments due to the load and body weight. From the mechanical stress standpoint, it is unfortunate that the muscles are positioned as they are, since they act through relatively small moment arms. This means that they can produce large motions with small degrees of shortening but for any external load operating on the body, high muscle and joint forces are produced.

For example, consider the major elbow joint flexor muscles (i.e., the brachialis and biceps brachii) illustrated in Figure 3.1. For the static conditions (such as holding an object),

$$T_M = T_L \text{ (i.e., the muscle and load torques are equal).}$$

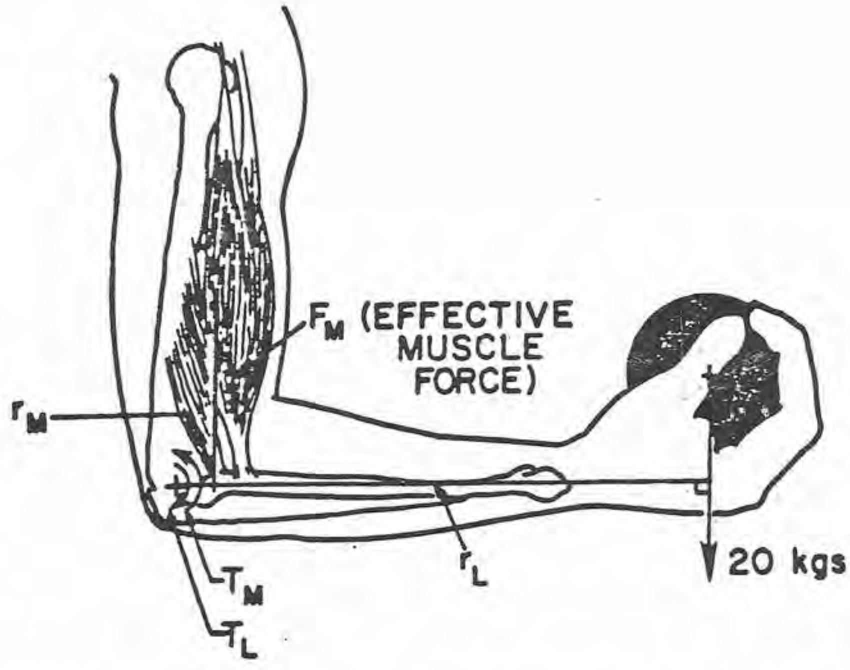

Figure 3.1: Illustration of Muscle Mechanics (Chaffin, 1975).

In terms of forces and moment arms, then

$$F_M \times r_M = 20 \text{ kg} \times r_L$$

With average male anthropometry r_M = 5 cm and r_L = 35 cm.

Therefore

$$F_M = 140 \text{ kg}$$

The weight of the forearm and hand would cause an additional 34 kg-cm moment for a total muscle force of 174 kg. Thus, simply holding a given load in the hands requires more than 7 times greater elbow flexion muscle force due to the mechanical disadvantage of the muscles.

To apply this concept, consider that a 20 kg (44 lb.) object must be lifted with both hands (10 kg in each) from the back of a shelf placed at about shoulder height. Figure 3.2 illustrates the posture. Note first that the elbow is extended, which reduces the flexor muscle moment arm to about 25% of its former value (i.e., r_M now is about 1.2 cm for an average man).

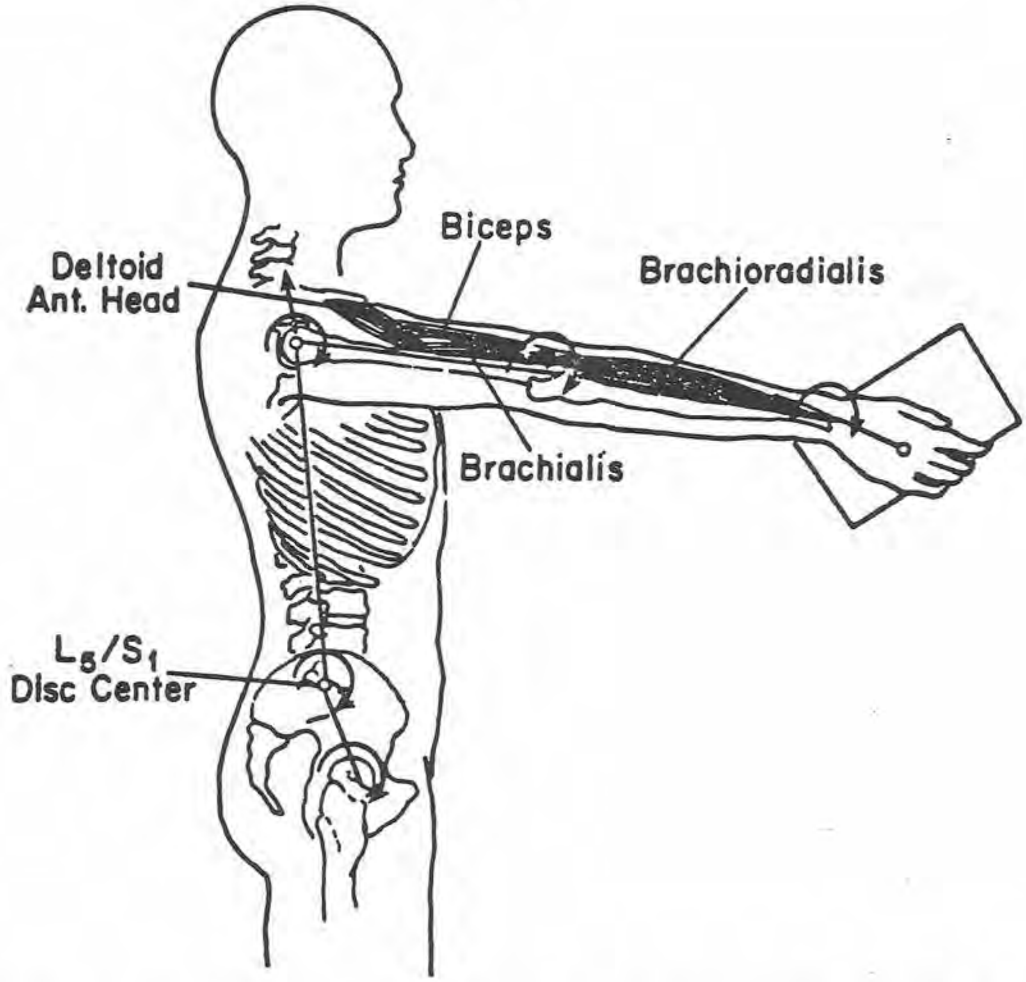

Figure 3.2: Illustration of Leverage on Shoulder, Elvow, and Lumbosacral Joints (Chaffin, 1975).

This means that the 10 kg acting on each hand requires about 292 kg of force in the elbow flexor muscles (not inclusing the extra load imposed by the weight of the forearm and hand). One might think that this muscle force is acceptable because muscles develop most tension when stretched. This is an important mechanical fact. The muscles may, indeed, be capable of producing such high forces, but what about the bones, joint cartilage and joint connective tissues? For instance, when the muscles pull across an extended joint, they compress the joint with about the same magnitude of force. This coupling of the muscle and bone compression forces is an important concept when considering low-back biomechanics. In addition, high muscle forces inhibit blood flow, placing extra stress on the heart and leading to early muscle fatigue.

Another biomechanical fact illustrated in Figure 3.2 is a large shoulder torque (and therefore shoulder muscle flexor force) produced due to the load acting through a large moment arm. The average male arm length is about 63 cm to the center of grip. This means that each shoulder torque is about 630 kg-cm (i.e., 63 cm multiplied by 10 kg). If one includes the weight and distribution of the masses of the arm, this value becomes closer to 734 kg-cm. Empirical investigations have found this torque exceeds the voluntary strength capabilities of 90% of the female industrial population and about 40% of the male industrial population (Chaffin and Baker, 1970; Martin and Chaffin, 1972). The major point, then, is that the shoulder joint is not well suited to withstand high forces when flexed or, as discussed by Tichauer (1978) when abducted.

One might suspect that such lifting requirements do not exist in industry today. One example of exactly this situation is shown in Figure 3.3. The layout of many machines, materials handling equipment and storage devices often compels the operator to assume biomechanically awkward and potentially injurious postures. Because the required posture has caused the worker to be straining himself close to his expected arm and shoulder strengths, any sudden slip of the object either could cause an overstrain injury or the object could fall onto the worker's foot. (This also illustrates the mutual concern for both health and safety in most operational situations.)

Shoot H-T

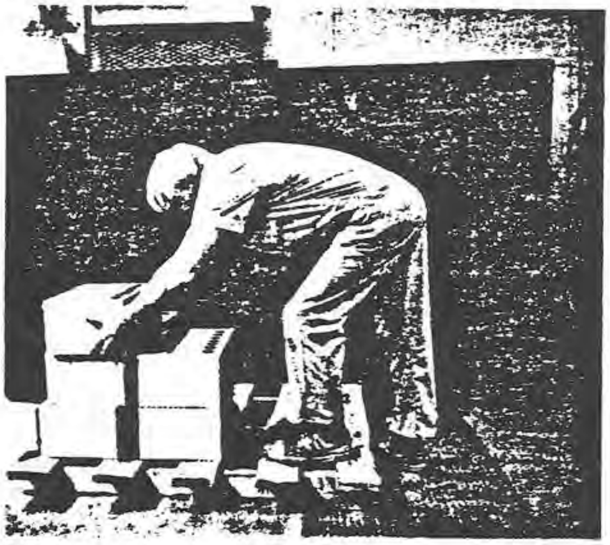

Figure 3.3: Illustration of lifting task requiring high arm and shoulder strengths

LOW BACK STRESS

Perhaps the most important point to be gleened from Figures 3.2 and 3.3 is that when a 20-kg load is held at arm's length, it produces a large torque at the lumbosacral joint of the back. For the average man's anthropometry, such a load produces more than 1200 kg-cm torque. This, in combination with the torso weight, produces a compression force at the L_5/S_1 disc equivalent to what holding about a 40-kg load between the knees would produce. In other words, one does not have to "bend over" to produce high forces on the low-back structures. A person with strong arms and shoulders, in particular, can position the body in postures that greatly multiply an external load's effect on the low back. The biomechanical consequences to the low back will now be considered in more detail.

The lumbar spine can be thought of as a set of small links with flexible articulations (discs) between each. With proper geometric and physiologic data, the forces in each disc during a specific lifting activity can be predicted. Because the clinical and biomechanical data indicate the greatest problem to be at the lower lumbar spine, the L_5/S_1 disc (lumbosacral joint) has been used to represent the spinal stresses of lifting in earlier studies by Morris, Lucas and Bresler (1961), Tichauer (1966) and Chaffin (1969). These models have clearly shown that during weight lifting, the bending moment at the lumbosacral joint can become quite large (on the order of 2000 kg-cm when lifting about 50 kg from the floor). To counteract this moment, the muscles of the low-back region (primarily the erector spinae group) must exert correspondingly high forces, since they operate on small moment arms (about 3.8 - 5.0 cm, as referenced by Chaffin and Moulis (1969) and shown in Figure 3.4).

The high forces generated by the low-back muscles are the primary source of compression forces on the lumbosacral disc. These concepts are illustrated in Figure 3.5 for a person holding a variable load, designated F_H. The graph at the bottom of Figure 3.5 displays the predicted compression forces at the L_5/S_1 disc for increasing loads held in the position depicted, using a 50 percentile man's anthropometric data and normative abdominal assistance values (Chaffin, 1969).

The important concept in Figure 3.5 is that even in the "reasonable" lifting posture depicted, high compression forces are created in the disc. Direct pressure transducer measurements by Nachemson and Elfstrom (1970) of the compression forces in the lumbar discs have confirmed the range of these predicted values.

The maximal amount of compression that can be tolerated by the lumbar spinal column has been estimated from axial loading compression tests on cadaver columns. Data from separate studies of this type by Evans and Lissner (1959) and Sonoda (1962) disclose large biologic variations in the disc's (and its weight-

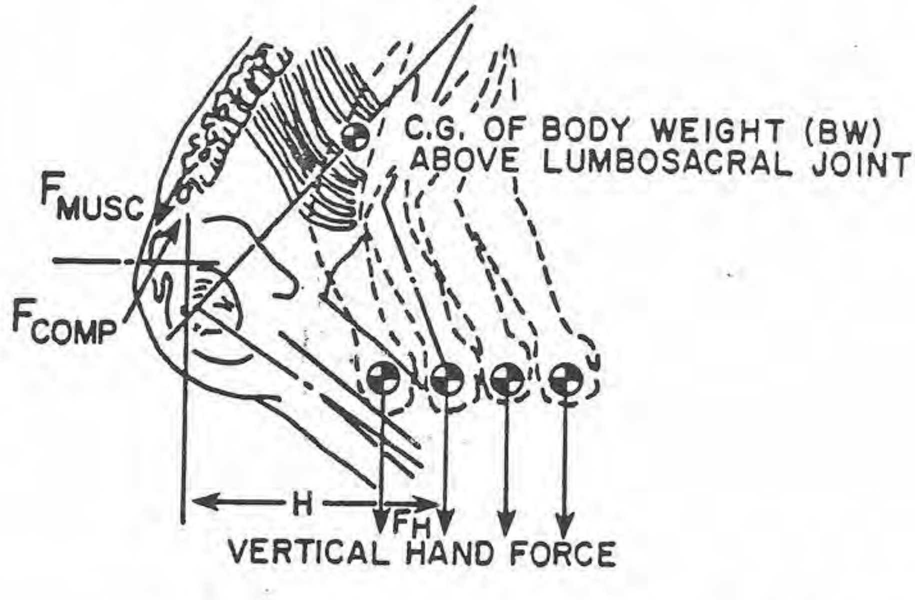

Figure 3.4: Forces and moments operating at L_5/S_1 disc during load lifting.

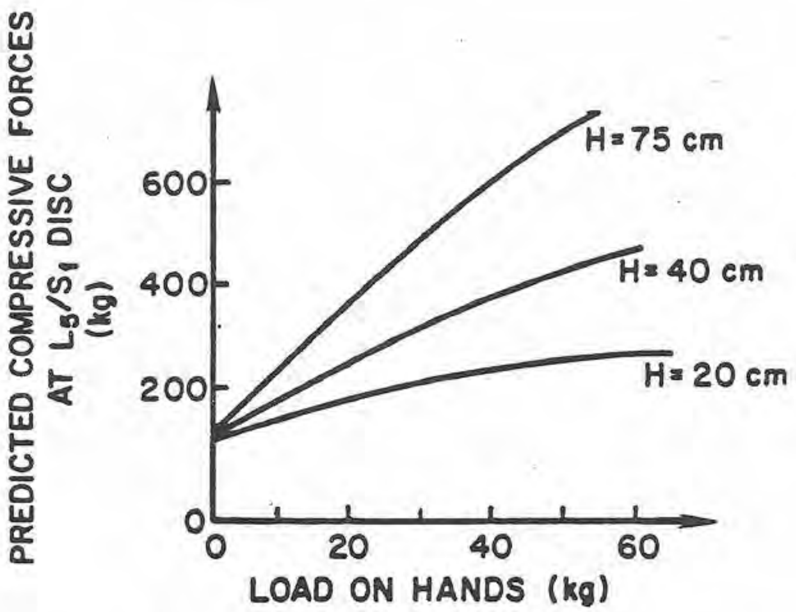

Figure 3.5: Predicted compressive forces acting on L_5/S_1 disc. (Adapted from Chaffin, 1975).

bearing cartilage end-plate's) ability to withstand such stresses. Figure 3.6 illustrates these data by age group. In general, the data from male cadavers under 40 years of age disclose a mean of about 675 kg before the cartilage end-plates begin to exhibit microfractures. The fracture levels range, however, from as low as 250 kg (over 60 years of age) to more than 950 kg (under 40 years of age). 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.

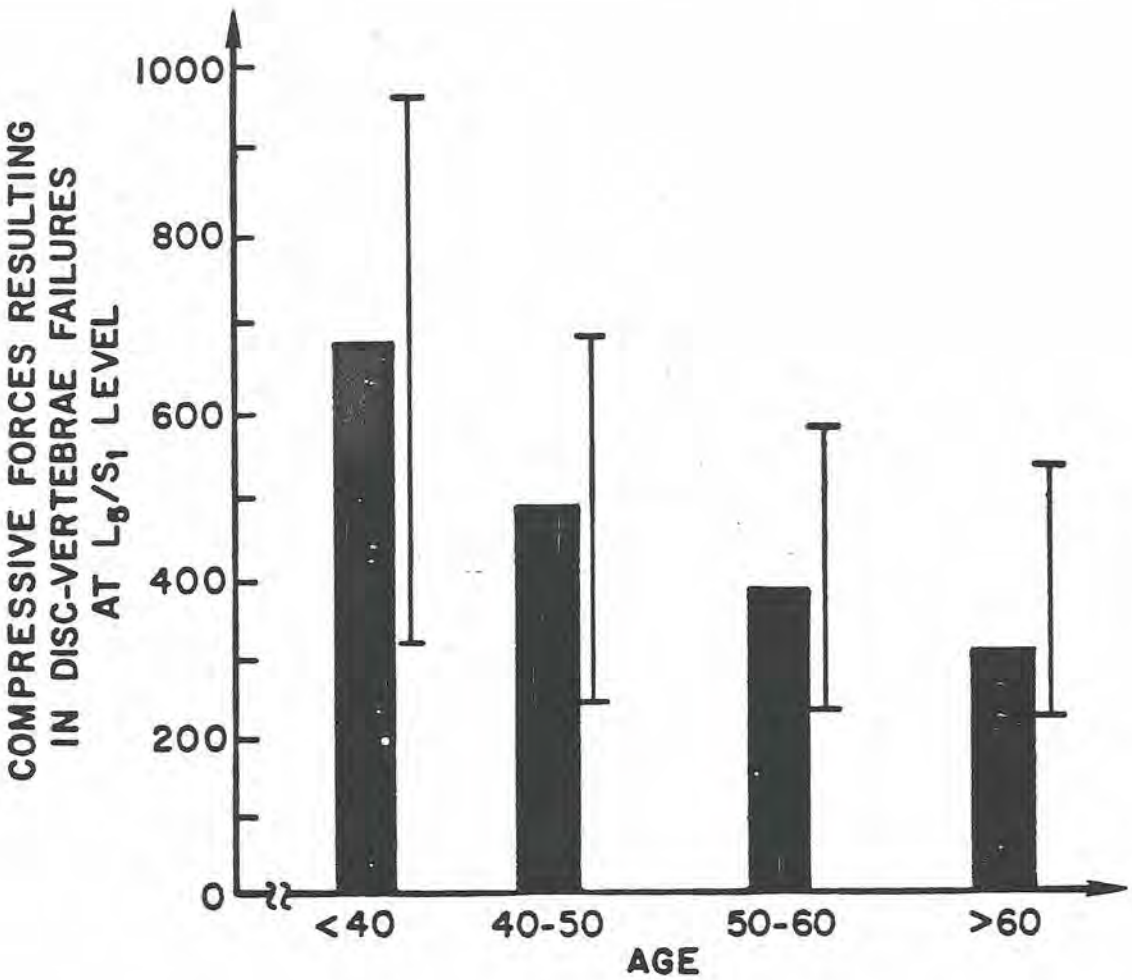

Figure 3.6: Mean and Range of Disc Compression Failures by Age (Adapted from Evans, 1959, and Sonoda, 1962).

Two further observations from these early cadaver studies are noteworthy. First, the discs themselves (if healthy) do not herniate. Instead, the cartilage end-plates that distribute the compression loads to the bodies of the vertebral segments fail, as described by Armstrong (1965). Second, the large variation 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 repeated compressive stresses of life (and lifting in particular) can be sufficient enough to cause microfractures in the cartilage end-plates and subchondral bone of the vertebral bodies which (it is hypothesized) would alter the metabolism and necessary fluid transfer to the disc. If this occurs, a degenerated capability of the discs to withstand further compression loads would develop. The end result of this process is that the annulus fibrosus bulges or ruptures, causing pressure on the adjacent nerve roots, as shown in Figure 3.7.

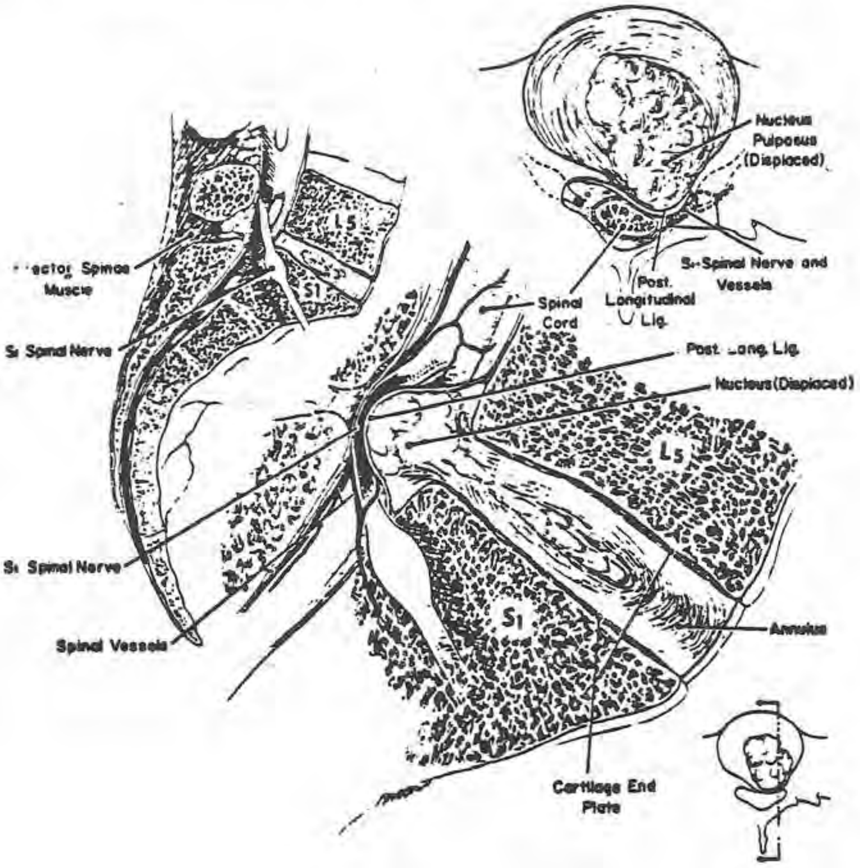

Figure 3.7: Displaced degenerated disc exerting pressure on spinal nerves (Chaffin, 1975).

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 latter 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 hernation, 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 development 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.

The implications of this disc degeneration theory are far-reaching. Most important is that assigning 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 by patients and physicians alike. 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. With this in mind, it is easy to rationalize why the statistics relating a person's physical acts to the incidence of low-back pain generally are so poor.

POSTURE EFFECTS

Returning to the biomechanical aspects of manual materials handling, several general concepts need further definition. First, there remains the issue of how a person's posture affects low-back stresses. It already has been shown that if the load is horizontally distant from the torso, large forces can result, even without bending over. Therefore, the most important rule in materials handling is to ensure that the person is able to bring the torso as close to the load center of gravity as possible before lifting it. This often requires having the person squat down beside the load with the legs straddling it when the load is on or near the floor, and lifting it between the knees. This assumes, of course, that the load is small enough to go between the flexed legs easily.

If the load is small, the companion rule regarding keeping the back near vertical is biomechanically justified, as it reduces the stresses on the low back due to the torso weight. Unfortunately, lifting with the legs from a squatting position with the back vertical (i.e., the classic recommended posture) often is not possible because the person so instructed does not have the quadriceps strength necessary to extend the knees and raise the body from such a position. In other words, most people, when lifting weights, lean their torso forward to reduce the moment on the knees. This is so common in lifting that the quadriceps muscles often are insufficiently developed to allow the person to "lift with the legs" when instructed to do so. Thus, the rule about "lifting with the legs while keeping the back vertical" must be qualified to include the physiologic fact that many people will not be able to perform such lifting without first increasing their leg strengths. In addition, with some individuals, muscle-stretching exercises will be needed to provide the necessary range of motion in the knees, hips and ankles. It should also be recognized that lifting from a squat position will require lifting of the torso, thus requiring extra energy expenditure, as discussed in the next chapter.

A second, more complex qualification on the classic "squat lift" rule must also be realized when lifting large objects that cannot pass between the knees. Studies by Park (1973) and Park and Chaffin (1974) disclose that when a large object is lifted around the front of the knees, as required in the squatting type of leg lift just described, it necessarily causes the moment arm of the load about the low back to be large. This causes the moment at the low back to be large, and hence high spinal compressive forces and muscle forces result. In contrast, the more often used stoop-back method of lifting allows the person to "move over" the weight to be lifted and thus reduce the load moment arm about the lower back. Figure 3.8 illustrates this concept. For the calculation of the forces in the example, a 15.5 kg (35 lb.) load is being lifted from a position that is 38 cm (15 inches) in front of the ankles and 38 cm (15 inches) above the floor. Nominal anthropometry and abdominal assistance values are assumed, as described by Chaffin (1975). It can be seen that the "stooped-over" position results in about one-third less compressive stress on the low back than the squatting type of lift. It should also be evident that the stooped-over position allows the person to reduce the load moment arm of 35 cm (14 inches) about the low back even further by moving in over the load more than is shown, whereas the load moment arm of 50.9 cm (20 inches) for the squat lift is as small as possible due to interference of the upper legs and the load. A further limitation on lifting large objects with a squat lift arises from the fact that the arms must be extended farther in the forward horizontal direction than with the stooped-over posture. As discussed earlier, such a position of the arms means that a high torque will be produced at the shoulders, which may not have the strength to move the load upward. Therefore, the person normally will lean forward more to lessen the load moment arm about the shoulders, and in so doing will cause greater stresses on the low back both by the effects of gravity acting on the torso mass and by hyperflexing the lumbar column. Such hyperflexion places a greater stress on the posterior positions of the annulus of the disc, thus distributing the compressive loads unevenly within the disc. As Davis and Troup (1965) have described moderate flexion of the torso does provide effective abdominal pressure assistance during lifting, thus reducing the low-back stresses. Therefore, some torso flexion appears to be

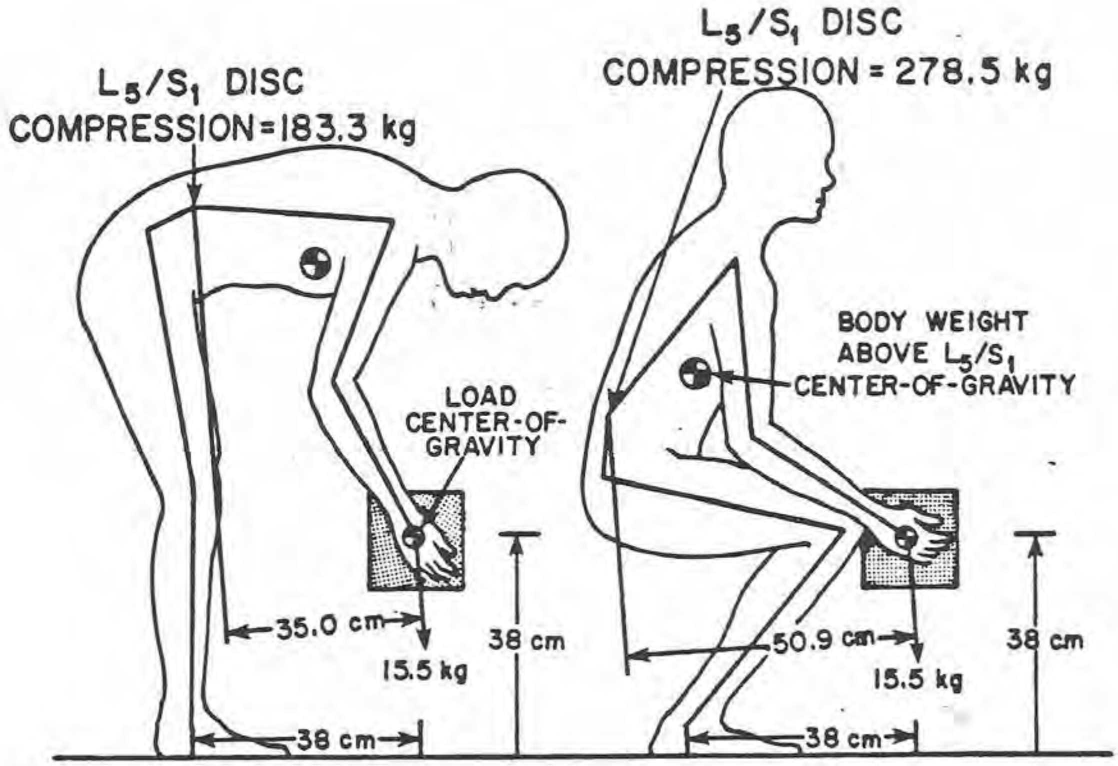

Figure 3.8: Low Back Compression Associated with Two Lifting Postures (Park and Chaffin, 1974).

acceptable but extreme flexion could predispose the lower back to injury when the peak load occurs, usually during the first 200 msec of the lift.

Based on simple quasistatic biomechanical concepts, one must conclude that instructions as to lifting postures must reflect concern for the person's strength and mobility as well as the size of the object to be lifted. Lifting of objects that cannot pass between the legs should be done with the traditional stooped-over torso and legs only slightly flexed. Where possible loads should be reduced in size to allow them to come between the legs. When this is possible, a squatting leg lift with the back nearly vertical is recommended. Unfortunately, these recommendations are based on biomechanical considerations only. Controlled field studies to determine the benefits associated with these recommendations have not been made. As Brown (1973) and Jones (1971) point out, much more research is necessary to establish the validity of any suggested methods of handling loads. For the present, however, biomechanically based recommendations certainly are worth serious consideration when counseling a person as to how a load should be lifted and carried safely.

ASYMMETRIC LIFTING

The preceding biomechanical discussion has considered relatively symmetric and smooth lifting of loads. Symmetric lifting, wherein the load is held with both hands in front of the body, is believed to be the most common method of handling a heavy load. This method equalizes the stresses bilaterally on the musculoskeletal system allowing a person to utilize their muscle strengths most effectively. There are situations, however, wherein moderate loads may be lifted asymmetrically. Unfortunately, the hazards of such lifting postures have not been documented in controlled field studies, but biomechanically one must be concerned. An asymmetric lift, which has the person bring the load up along the side of the body, causes not only a lateral bending moment on the lumbar column but, because of lordodic curvature of the column, produces a rotation of each vertebra on its adjacent vertebra. One laboratory study by Farfan, et al., (1970) indicates that disc degeneration most often involves the annulus fibrosus, which is the structure that provides 40-50% of the torsional resistance to twisting of the lumbar vertebrae. With disc degeneration, this torsional resistance can be reduced to less than one-half its normal strength, thus providing a significant injury potential. In addition, the asymmetric loading of the musculature of the back could produce a concentrated stress of sufficient magnitude to strain a specific muscle of the many muscles required to stabilize the column. In general, it must be concluded that lifting of loads along the side of the body is to be avoided. A person's arm and shoulder strengths are not well enough developed to lift heavy weights in an asymmetric fashion. Moderate load lifting, however, may be attempted using a side lift, and therefore instructions and job redesign often are indicated to reduce the stresses associated with such lifts.

DYNAMIC LIFTING

Another limitation regarding the present state of knowledge concerns the dynamics of load lifting. One investigation by Park (1973) disclosed that the lifting of loads between 6.5 kg (15 lbs.) and 23 kg (50 lbs.) from the floor to an erect carrying position (load against the front of the upper legs) resulted in an acceleration effect that added between 15% and 20% to the static load 100 msec after the beginning of the lift. Furthermore, with fast motions the ability of the somatic nervous system to coordinate the many muscles necessary to stabilize the spinal column is stressed. Electromyographic studies by Donish and Basmajian (1972), Tichauer (1971), Morris, Benner, and Lucas (1962) have only recently begun to identify the temporal complexities involved in coordinating the recruitment of the back muscles. It is hypothesized by Brown (1973) that some low-back problems are related to muscle fatigue, which further inhibits coordination of the back muscles. Tichauer (1966) suggests that unanticipated motions due to trying to catch falling or tossed objects can cause low-back injuries.

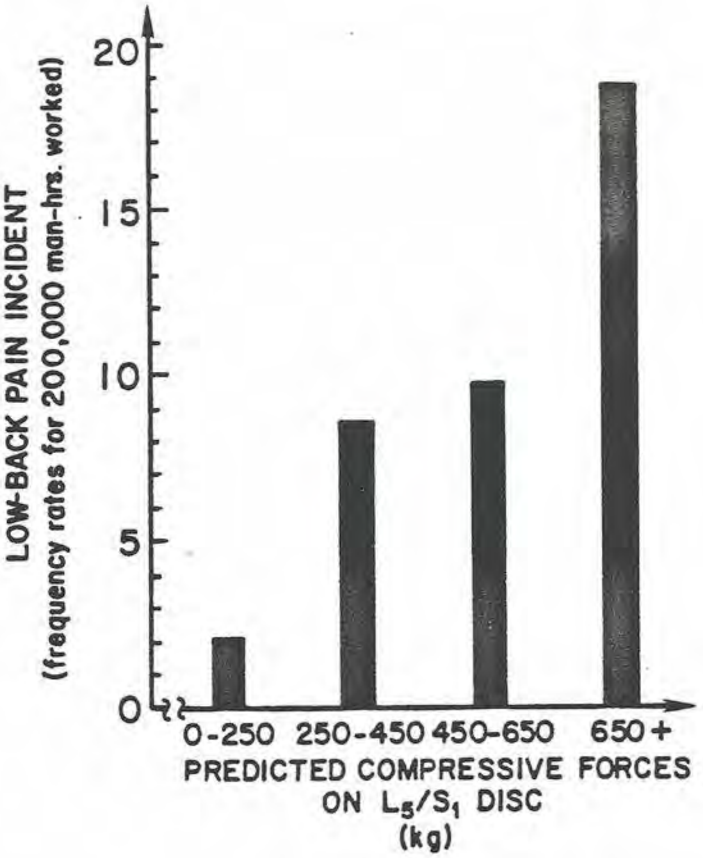

Figure 3.9: Relation Between LBP and Compressive Force (Chaffin and Park, 1973).

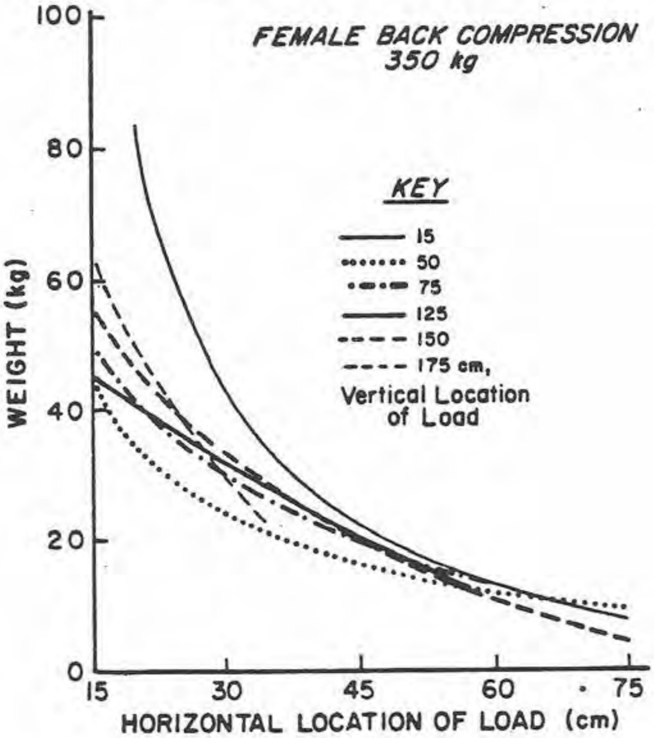

Figure 3.10: Task Variables Producing 350 kg Female Back Compression.

Clearly, dynamic actions that result in high inertial forces are more difficult for one to control. Therefore, it is reasonable to require of people who are engaged in manual materials handling that they move the loads in a smooth and well-planned manner. Further, as part of this concern is the need to provide good foot tractions and hand grips on such loads to avoid any possible slips and/or falls.

BIOMECHANICAL DESIGN CRITERIA

The biomechanics of lifting and handling loads provides one basis for why certain musculoskeletal overexertion injuries and illnesses develop. Specifically, biomechanical studies indicate that the low-back is vulnerable to continual overstress damage during even moderate load handling, but that symptoms may not manifest themselves until later in life. In essence, existing knowledge supports a "wear-and-tear" hypothesis of low-back pain, which requires that load handling activities be limited and carefully specified.

Figure 3.9 illustrates the observed incidence rates for low back pain related to predicted back compressive forces on the L_5/S_1 disc (Chaffin and Park, 1973). Based on this industrial study of 400 workers and earlier compressive tolerance cadaver studies of Evans and Lissner (1959) and Sonoda (1962) (see Figure 3.6) it is apparent that jobs which place more than 650 kg compressive force on the low-back are hazardous to all but the healthiest of workers. In terms of a specification for design, a much lower level of 350 kg or lower should be viewed as an upper limit. This will not necessarily be protective for most individuals over 50 years of age or other susceptible populations. However, based on current knowledge of injuries in industrial work a lower limit is not supported at this time. This is, in part, due to historical self-selection mechanisms which have precluded weaker individuals from performing rigorous MMH.

To convert low back compression values into load limit recommendations, computerized biomechanical models which allow simultaneous analyses of the stresses placed on the many linkages and joints of the body during lifting are needed. Chaffin (1972) and Garg and Chaffin (1975) have reported a Static Sagittal Plane Lifting (SSPL) model in the literature. As the name infers, this particular model has been developed to evaluate various static situations, such as when one is holding a weight or pushing or pulling on a non-moving container. The large static component of a lift enables the SSPL model to be useful in establishing safe lifting limits. Figure 3.10 illustrates the trade-offs between horizontal (H) and vertical (V) locations of a load which would produce 350 kg compressive force on the L_5/S_1 disc of the average female based on the most recent model of Chaffin, et al., (1978). The assumed female anthropometry was reported by Dempster (1975). Horizontal location is measured forward of the body centerline from the mid-point between the ankles. Vertical location is measured from the floor or foot sole. Likewise, Figure 3.11 illustrates the same combinations which would produce 650 kg compressive force on the

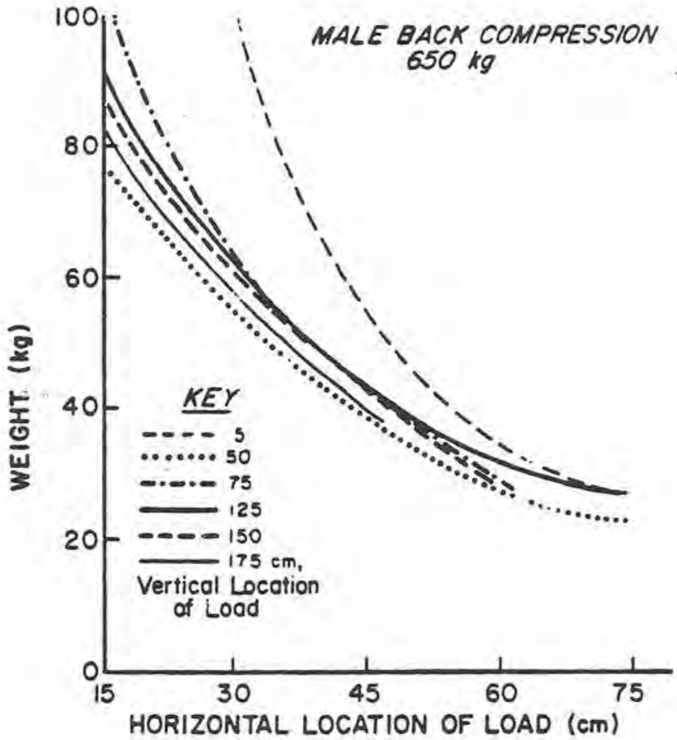

Figure 3.11: Task Variables Producing 650 kg Male Back Compression.

L_5/S_1 disc of the average male. In each case, the most advantageous posture (that producing minimal compression) is assumed for these illustrations.

These figures suggest a simple inverse linear relation between the maximum weight lifted (W) and the horizontal location of the load (H). This is,

$$W = K(1/H)$$

where K is a constant which depends on gender and vertical location of the load.

A Dynamic Biomechanical Lifting model developed by El-Bassoussi (1974) and further reported by Ayoub and El-Bassoussi (1978) also appears in the literature. This model calculates the compressive and shear forces on the L_5/S_1 disc during the time course of a lifting movement for lifts made in the sagittal plane from the floor to a height of 30 inches. The output forces of this model include a static component resulting from the respective weights of the load and body segments plus a dynamic component due to the acceleration of the same during a lift. Figure 3.12 shows the compressive and shear forces for both a leg lift and a back lift when lifting a 4.5 kg (10 lb.) load with a horizontal location of 50 cm (20 in.). It is important to note that for either type of

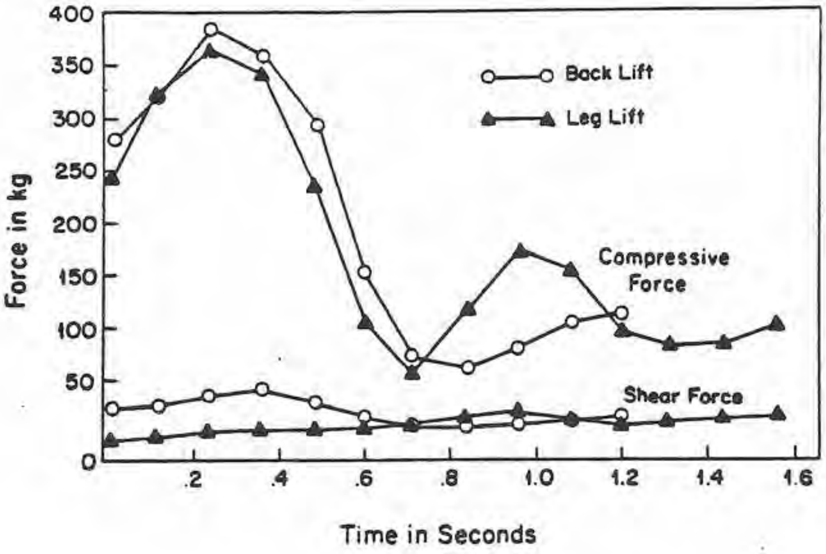

Figure 3.12: Changes in Compressive and Shear Forces on the Low Back for a Leg Lift and Back Lift During the Lifting Action

lift, the compressive force reaches a maximum after about 200 msec. Figures 3.13 and 3.14 illustrate the combination of weight and horizontal location of the load lifted which result in compressive forces of from 400 to 700 kg on the L_5/S_1 disc for leg (squat) lifts and back lifts (stooped), respectively. For each figure average male anthropometry and body segment weights are assumed. Horizontal location of the load with respect to the spine is determined using the equation $H = (W/2 + 20)$ cm, where W = width of the object away from the body.

Davis and Stubbs (1977a, 1977b, 1978), in a three-part series, expressed safe levels of manual forces for young males in various standing, squatting, sitting, and kneeling postures based on biomechanical considerations. Morris, et al., (1961) and Davis and Troup (1964) noted a correlation between magnitudes of forces acting on the lower spine during manual activity and the magnitudes of intra-abdominal pressure. Using this relationship, Davis and Stubbs monitored intra-abdominal pressure with a swallowed radio pill on 200 male soldiers while they performed the aforementioned activities.

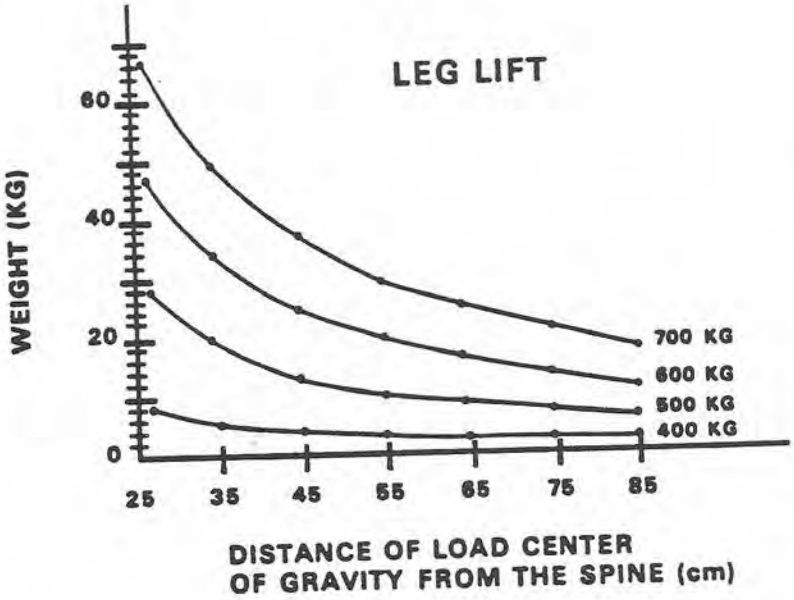

Figure 3.13: Combination of Weight and Horizontal Location of Loads Resulting in from 400 to 700 kg. Compressive Force for Leg Lifts.

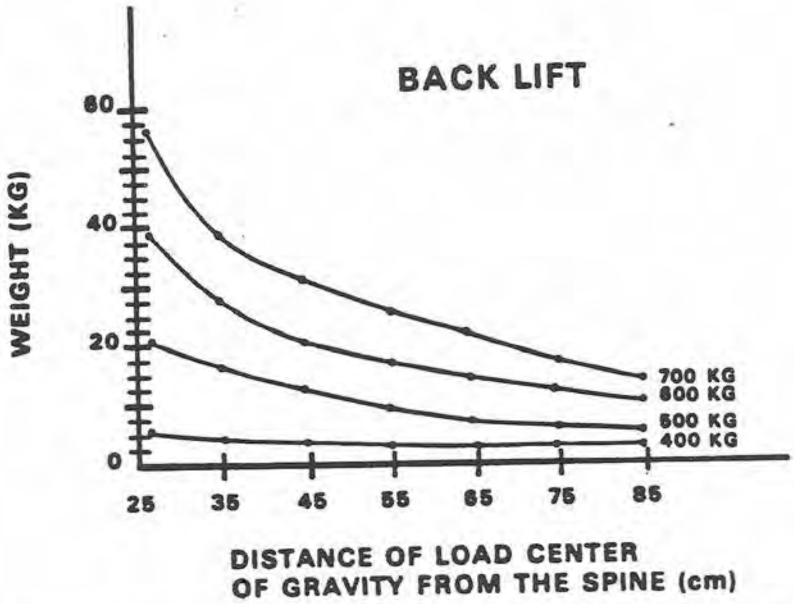

Figure 3.14: Combination of Weight and Horizontal Location of Loads Resulting in from 400 to 700 kg. Compressive Force for Back Lifts.

From this, they generated contour maps of acceptable forces while in these postures based on a maximum of 90 mm Hg of intra truncal pressure.

What is evident from the preceding section is that a biomechanical criterion (back compression tolerance) can be converted into practical recommendations for acceptable lifting task descriptions. This criterion and those of the following chapters were used to establish the guidelines for lifting which are presented in detail in chapter 8.

In terms of the biomechanics of lifting it can be concluded that:

1. Lifting a 5 kg compact load (wherein the mass CG of the load is within 50 cm of the ankles) could create compressive forces sufficient to cause damage to older lumbar vertebral discs.

2. As the load mass center of gravity is moved horizontally away from the body, a proportional increase in the compressive force on the low-back is created. Thus even light loads need to be handled close to the body.

3. When a load is lifted from the floor, additional stresses are exerted on the low-back due to the body weight moment when stooping to pick the load up. Thus 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. The postures used to lift loads from the floor can exert a complex and relatively unknown effect on the stresses of the low-back during lifting. Specific instructions as to the safe posture to use will be necessarily complex, reflecting such factors as leg strengths, load and load size. Until such complexities are better researched, it is recommended that instructions as to lifting postures be avoided.

5. Lifting loads asymmetrically (by one hand or at the side with the torso twisted) can impart complex and potentially hazardous stresses to the lumbar column. Such acts should be avoided by instructions and workplace layouts which permit the worker to address the load in a symmetric manner.

6. The dynamic forces imparted by rapid or jerking motions can multiply a load's effect greatly. Instructions to handle even moderate loads in a smooth and deliberate manner are recommended.