PB88-237805

FINAL REPORT

DETERMINATION AND MODELING OF LIFTING CAPACITY

Grant Nos. 1R010H00545-01 S0H
and 5R010H-00545-02

September, 1978

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50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO.	2.	3. Recipient's Accession No. PB88 237805/AS
4. Title and Subtitle Determination and Modeling of Lifting Capacity			5. Report Date 78/09/00
			6.
7. Author(s) Ayoub, M. M., N. J. Bethea, S. Deivanayagam, S. S. Asfour, G. M. Bakken, D. Liles, A. Mital, and M. Sherif			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Institute for Biotechnology, Texas Tech University, Lubbock, Texas, Final Report			10. Project/Task/Work Unit No.
			11. Contract(C) or Grant(G) No. (C) (G) OH-00545
12. Sponsoring Organization Name and Address			13. Type of Report & Period Covered
			14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

A literature review was conducted to define the lifting capacity of the working population, predict individual lifting capacities, and determine the effects of the components of job stress on the occurrence of occupational injuries. Specific factors studied as possible contributors to lifting injuries included improper lifting methods, the age of the worker involved, the sex of the worker involved, the weight of the worker involved, individual motor characteristics, personality characteristics, inexperience on the job, work environment, general health of the worker, work pace, height of the individual, repetition and constancy of the task, weight of the load to be moved, vertical height of the lift required, noise levels, illumination, temperature and humidity, and the size, condition, and liftability of the load itself. Methods studied to control the incidence and severity of materials handling injuries were divided into three parts: the general area of preplacement medical or other examinations of the worker; the assignment of more or less arbitrary lifting weight limits; and the more logical comprehensive approach of attempting to scientifically match abilities of the worker to the lifting requirements of the job.

17. Document Analysis a. Descriptors

DIS.

b. Identifiers/Open-Ended Terms

NIOSH-Publication, NIOSH-Grant, Grant-Number-OH-00545, Injuries, Work-capacity, Muscle-function, Musculoskeletal-system, Physical-capacity, Physical-stress, Age-factors, Materials-handling, Sex-factors, Repetitive-work

c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages 275
	20. Security Class (This Page)	22. Price

See ANSI-Z39.18) See Instructions on Reverse

OPTIONAL FORM 272 (4-77)
(Formerly NTIS-35)
Department of Commerce

ATTENTION

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ACKNOWLEDGEMENTS

Dr. H. F. Martz and Dr. S. S. Panwalkar developed the experimental design for this project. A majority of the subjects utilized for the generation of data in both the experimental and field study phases were obtained through the cooperation of various corporations in the State of Texas. The typing of this final report and the many preceding manuscripts were done by Mrs. Pat Austin, Mrs. Susan Maddux, Mrs. Anne Seitz, and Mrs. Terry Wilson. To each contributor is offered a heartfelt thank you.

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I. INTRODUCTION

The reduction of injuries which are attributable to the manual handling of material, particularly due to lifting, is a priority concern of the federal government, industry, insurance companies, labor, and researchers.

In response to that concern this work was undertaken to determine the lifting capacity of the working population, to predict lifting capacity for individuals, and to determine the effects of the job stress index (JSI) components on the occurrence of occupational injuries.

In general, the end result is the generation of information useful in the design of MMH tasks and/or the assignment of workers to MMH tasks enabling a better match between the tasks' physical demands and the individual's capacity.

The following literature review will provide the reader with a background on manual materials handling, lifting associated injuries, the control of those injuries, and the prediction of lifting capacity.

A. Manual Materials Handling and Injury

Manual materials handling, lifting in particular, has been identified by the National Institute for Occupational Safety and Health (NIOSH), insurance companies, industry and several independent researchers (e.g., Becker, 1961; Snook and Ciriello, 1972; Herrin, et al., 1974) as a priority concern. Lifting is the leading cause of back injury (National Safety Council, 1974; Jones, 1971; Troup, 1965). Back injuries are costly to the individual, the employer, and society in terms of income, productivity, medical cost, and quality of working life.

Within the past 6 years NIOSH has sponsored three major symposiums (Badger, Dukes-Dobos, and Chaffin, 1972; Herrin, Chaffin, and Mach, 1974; and Drury, 1976) during which internationally noted authorities on manual materials handling discussed and established as a priority objective for NIOSH the pursuit of research for determining safe lifting capacities of individuals.

Injury associated with manual materials handling accounted for a significant portion of the occupational accidents and illnesses. The National Safety Council (1974) estimated that between 20 and 25 percent of all industrial injuries were associated with manual materials handling. One type of manual materials handling injury that has received special attention is that caused by lifting. The Ergonomics Guide of July-August 1970 reported that 25 percent of all materials handling accidents were due to lifting. The National Safety Council (1974) reported that 400,000 back injuries were attributable to the "manual handling of objects." In 1971 they reported that 22.6 percent of 487,200 of all reported injuries were again attributed to the "manual handling of objects." The average cost for each of those injuries was $990.

Becker (1971) reported that in 1955 2.7 percent of 10,318 employees of Western Electric's Hawthorne Plant suffered back injuries. Jones (1971) claimed that in North America over 20 percent of the compensation dollar was spent on lifting related back injuries. Troup (1965) stated that in the United Kingdom about 19 percent of all injuries affect the trunk and spine. Forty percent of those back injuries were reported to be due to lifting. Noreton (1964) reported that "low back pain has caused more manhours in industry than any other single condition." In Wisconsin compensable back injuries increased from 7.7 percent in 1938 to 19.1 percent in 1965, while the average cost per case increased from $164 to $282 (Jones, 1971). Rowe (1969) reported that Eastman Kodak averaged 4 hours per employee per year lost-time due to los back problems. Rowe (1971) reported an increase in the figure to 8 hours per employee. A number of studies, for example, Moreton (1964) and Kosiak, et al. (1969), detailed work loss and identified the lumbar region, expecially the fourth, fifth, and sacral joints as areas of most frequent injury. More recently a major U.S. corporation, through personal communication (Ayoub, 1978b), has indicated that over 50 percent of the injuries in a recent manual materials handling injury survey were back injuries attributable primarily to lifting.

Brown (1975) reported that 49 percent of all material handling injuries were caused by lifting. He also stated that the materials handling injuries studies were composed of 44 percent muscular sprains and strains, 28 percent back injuries, and 28 percent other injuries. This same study indicated that between 5 and 6 percent of both men and women suffered symptoms of back injury for periods in excess of 6 months. Becker's study, reported in 1961, indicated that employees of the Western Electric Hawthorne facility suffered back injuries at the rate of 2.7 per 100 workers. Both Kraus (1964) and Kosaik and Hartfill (1966) stated that the problem has been getting worse over the years. Kosaik and Hartfill indicated that this was "in spite of improved medical care, use of pre-employment examinations and automation...". Snook and Ciriello (1972) also found this to be true. A number of other sources (McDaniel, 1972; Dryden, 1973; Knipfer, 1974; Aghazadeh, 1974; Herrin, et al., 1974; Chaffin, et al., 1976; and Garg, 1976) have reported similar information based on corporate records.

The costs associated with materials handling injuries can be expressed in terms of human suffering, decreased worker performance, and direct expenses. The first two of these have been difficult to measure in terms of dollars, but the third has been measured. These direct expenses included such items as compensation costs, medical costs, and lost wages, Jones (1971), reporting in a study of back injuries, indicated that while back injury frequency increased by 250 percent, the cost of those injuries increased by a factor of 470 percent. He also stated that currently in excess of 20 percent of the compensation amounts paid in North America were paid to victims of back injury. Snook and Ciriello (1972) also reported that the cost of back injury is increasing at a pace greater than the actual frequency of injury. For the year 1961 the BLS (#318, 1967) estimated that in excess of 13 million dollars in lost wages were experienced by those having back injuries. This was exclusive of other direct costs. The indirect costs associated with decreased work place efficiency may amount to up to ten times the direct costs according to

Matthysen (1973). Chaffin and Ayoub (1976) quoted statistics that indicated that materials handling injuries resulted in a total loss of 3 billion dollars in medical expenses and lost wages during 1975.

The Ergonomics Guide (1970) stated that in addition to the weight that was lifted, there were other hazard conditions and situations which may have contributed to the increase and severity of manual materials handling injury. Among these were incorrect lifting method, relative age of the worker, the new worker, stressful environments awkward working position, and the general health of the worker.

The Ergonomics Guide indicated that "back lifting or fast, jerky lifting can double the amount of stress placed upon the lower back" and therefore increase the risk of injury. The authors also stated that these incorrect lifting methods were most likely to occur when the lift began at knuckle height or lower. It was recommended that such lifts be executed with the legs, keeping the back straight and vertical, and performed slowly and smoothly. However, there was no universal agreement in this area. One writer (Brown, 1972) reported that there has been little reduction in lifting injuries during the 30 years that the above method has been advocated. He went on (1973) to discuss and recommend the dynamic or "free" lift which essentially allows the back to be flexed. Troup (1965) stated that certain bent knee lifting methods may place excess stress upon the body. He indicated that untrained workers tended to raise their hips first, thereby placing their backs in the horizontal position. This may have caused excessive forces of acceleration upon the back. Davis, et al. (1965) agreed that the hips tended to raise first in bent knee lifting which places the back in an inclined position. Maxwell (1957) recommended the kinetic method which uses body momentum thereby reducing the demand on the back muscles. Van Wely (1961) reported that leg lifting was physiologically less efficient than back lifting when heavy loads were lifted. This was due to the fact that lifting with the legs entailed lifting the upper body in addition to the load. The leg lift was said to afford a stronger vertical pull than back lift and therefore has less risk of injury (McFarland, 1969). Asmussen, et al. (1965) recommended the leg lift method as does Davis (1959), Munchinger (1961), Grandjean (1969), and Davies (1969).

During the industrial phase of this experiment it was observed that the straight back lift was probably the most accepted and most often taught lifting method. However, it may be said that this is incorrect and may even lead to injury (Brown, 1970). Brown (1975) reported that of those people who experienced injury, 82 percent of them were using the prescribed method (i.e., leg lift). On the other hand, only 77 percent of the uninjured people lifted with their legs. This would indicate that the leg lift was no better than other methods. Several authors stated that there should be no single lifting method prescribed. Anderson (1951) stated that lifting methodology was dependent upon the object being lifted, the type of lift employed, and the characteristics of the individual performing the lift. Brown (1973) stated that "... there can be no specific amd mandatory method for lifting all weights." He went on to report that most people in industry tended to adopt a "natural" posture while lifting. This natural position was dictated by the personal preferences of the individual. Brown (1973) and Jones (1972) contended that other factors such as physical conditioning, postural fatigue, and lack of coordination may have been the most important factors. One author, Hart (1968), reported that "back injuries are not caused by improper lifting."

Repardless of lifting method (e.g., leg lift) the Ergonomics Guide's prohibition against "fast jerky lifts" can be supported. It can also be said that lifting that involves twisting or turning may result in additional hazard. Anatomical studies performed by Davis and Troup (1964) of intra-abdominal and intra-thoracic pressures during lifting suggested that the large pressures observed during high rate of onset of force application are likely to cause physical damage such as herniation. They, therefore, recommended that lifting be done slowly. Troup (1965) indicated that spinal damage was more likely under shear or rotational forces than under compression only. Farfan, et al. (1970) reported extensive studies that indicated that torsion was a significant cause of disc degeneration and therefore injury.

The second hazard category discussed in the Ergonomics Guide (1970) dealt with the age of the worker. The 'Guide' indicated that moderately heavy lifting can be both good and bad for the older worker. Physical activity was said to offset some of the effects of aging. However, certain age related problems such as intervertebral degeneration, cardiac, and pulmonary disorders may be aggravated if certain older workers are placed in heavy tasks. It was said that age affects physical strength less than reflex response and perceptual skills and therefore self-paced jobs were more suitable for older workers than certain light machine-paced jobs. Asmussen and Heebøll-Nielson (1961) supported this by reporting that in older people, the limiting factor was not declining muscular strength but decreased ability of the body to deliver energy to the muscles for continued work. Research by several individuals, Astrand and Rodahl (1970), Astrand, et al. (1973), Shepard (1974) indicated that an individual's maximum oxygen uptake decreased with age such that the mean value for a 65 year-old individual was approximately 70 percent of the maximum oxygen uptake of a 25 year-91d (Astrand and Rodahl, 1970). Reasons given for this decrease were: lung volume reduction (Shepard, 1974); 25 percent reduction in the oxygen transport system (Shepart, 1974), stroke volume decreases (Astrand and Rodahl, 1970), and heart rate decrease (Astrand and Rodahl, 1970).

On the other hand, Shepard (1974) and Muller (1962) have studied the oxygen consumption for a given submaximal load across age. They reported that similar oxygen consumption was required for younger and older individuals. Hence, although age was thought to not affect the metabolic energy expenditure rate, it did change the stress level of what Muller (1962) termed the occupational work capacity. For example, given the same task, a 25 year-old individual would perform the task at a lower percent of his maximum oxygen uptake than a 65 year-old would of his. Consequently,the older individual was performing the task much closer to his maximum stress level, resulting in an increased risk.

A comparison between a group of industrial workers who had experienced back injury and a randomly selected group who had not, revealed that there was no significant age difference between groups (Chaffin and Moulis, 1969). Rowe (1969), however, had determined that the largest rate of lower back pain exists among workers in their late thirties and forties. Schein (1969) reported a study that indicated that those between 40 and 49 years of age have the highest incidence rate. However, Rowe (1969) reported that workers over 50 seem to regain vertebral stability. He indicated that this may be due to an increased scar tissue buildup across the intervertebral disc. Hirsch (1966) noted that even though workers over 60 have high rates of disc degeneration, they seemed to have markedly fewer back pain problems than workers 20 years younger.

Another consideration that has been discussed in the literature is the effect of the sex of the lifter. Brown (1975) reported that 10 percent more women suffered back pain than men. Chaffin and Moulis (1969) reported that certain spinal measurements taken from X-rays might indicate that women are more susceptable to back injury than men. Hirsch (1966), however, stated that back pain was found among men and women equally.

Studies by Astrand (1960) and Astrand and Rodahl (1970) have shown that there is a significant difference in maximum oxygen uptake, after puberty, between males and females. Astrand and Rodahl (1970) reported female values to be 70 to 75 percent that of males. Garg (1976) cited a few of these reasons for this disferences as follows: higher oxygen-binding capacity of the blood of males, 10.9 percent to 14.3 percent greater hemoglobin concentration in males (Ross, et al., 1960); smaller body dimensions for females (Astrand and Rodahl, 1970); and smaller cardiac output, lung capacity, blood volume, and maximal ventilation (Ross, et al., 1969).

Garg (1976) cited several researchers to show the contradictory data contained in the literature regarding sex difference studies. Some studies indicated that females, for submaximal loads, had a higher work efficiency. Others, when corrected for body weight, showed no difference between males and females. Others showed a significant sex difference in energy expenditure, even when corrected for body weight. Substantiation on any of the findings is unclear at this time. Garg (1976) cited the above as sufficient cause for including both males and females in his study. On this point there did not appear to be sufficient evidence to permit generalizations regarding metabolic energy expenditure across sex.

According to Herrin, et al. (1974) sex may be related to the risk of manual materials handling injury or liness and is therefore worthy of further consideration. Asmussen and Heebøll-Nielson (1962), Chaffin (1974), Chaffin, et al. (1976), Snook and Ciriello (1974) indicated that, overall, female strength ranged from 60 to 70 percent that of males. Chaffin et al. (1976) cited Laubach (1976) when stating that for specific strengths, female strength may range from 35 to 85 percent of male strength.

Wyndham, et al. (1963), Cotes (1969), and Giten, el al. (1964) have studied the effects of body weight on energy expenditure. Each study reported a positive, linear relationship between body weight and energy expenditure. Garg (1976) reported that, in general, heavier subjects consume more energy than lighter subjects in a "no external load" task. However, as the load increased, the differences in net metabolic costs decreased. Initially, the lighter subject had the advantage in that there was less mass to lift. As the load increased, the mass of the heavier individual provided an advantage over the lighter individual. The lighter individual was having to expend more energy to compensate for less body mass and strength.

Herrin, et al. (1974) and Chaffin, et al. (1976) stated that body weight, age, and gender had a complex effect on the lifting capability of individuals, but that they were probably secondary when compared to the overall strength and physical work capacity of the individual. Both sources also stated that heavier individuals usually demonstrated greater strength than lighter individuals (Snook and Irvine, 1967; Konz, et al., 1973) but that overweight individuals tended to experience isometric muscular fatigue more readily (Petrofsky and Lind, 1973). Astrand and Rodahl (1970) stated that Ikai and Fukanga (1968) found that strength per unit cross-sectional area was approximately the same for males and females, not was there any difference in ordinary or trained adults.

There are a number of worker characteristics, pertinent to this report, which may have an effect on the worker's capacity but have been found to be less significant than strength, physical work capacity, age, sex, or body weight or have not been studied in sufficient detail to make such a statement.

Regarding motor characteristics, Herrin, et al. (1974) indicated that little if any research has been done in the area of manual materials handling regarding range of movement, kinematic and endurance capabilities or in muscle training. They indicated the same for the psyhomotor characteristics: information procession capabilities, reaction/response times, and coordination abilities.

Personality characteristics, as agreed upon by the Herrin, et al. (1974) symposium members, did affect an individual's ability to lift. The literature did not provide a definitive role as to its contribution, primarily because of the difficulty in measurement and interpretation of data pertaining to worker values and job satisfaction. Herrin, et al. (1974) indicated that the areas of concern were attitude (towards work, training, manual materials handling, life, etc.), risk perceptions and its interaction with attitude, and the risk acceptance - economic need interface. They cited a few studies regarding age and training/attitude (Blow and Jackson, 1971), education and religion (Magora, 1970), psychosocial background (Magora, 1970), and compensation for exaggerated low-back pain versus personality (White, 1966).

The new worker, as reported in the Ergonomics Guide (1970), is especially prone to have MMH injuries "because of improper selection procedures and lack of training, experience, and physical conditioning." The Guide stated that new workers should be screened with medical examinations, including X-rays, and injury history examinations. New workers should also be properly trained and gradually acclimated to the new job. Snook and Ciriello (1972) reported that new workers have high incidence rates of back injuries.

The Ergonomics Guide (1970) also indicated that work in a stressful environment may add to the injury risk of manual materials handling jobs. Environments that were hot and humid reduced the working capacities of individuals. Cold environments required additional clothing which may, because of restricted mobility, add risk. Other environments may have associated factors which could add to the injury potential of materials handling.

Awkward working positions and bad posture, according to the Ergonomic Guide (1970), were also major causes of back injury. These risks can be partially eliminated through adequate work place design. Brown (1973) suggested that back pain may be a result of natural processes rather than lifting. For example, when non-traumatic back pain was attributed to lifting, it was often the result of postural fatigue. Brown defined postural fatigue as the fatigue of certain muscles creating a muscular or coordination imbalance which limits the ability of the lifter to lift safely. It was suggested that posture be considered in job design. Chaffin (1973) reported limited experimental fatigue data which can be applied under specific conditions and to certain design situations. The relationships between object weight, object position and fatigue time were given for several job positions including: shoulder angle, hand position, arm position, and head tilt. Jones (1972) also supported the contention that back injury due to lifting is a result of a lack of coordination which may be caused by fatigue, disease, or other cause. Corlett and Bishop (1976) stated that job design and pain due to bad posture were related and that a change in design may reduce incidence of pain.

The Ergonomics Guide (1970) also indicated that the health of the worker has an effect on what he or she can be asked to do safely. The magnitude of the effect was dependent upon the type and seriousness of the health problem. The degeneration or rupture of the intervertebral disc was among the most often given causes of back pain. Rowe (1969) reported a study in which disc problems accounted for approximately 70 percent of the low back cases experienced by men in industry. He also found, however, that these problems seem to affect office and factory workers equally. Other spinal anomalies, osteoarthritis, and disc protrusion accounted for about half of the low back patients (Ghrormley, 1958). According to Dively, et al. (1956) about one third of the subjects in a study of low back pain showed congenital anomalies. It would, of course, be advisable to restrict the activities of persons with these and similar health problems. However, it is certainly possible to suffer back pain, as Connell (1968) reported, with no apparent cause. According to one study (Kraus, 1964), some 80 percent of the patients with low back problems had no apparent organic or mechanical cause. LaRocca and MacNab (1970) have found that there is no significant difference between back pain patients and people without back pain when comparing a number of anomalies. Snook and Ciriello (1972) and Magora and Taustein (1969) stated that overall physical fitness is probably the best injury prevention. Snook and Ciriello (1972) reported that job design, employee selection and instruction are next best. Rowe (1969) stated that programs of exercise and instruction are helpful in reducing low back problems.

Other studies indicated that certain occupational groups are subject to more materials handling injury risk than others. This may be related to varied lifting stress or other factors. The Ergonomics Guide (1970) quoted statistics that indicated that persons involved in heavy work have an expected frequency of back injury that is 12 percent higher than those people working in lighter jobs. It also stated that heavy jobs result in 18 percent more lost time than do light jobs. Magora and Taustein (1969) reported a study, of eight occupational groups, that indicated that heavy industry workers have the highest incidence of lower back problems. This group was followed by nurses, farmers, light industry workers, bus drivers, post office clerks, bank clerks, and policemen.

Herrin, et al. (1974) and Chaffin, et al. (1976) described a few other, but seemingly less important, factors that have been studied with respect to lifting. They cited Tauber (1970) as reporting that taller individuals had higher frequencies of low-back pain than shorter individuals. Tichauer (1973) was cited as stating that lordotic curvature, and possibly somatotype may be related to increased back injuries. They cited Troup and Chapman (1969b) as reporting that a study of trunk/hip mobility did not correlate with the trunk lifting strength or lifting capacity during flexion or extension.

The literature reviewed suggested that the frequency of lift may affect the amount of weight that can be lifted by an individual (Van Wely, 1969; Aberg, 1961; Bastina, et al., 1961; Jorgensen and Poulsen, 1974; Ayoub, et al., 1976). Noro (1967) emphasized that pace had an effect in fixing the maximum permissible weight to be carried by one worker. Aquilano (1968) and Hamilton and Chase (1968) have shown that increasing the pace of handling loads also increased the energy expenditure.

Aghazadeh (1974) fitted a least square regression line to the data obtained by Snook (1971) and found that the load lifted decreased with an increase in frequency. Snook and Irvine (1968) utilized a psychophysical approach to determine the maximum frequencies of lift acceptable to male industrial workers. Their findings also indicated a decrease in the acceptable weight of lift with an increase in frequency.

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.

Aberg (1961) investigated baling operations in a pulp factory. The investigation showed a marked dependence on the relation between momentary work load and the distribution of pauses.

Bastina, et al. (1961) examined 146 women workers at two brick works. These women were continuously transporting small loads during the whole work day. It was found that these women suffered from reproduction disturbances, physiological shifts, and occupational diseases of the skeletal and motor systems. The authors suggested that the total weight shifted per working day by women should be subject to a standard rating.

Noro (1967) emphasized that in trying to fix the maximum permissible weight to be carried by one worker many factors must be taken into consideration such as duration of carrying, technique, work breaks, etc.

Jorgensen, et al. (1974) conducted an experiment on repetitive lifting of loads from floor to table. Four males and four females participated in the experiment. For each subject both the maximum load which could be lifted from the floor to table height and the maximum oxygen uptake was determined. From the maximum load the investigators calculated each subject's relative loads of 10 percent, 25 percent, 50 percent, and 75 percent. Lifting, at a minimum of three different frequencies, was performed for each relative load. The maximum lifting frequency which did not demand more than 50 percent of the subject's VO_2 max was then determined for each relative load for each subject. The results showed that the maximum lifting frequency for females was 0.7 that of the males at the same relative load.

Aquilano (1968) studied the effect of pace on energy expenditure and showed that increasing the pace of handling cartons was accompanied by an increase in the energy expenditure.

Hamilton and Chase (1969), in an experiment to determine the main differences in effects from variations of weight and work pace in a carton handling task, found out that pace and weight were significant in their effects on energy expenditure rates and heart rates. They also found, from the trend analysis of work pace on energy expenditure rate, that the relationship between work pace and energy expenditure was linear. In their conclusion they recommended moving heavier weights at a slower pace and lighter weights at a faster pace.

Aghazadeh (1974) fitted a least square regression line to the data obtained by Snook (1971) where three different frequencies for floor to knuckle height lift (the three frequencies were 1, 3.75, and 4.29 lifts per minute) were used. The regression line was negative, i.e., the weight of lift decreased with an increase in the frequency of lift.

Snook and Irvine (1968) utilized a psychophysical approach to determine the maximum frequencies of lift acceptable to male industrial workers. The subjects were asked to perform a repetitious lifting task using a 35 pound weight and subjects were permitted to adjust the frequency of lift until they reached the frequency they could maintain without becoming excessively fatigued. Three height levels were used: floor to knuckle, knuckle to shoulder, and shoulder to reach. Negative correlations were found between the selected frequency of lift and subject's height and weight.

The amount of weight lifted by an individual was one of the task variables that has been studied extensively as both a dependent and independent variable. However, the results from these studies (Chaffin, 1967; Aberg, et al., 1969; Garg, 1976; Fredrick, 1959; Aberg, 1961; Aquilano, 1968; Poulsen, 1970) were controversial. These data have not permitted the development of an acceptable guideline for determining the maximal permissible and maximal acceptable loads for workers.

The vertical height of lift directly influenced the amount of energy expenditure (Aquilano, 1968; Snook, 1971; Garg, 1976) and consequently the lifting capacity.

The environment in which the material was handled by a worker affected his performance. Temperature, humidity, air movement, and atmospheric contaminants were the most common and important environmental factors which influenced the worker's physiological behavior (Brouha, 1967).

Noise, radiation, and illumination, though they are health hazards, had a pathological effect rather than a physiological effect. Heat combined with humidity was frequently encountered. Very little was known about these environmental factors and how they interact with other system characteristics to affect the human performance, particularly as related to the task of manual materials handling.

Kamon and Belding (1971) conducted a study to determine the physiological cost of carrying bulky cardboard cartons weighing 10, 15, and 20 kg at speeds of 4 and 4 km/hr on level and 4 percent grade at dry ambient temperatures of 20, 35, and 45°C. They determined that the metabolic costs were not significantly different under the three thermal conditions. However, they did report that the heart rate increased by 7 to 10 beats per minute for each 10°C rise in temperature.

Magora (1970) studied low-back pain data with respect to an individual's region of residence and employment to investigate for the possibility of climatic influence. Two cities with hot-humid and cool-low humid climates, respectively, were chosen. He concluded that the climate does not seem to be of importance. However, he reported that a very hot and humid condition will cause general fatigue.

Tauber (1970) analyzed the cases of backache that occurred during a one-year period in a large plant. He found that the highest frequency occurred during the warm months. However, he concluded that the influence of weather upon backache, at least from his study, is not understood.

In the survey conducted by Shaw (1956) of dock labor accidents, small seasonal peaks for minor accidents were found in summer and winter, but there was no evidence found to support the view that a large proportion of accidents could be attributed to environmental conditions.

Kloetzel, et al. (1973) undertook a systematic survey of the relationship between professional exposure to heat and hypertension. It was found that hypertension is strikingly frequent in metallurgical workers exposed to high levels of heat. They concluded that prolonged exposure to high levels of environmental heat has to be considered as an additional factor of risk in the development of hypertension.

Container dimensions of the load have received very little attention in the literature, although their significance has been recognized by many researchers (Tichauer, 1971; Davies, 1972; Badger, et al., 1972; and Garg, 1976). The "Ergonomics Guide to Manual Lifting" (1970) has considered size of the load as one of the important task variables. Martin and Chaffin (1972) observed that the lifting force decreased linearly with the increase of box dimension in the sagittal plane. Similar conclusions have been drawn by Aghazadeh (1974). Drury and Pfeil (1973) reported that lifting capacity was reduced by 40 percent while using non-compact (bulky) loads. Tichauer (1971), and Tichauer, et al. (1972, 1973) presented the concept of weight/bulk ratio, which is directly related to the size of the object, and attempted to quantify the physical stress to which the anatomical structures are subjected. Their findings indicated that lifting stress cannot be dependent on the weight of the object but rather on the moment exerted on the vertebral column. The only serious attempts considering the size of the container, in the last 30 years, have been made by Kellerman and Van Wely (1961) and by Ayoub (1976). However, Kellerman and Van Wely's study did not take into consideration the weight/bulk ratio. Ayoub (1976) used an optimization technique and simple mechanics to determine the optimum container size but with no experimental verification.

Standards have been suggested for a few container/object sizes (Woodson and Conover, 1964; McFarland, 1969). However, they gave no justification or basis for recommending a particular size box for a given weight of the object. Personal correspondence with various agencies and industries indicated that the container/package sizes used in industry are based on arbitrary specifications rather than on technical and ergonomic considerations.

Handles or gripping surfaces are thought to have a significant effect on lifting capacity; however, investigation of this variable has been sparsely reported in the literature. Anderson (1951) analyzed the act of bag lifting. He recommended grips except when they were either weak or simulated undue contraction of flexor muscles and excessive bending of the spine. Similar recommendations have been made by Himbury (1962). It was observed by Koskela, et al. (1968) that problems related to lifting can be reduced by equipping the loads with handles. Similar recommendations have been made by the International Labour Office (1958, 1966).

B. Control of Manual Materials Handling Injury

The procedures currently being used or recommended for use to control the incidence and severity of manual materials handling (MMH) injury may be grouped into three general areas of effort. The first of these is the general area of preplacement medical or other examination of the worker. The second is the assignment of more or less arbitrary lifting weight limits. The third is the more logical comprehensive approach of attempting to scientifically match the abilities of the worker to the lifting requirements of the job.

The use of pre-employment medical X-ray examination has received much attention in recent years as a method to identify those job applicants who may have a higher risk of back injury. The value of such examinations is widely disputed. It is said by some that the use of these methods merely transfers the problem to industries where pre-employment examination is not used. Others have shown that these examinations identify only a small number of those who have back problems. In a study conducted by Rowe (1969) only ten percent of low back problems could have been predicted by examination when the person was hired. He stated that injury history was usually a good indicator of future problems. Rowe's work was based upon a study of people doing both light and heavy work. Alexander, et al. (1975) and Alexander, et al. (1977) indicated that preplacement medical exams were of little value in predicting absence rates of sedentary workers. Glover (1970) stated that while pre-employment X-ray examination was worthwhile, it did "become known in the locality, and patients with a history of back pain tend not to apply for jobs in organizations which are known to use lumbar X-rays to screen applicants."

McGill (1968) reported the use of X-ray examination as an employment screening method for 9,593 applicants for work. The rejection rate was about ten percent. He stated that the use of this method reduced the incidence and costs of back problems. Rejection was for spondylolisthesis (dislocation of spine), sponclylolysis (gap in the vertebral arch), arthritic conditions, surgical defects, and bone or joint lesions.

Crookshank and Warshaw (1961) compared a group of 1,927 persons who were given preplacement examinations to a group of 3,395 individuals who were not given exams. Of the people examined, 2.2 percent were rejected for narrow disc, spardlylolisthesis, previous injury evidence, arthritis, and spondylolysis. Seven of the persons examined and passed experienced back pain at a later time. Little time was lost. During the same time period, 254 of the control group experienced back injuries. The authors concluded that preplacement examinations are valuable tools.

Kosiak and Hartfill (1966) reported a program of preplacement examination, training, and early diagnosis and treatment of back pain. They concluded from the results that such a program could reduce back pain losses. Kosiak, et al. (1968) stated that persons with unacceptable back X-rays accounted for about 43 percent of compensation claims. It was also found that lifting was the cause of most of the claims and caused the most days lost.

Moreton, et al. (1958) concluded from preplacement studies that the method was an excellent way to detect certain abnormalities linked to the incidence of back pain but not necessarily for the exclusion of disc problems or major trauma problems. He also reported (Moreton, 1969) a comparative study of two groups of men over forty. There was no significant difference in the number of X-ray abnormalities between the group suffering with back pain and the group not suffering.

Redfield (1971) reported that those individuals identified as high risk according to pre-employment examination did not have a significantly higher rate of back pain than those identified as low risk. This study was based on the injury experience of 209 persons with abnormal X-rays and 1.992 persons with normal X-rays. Pillmore (1960) reported essentially the same findings.

Connell (1969) reported that persons with identifiable spinal abnormalities have back pain incidence three times that of individuals with normal X-rays. Becker (1961) also reported a significant reduction in the number of disabilities when high risk individuals were rejected for heavy work using an X-ray screening procedure.

Snook and Ciriello (1972) and Rowe (1969) all agreed that pre-employment examination can identify only about 10 percent of the men who will eventually suffer from low back disability. Snook and Ciriello went on to state that an examination of the individual's injury history is a more productive approach. LaRocca and MacNab (1970) questioned the existence of any valid rejection criterion for use with pre-employment examination. Chaffin (1974) concluded that there were other methods of preplacement selection that were more effective than either X-ray examination or medical history examinations. These methods involved standardized strength testing, a view supported by Chaffin, et al. (1976).

Harley (1972) reported a 6 year study of the relationship between injury resulting from heavy work and physical exmaination including X-ray. He concluded that it is impossible to eliminate back injury but that perhaps the use of X-ray examination and careful selection could reduce time lost due to back injury. Plunkett and Morris (1973)concluded that pre-employment X-ray examinations were equally applicable to men and women. Splithoff (1953) found no significant difference in structural variation when comparing two groups of 100 persons, one with chronic backache and one without. However, he did not discount the importance of X-ray examinations as they were indeed helpful in identifying many structural problems which may be partial causes of back pain.

Montgomery (1976) presented an extensive review of opinions regarding the value of pre-employment X-rays. He also discussed findings from his own experience. Of the group of people studied, a larger percentage of those individuals not experiencing back pain had X-ray evidence of abnormality than did those individuals with back pain. He contended that much of the dispute over the value of X-ray pre-employment examination may be a result of incorrect conclusions made by many researchers. He contended that studies reporting the criterion of rejection and rejection rates of X-ray examination have little or no value for the resolution of the conflict. He also stated that reports of significant reduction in back injury rates after the institution of pre-employment procedures were also questionable because they failed to account for the increase of other safety efforts that normally accompany such programs. According to Montgomery, conclusions concerning the validity of preplacement X-ray examination must be based upon comparative studies such as many of the above citations. His conclusions, based upon several comparative studies, was that the pre-employment X-ray examination was of dubious value. This conclusion was summarized as follows. "The use of pre-employment back X-rays has been based primarily upon the hypothesis that developmental abnormalities predispose to an increased incidence of low back injury. The preponderance of evidence would indicate this hypothesis has not been substantiated."

Commenting on the larger societal problem that resulted from the rejection of medically unfit persons, Hanks (1977) stressed the need for rational placement methods which do not arbitrarily prohibit certain persons from gainful employment. He claimed that many people who are rejected on the basis of medical and injury history examinations were forced to accept marginal employment, unemployment and welfare, and crime as a means to exist. These people were often exposed to significant hazards in the smaller companies that would accept them. He stated that since most rejections are done to protect the employer from risk, it is possible that legal reform is needed in addition to better placement procedures.

The second method used as an injury control procedure was, as stated earlier, the assignment of maximum weights that a worker should be allowed to lift. These limits may apply to all workers, workers of different sex and age, or to various percentages of the worker population. In any case, these attempts provided no direct relationships between the weight that a given person lifts and what might be expected with respect to injury incidence.

The International Labour Office (ILO) reports of 1965 and 1966 dealt extensively with the history and current practice of the setting of load limits. The first of these reports stated that: "The weight of the loads carried manually varies widely. In certain cases, the maximum weight is fixed by national laws or regulations. In many other cases the weight is determined by local tradition or by commercial custom in the matter of packaging. In many instances it is the method of manufacture or material breakdown of the goods which determines the weight to be carried."

According to the ILO, governmental legislation in various countries took one of two approaches. The first approach was to make a general statement that no person should be required to carry a load so heavy so as to be injurious. The second was to fix a limit which may not be exceeded by any worker, various worker classes, or workers working in certain conditions. The provisions, either general or specific, may apply to men, women, young people, and/or a combination.

The Factories Act of both the United Kingdom and Ireland specify that no person shall be required to lift, carry or move a load so heavy that it may cause him injury. Both laws also empower various governmental officials to set maximum weight standards that may be applied to workers in general or to various categories of workers. India, Guatemala, and the Netherlands have similar laws.

Many countries have laws and regulations, both specific and general, dealing with the demands placed upon women and young people. In Australia, the South Australian Industrial Code specifies that no girl under the age of twenty be allowed to lift or carry a load in excess of 25 pounds. Spain specifies that males under 16 years of age should not transport by hand any load over 16 kilograms in weight. The same law specifies what may be carried by women younger than 18, between 18 and 21, and over 21. Austria, Bolivia, Bulgaria, France, Greece, India, and others also have laws regulating load carrying by women and young people.

The laws in force in the United States also apply primarily to women and young persons. Most of the state laws are specific in nature. The weight limits vary from 10 to 30 pounds for women and up to 50 pounds for young men of 16 and 17. Only one state law applies to adult males. In Massachusetts, those adult males working in the textile industry may not be required to lift in excess of 325 pounds. For those working in foundaries, the limit is 100 pounds.

A number of other countries including the U.S.S.R., India, United Kingdom, Mexico, Panama, and others have laws dealing with the adult worker. Weight limits range up to 100 kilograms.

In addition to statute lifting limits, labor agreements and other accepted practices in many countries have continued set weight limits. These agreements apply to women as well as men in some cases and are found in Argentina, Austria, Canada, United States, Israel, and Great Britain. These unofficial limits may also go as high as 100 kilograms.

The International Labour Office (ILO, 1966) has made a number of recommendations with regard to the weights of lift that should be permitted. These recommendations are summarized below.

1. No worker should be required to carry a load of a weight likely to affect his health (includes lifting and lowering).

2. No person under 16 years of age should be assigned to the manual transport of loads.

3. The maximum permissible weight to be carried by one male worker under the age of 18 years of age should be 20 kilograms.

4. The maximum permissible weight to be carried by one woman worker under 18 years of age should be 15 kilograms.

5. The maximum permissible weight to be carried by one adult woman worker should be 20 kilograms.

6. No woman should be assigned to manual transport of loads during pregnancy.

7. The maximum permissible weight to be carried by one adult male worker should be 50 kilograms.

Obviously, these and all such arbitrary limits of lift totally ignored various job and individual differences other than age and sex. In addition, the use of such limits as control methods for injury seems less than justified because such limits seem to have little or no definable relationship to measurable injury parameters. The Department of Labor recognized that many with a practical need to know have long awaited the issuance of objective criteria and the setting of permissible maximum weight-lifting maximums by outside expertise. But the Department was reluctant to accept these limits unless they were surrounded by qualifications specifying the conditions under which the weights were to be lifted and carried (Dryden, 1973). Some of these qualifications included job factors, such as range of lift and environment, and worker characteristics, such as "physical capabilities and physiological makeup." This position (i.e., the need to consider individual differences and job characteristics) was supported by Chaffin and Baker (1970), Chaffin (1973), Snook and Irvine (1967), Snook (1971).

Introductory to the third section is a discussion of a series of studies dealing with the prediction of maximum weight of lift, maximum acceptable weight of lift, and maximum frequency of lift or work rate. These were almost exclusively based upon the psychophysical perception of task acceptability of experimental subjects. The assumption was made that there is a relationship between what (i.e, how much weight) an individual will accept in the lab and his or her injury potential. This may be true but the exact relationship has not been determined. However, these values were a valid means to compare individuals. In fact, one such capacity predictor was used in this work to determine the important individual differences.

More recent work may provide the basis for a third and much more comprehensive approach to the control of materials handling injury: the correct matching of the worker's abilities to the lifting requirements of the job. This proper matching required the assessment of all factors that are a part of the manual materials handling system. Chaffin and Ayoub (1976) presented a summary of the component factors of the materials handling system that must be recognized in attempts to control materials handling hazards. These component factors are given below.

Worker Characteristics

A. Physical: include general worker measures, such as: age; sex; anthropometry; postures.

B. Sensory: measures of worker sensory processing capabilities, such as: visual; auditory; tactual; kinesthetic; vestibular; proprioceptive.

C. Motor: measures of worker motor capabilities, such as: strength, endurance, range-of-movement; kinematic characteristics; muscle training state.

D. Psychomotor: measures of worker capabilities interfacing mental and motor processes, such as: information processing; reaction/response time; coordination.

E. Personality: measures of worker values and job satisfaction by attitude profiles, attribution; risk acceptance; perceived economic need.

F. Training/Experience: measures of the worker education level in terms of formal training or instruction in manual material handling skills; informal training; work experience.

G. Health Status: measures from worker general health appraisal, such as: previous medical complaints; diagnosed medical status; emotional status; regular drug usage; pregnancy; diurnal variations; deconditioning.

H. Leisure-Time Activities: measures of the persons choosing to be involved in physical activities during leisure hours, such as: holding a second job or regular participation in sports.

Material/Container Characteristics

A. Load: measure of mass; pushing/pulling force requirements; mass moment of inertia.

B. Dimensions: measures of size of unit workload, such as: height; width; breadth when indicating the form of rectangular, cylindrical, spherical, etc.

C. Distribution of Load: measure of the location of the unit load CG with respect to the worker for one-hand and two-handed carrying.

D. Couplings: measures of simple devices used to aid in grasping and manually manipulating the unit load, such as: texture; handle size, shape and location.

E. Stability of Load: measures of load CG location consistency, as a concern in handling liquids and bulk materials.

Task Characteristics

A. Workplace Geometry: measures of the spatial properties of task, such as: movement distance; direction and extent of path; obstacles; nature of destination.

B. Frequency/Duration/Pace: measures of the time dimensions of the handling task including frequency, duration, and required dynamics of activity over the short term and long term.

C. Complexity: measures of combined or compounding demands of the load, such as: manipulation requirements of movement; objective of activity; precision of tolerance; number of kinetic components.

D. Environment: measures of added deteriorative environmental factors, such as: temperature; humidity; lighting; noise; vibration; foot traction; seasonal toxic agents.

Work Practices Characteristics

A. Individual: measures of operating practices under the control of the individual worker, such as: speed and accuracy in moving objects; postures (i.e., lifting techniques) used in moving objects.

B. Organizational: measures of work organization, such as: physical plant size; staffing of medical, hygiene, engineering, and safety functions; and utilization of teamwork.

C. Administrative: measures of administration of operating practices, such as: work and safety incentive system;

compensation scheme; safety training and control; hygiene and safety surveys; and medical aid and rescue; long work shifts; rotation; personal protective devices.

The authors (Chaffin and Ayoub, 1976) stated that at present the research depicting how the components singularly and collectively pose a given type of hazard is not yet adequate for the development of standards. But, the research base may have supported certain general guidelines, many of which directly impinge on the practice of Industrial Engineering. These guidelines encompassed four areas of job design. These were work place layout, object size and weight, speed of load handling , and rest allowances.

The guidelines for work place design could be summarized with the following four statements:

1. Design should be such that the load (especially heavy loads) is kept as close to the body as possible in order to control the force moment placed upon the spinal column.

2. The load should be positioned so that the worker's hands do not go below 20 inches from the floor when handling heavy objects. The stooped or squatted posture can place undue stress on the lower back.

3. Loads should not be lifted above 50 inches (approximately) from the floor. The lifting capacity of most people is markedly reduced above shoulder height. If the load is dropped from this height the danger of impact injury to the legs and feet is excessive.

4. Jobs should be designed such that asymmetric load handling is minimized. Avoid one-handed lifts.

The guidelines for object size and weight indicated that packages that required the hands to be more than 16 inches in front of the body should not be carried by one person. This was especially critical when the load was heavy. It was also stated that properly designed handles should be provided for good control of load movement.

The general statement was made, concerning the weight of load, that "loads of greater than 35 pounds could be hazardous to some people" and should be avoided. This was apparently based upon the population statistics (90th percentile males) provided by McDaniel (1972), Dryden (1973), and Knipfer (1974). It should be realized, however, as the authors pointed out, that individual differences were important and cannot be accounted for using a single lifting limit. The authors presented population distributions of maximum acceptable weight of lift for male and female industrial workers for three lifting ranges.

The guideline dealing with speed of handling stated that work practices should be such that the "normal, smooth, well controlled movements of loads" is encouraged. This was meant to control the damaging effects of the forces necessary to accelerate the load quickly. The authors stated that new workers should be allowed to adapt slowly to the demands of the job. With regards to rest allowances, the authors contended that they should be determined on the basis of heart rate and metabolic energy expenditure rates.

The recent development of a comprehensive injury control procedure was reported by Chaffin, et al. (1976 & 1977). This procedure was an attempt to logically match the job and the worker. The method involved a detailed job observation and description to determine the extreme body positions and hand forces required to perform the job. These observations were then used as inputs to a computerized biomechanical strength model which evaluated the muscular strength requirements of the activity relative to assumed worker population strengths. The output of the model was a prediction of the proportions of the male and female populations who could perform the task. The authors stated that the output helped in three areas of decision making. First, the output gave a quantitative indication of which jobs should not be filled with weaker persons and may have indicated which jobs are potentially hazardous with respect to lifting. Secondly, the procedure identified physical acts which are especially stressful so that changes in work place design can be affected. Finally, with the knowledge of the various stresses required, injury and illness reports may be more easily understood.

Chaffin and Park (1973) reported earlier work which used a simpler job evaluation technique: a quantity called the Lifting

Strength Ratio (LSR). The LSR was the maximum weight required for a lifting job divided by the strength capability of "a large strong man" performing the required lift. This strength capability evaluation used a graphical method developed by Martin and Chaffin (1972). As the LSR approached 1.0, only the largest and strongest men were able to perform the task. A study was conducted (Chaffin and Park, 1973) to determine the effectiveness of the LSR measure. It was reported that job related lower back problems increased from almost zero at LSR values close to zero to almost four injuries per 1000 man-hours at LSR values close to one. The study also showed that a history of back pain and an inability to demonstrate the isometric strength required by the job were both highly correlated to injury incidence.

Herrin and Chaffin (1978) summarized the two works cited above and other similar work to conclude that methods which compare the lifting forces required by the job to the lifting strengths demonstrated by individuals can be used as a basis for materials handling injury control. It should be noted that all of Chaffin's work was based upon the static force requirements of a given job. The forces produced in the dynamic situation were not considered.

C. The Prediction of Lifting Capacity

This effort required the determination of a safe lifting capacity for individuals and groups of individuals. The assumption was that there is a relationship between an individual's lifting capacity and his or her injury potential. In other words, a person with a small capacity with respect to a given task requirement is more likely to be injured than another person with a larger capacity.

The measure of capacity used in this work was "maximum acceptable weight of lift." Maximum acceptable weight of lift was generally defined as that weight of lift which can be accepted by a specific individual. It was the maximum weight, determined experimentally, that a given person could lift repeatedly for long periods of time without undue stress or overtiring.

The general method used by experimenters (McDaniel, 1972; Dryden, 1973; Knipfer, 1973) to develop predictive relationships for maximum acceptable weight of lift consisted of several steps. The first step generally was to select an appropriate subject population and make various human measurements. These measurements usually included certain strength, endruance, and anthropometric measurements. Sex and age were also noted. Each subject was then asked to perform a simulated lifting task in the laboratory. Depending on the task of interest, the task was described by a given frequency of lift, range or height of lift, and load dimension or box size. While performing the task, the subject was asked to adjust the weight of lift (usually by adding or subtracting lead shot) to a weight level that he or she felt could be lifted repeatedly throughout the work day. The subject was asked to "work as hard as you can" (lift as much weight as possible) "without straining yourself or without becoming unusually tired, weakened, overheated, or out of breath." The third step was to determine the functional relationship between this maximum acceptable weight of lift and one or more of the human measurements and one or more of the task variables. This relationships was then used for predictive purposes.

This method of allowing the subject to adjust his or her weight of lift was a variation of an old and frequently used method in psychology. It is called psychophysics. Psychophysics was concerned with the relationships between human sensation and their physical stimuli and has been used to determine effective scales of temperature, loudness and brightness (Snook, 1971). According to Snook and Ciriello (1974), the perceived strength of a sensation was directly related to the intensity of its physical stimulus by means of a power function. The relationship of interest in materials handling was that between the perception or sensation of msucular effort and the stimulus of external force (the force required to lift an object). Snook stated that this relationship obeys the psychophysical power function. Snook quoted a number of sources which validate the application of this method to manual materials handling situations. Snook's early studies cited in the text below were the first to report the use of psychophysics in materials handling. However, he credited the suggestion for its use to earlier studies conducted by Emanuel, et al. (1956) and Switzer (1962).

The following is a review of the studies reported in the literature that have used the above approach to determine maximum acceptable weight of lift. Included are citations of works which give experimental maximum acceptable weight of lift information with no attempt to develop predictive relationships, as well as the determination of psychophysical based quantities of interest other than maximum acceptable weight of lift.

Several factors have been investigated and reported in the literature. On such important factor is frequency of lift. Snook and Irvine (1968) used the psychophysical approach to determine the maximum acceptable frequency of lift for male industrial workers for three ranges of lift. This was essentially a repeat of an earlier experiment which used physiological measures. The subjects were instructed to adjust the lifting frequency for 35 and 50 pound loads until they reached a maximum which could be maintained without becoming excessively tired. The results indicated that the subjects accepted a higher lifting frequency in the middle lifting range (i.e., knuckle to shoulder). This may have been due to the fact that the lower range (floor to knuckle) required that the torso be lifted as well as the weight. Shoulder to reach height was perhaps more awkward than the middle range. Van Wely (1961), Shephard (1967) and Ronnholm (1962) reported various studies that indicated relationships between frequency of activity and physiological work efficiency. Ronnholm (1962) reported that the optimum rhythm or frequency of lift is apparently different for different people.

Lifting height was also an important consideration. Snook and Irvine indicated that different lifting heights resulted in different maximum frequencies. Emanuel, et al. (1956), Switzer (1962), and Ronnholm (1962) reported relationships between weight of lift or frequency of lift and lifting height. As will be discussed later, lifting height or range was an important factor in the experiments conducted and reported dealing with the maximum weight of lift (Snook, 1971; McDaniel, 1972; Dryden, 1973; Knipfer, 1974).

MacFarland (1969) indicated that an object became "heavy" at about 35 percent of body weight. He also stated that bulky objects with a center of gravity in excess of 20 inches from the body should not exceed 20 pounds and that 60 pounds should be the limit for objects carried a short distance and 35 pounds for objects carried a long distance. Women should be limited to 55 to 65 percent of male lifting limits. Cathcart, et al. (1967) estimated that men should not lift more than 50 percent of body weight for occasional lifting and 40 percent of the body weight for continuous lifting.

Asmussen, et al. (1965) reported a relationship between electromyograms and isometric backward pulls. The study concluded that the weight allowed for repetitive lifting should be between 40 and 55 percent of isometric back strength.

Poulsen (1970) reported an investigation of the maximum possible lifting burden. This was done for two heights of lift; floor to table height and table height to head height. Measurements were taken of arm, back, and leg strengths, weight, and others. The subjects were asked to perform the lifting tasks adjusting the weight of lift until a maximum weight of lift was determined. Poulsen's findings were said to be highly correlated to Asmussen, et al.'s theoretical model based upon electromyograms. Poulsen recommended that the maximum be reduced by 30 percent for occasional lifting and by 50 to 60 percent for repetitive lifting.

Snook (1971) summarized several of his earlier works (Snook and Irvine, 1966; Snook and Irvine, 1967; Snook and Irvine, 1969; Snook, et al., 1970). Based on the results of these studied and Snook and Ciriello (1974), the authors developed psychophysically based maximum acceptable weight of lift guidelines for various materials handling tasks including lifting, lowering, pushing, pullins, carrying, and walking. The values for lifting and lowering were determined using a simulated laboratory lifting task such as one described earlier. These studies made no attempt to develop predictive equations. It was interesting to note the maximum weights of lift and lower for the above studies were not appreciably different. This was true regardless of sex or lifting range. However, the work rate acceptable for lifting tasks in all cases was less than that acceptable for lowering tasks. The lifting frequencies used in the experiment were slightly lower than the lowering frequencies. Conclusions from Snook and Ciriello (1974) indicated that there were significant statistical differences between men and women when considering maximum acceptable weight of lift (and lowering) weight.

A series of three experiments to derive psychophysically based predictive relationships for maximum acceptable weight of lift were reported. McDaniel (1972) dealt with the floor to knuckle lifting range. Dryden (1973) discussed the knuckle to shoulder lifting range. Knipfer (1974) discussed the shoulder to reach lifting range. In each experiment, a tote box was lifted repeatedly at various frequencies of lift. McDaniel used four lifts per minute. Dryden used six lifts per minute. Knipfer used five lifts per minute. These lifting frequencies correspond roughly to the maximum acceptable lifting frequencies reported by Snook as discussed earlier. The lifting ranges used were based upon measured knuckle height of the individual subject. Floor to knuckle was self explanatory. Knuckle height to shoulder height was defined as measured knuckle to measured knuckle height plus 20 inches. Shoulder height to reach was defined as knuckle height plus 20 inches to measured knuckle height plus 40 inches. Therefore, for the two upper ranges, the distance of lift was 20 inches regardless of subject. Each of these authors measured a number of individual characteristics (strength, etc.) and constructed linear regression models to predict the maximum acceptable weight of lift as functions of these characteristics.

Dryden and Knipfer used industrial workers as test subjects while McDaniel used college students. Knipfer attempted to validate McDaniel's model using industrial subjects. The results were inconclusive. Knipfer also reported on an attempt to formulate a combined model for all three lifting ranges. He concluded that the use of three separate models gave better results than a single combined model.

It should be remembered that maximum acceptable weight of lift or capacity was simply a measure of what a given person feels he or she could do without becoming "overheated or overtired." The quantity alone had no direct relationship to injury potential except for the assumption that a person with a small capacity would be expected to have a larger injury potential than a person with a large capacity. It was felt that these models were adequate to predict the relative lifting capacity of individuals and could therefore be used to account for individual differences.

II. OBJECTIVES

The purposes of this research were to generate data and determine procedures which could be effectively utilized to match the physical requirements of MMH lifting activities with the abilities of individuals performing those activities. This information may permit a more effective control of MMH related injuries and the associated costs.

The objectives for attainment of the above described purposes were as follows:

A. The generation of lifting capacity data in terms of the maximum acceptable weight of lift by a sample of experienced MMH workers representing a broad spectrum of the MMH population (age, sex, body weight) while performing lifting tasks which varied in accordance with the frequency of lift, height and range of lift, and box size.

B. The development of lifting capacity prediction models (an estimate of an individual's lifting capacity) wherein the independent variables are comprised of selected individual (strength and anthropometric) and task (frequency of lift, height and range of lift, and box size) variables.

C. The determination of the effects of the ratio (Job Stress Index-JSI) between the physical demands of lifting jobs and an individual's lifting capacity on occupational injuries associated with lifting activities.

III. METHODS AND PROCEDURES

To achieve the objective of this project, two distinct phases: a laboratory experiment and a field study were conducted. The experimental phase was concerned with generating the lifting capacity data and the development of lifting capacity prediction models. The field study was concerned with the problem of determining the effects of the Job Stress Index (JSI) on occupational injuries attributable to lifting.

A. Experimental Phase

The experimental phase consisted of a laboratory experiment to:

1. Generate lifting capacity data in terms of the maximum acceptable weight of lift from individuals experienced in MMH activities, lifting in particular, who performed a lifting task which was pre-selected, based on an experimental design, where height and range of lift, and box size were varied to reflect different task demands.

2. Collect strength and anthropometric data from each of the experimental subjects. These measurements will be utilized in the development of lifting capacity prediction models.

3. Develop the lifting capacity prediction models utilizing selected individual variables (strength and anthropometric) and task variables (frequency of lift, height and range of lift, and box size) as the independent variables.

The experimental procedure consisted of subject recruitment and screening, subject strength and anthropometric data collection, and the development of lifting capacity prediction models. For the purposes of this report the experimental phase discussion has been divided into three areas: the generation of lifting capacity data, the collection of strength and anthropometric data, and the development of prediction models.

1. The Generation of Lifting Capacity Data

The lifting capacity data was generated in Texas Tech University's Department of Industrial Engineering laboratory through the performance of lifting tasks which consisted of unique combinations of frequency of lift, height and range of lift and box size. Each subject performed nine combinations of the lifting tasks. In every case the subject lifted a box of lead weights where the amount of weight to be lifted was determined by the subjects.

a. Experimental Variables

There are three categories of variables that can influence the lifting capacity data values. These are: (a) worker variables, (b) task variables, and (c) environmental variables.

1. Worker Variables

The subjects participating in this project were all industrial workers with experience in manual materials handling and were recruited and screened so that the subject sample reflect the following characteristics:

Sex: Male and female subjects were utilized. A total of 73 male and 73 female subjects were used in this experimental phase.

Age: Subjects recruited were screened to form three different age groups in 10 year increments. Hence, the following age groupings were formed: 20-29, 30-39, 40-49 years of age.

Weight: Subjects were screened to represent the population in terms of body weight in two ranges. One range is that below the median and the second range is that above the median of the U.S. population. Hence, the integration of subjects dependent on whether their body weight was above or below 77.1 kg for males and 61.2 kg for females.

Skill and Motivation: All subjects were recruited from industry and screened based on their prior MMH experience. All subjects have had a minimum 6 months MMH experience immediately preceeding their participation in the experiment. All the subjects were paid subjects, however, none of the subjects were forced to participate or to complete the test protocol in order to receive their pay.

Method of Lift: All subjects had MMH experience and therefore were asked to lift in the manner they were accustomed to. No attempt was made either to change or standardize each subjects method.

All subjects were recruited and screened not only in terms of their age, sex, body weight and skill, but also to ensure that the employed subjects were of good health and did not have a history of back injury or other injuries which may affect their performance on the lifting task or may further stress them in their participation in this project.

To aid the recruitment and screening process each subject was required to complete a Personal Data and Consent form (see Appendix A).

2. Task Variables

Frequency of Lift: The frequency of lift for each task consisted of one of four levels utilized in the experiment. These were: 2, 4, 6, or 8 lifts per minute. The subjects were paced in order to maintain the assigned lifting frequency for the duration of that particular lifting task combination.

Height and Vertical Range of Lift: The vertical range of lift consisted of six levels, each with a specific starting and terminating point. The combinations were as depicted in table 1.

TABLE 1

Vertical Range of Lift

Range	Starting Point	Ending Point
Floor to knuckle	Floor level	Measured knuckle height (MKH)
Floor to shoulder	Floor level	MKH + 50.8 cm
Floor to reach	Floor level	MKH + 88.1 cm*
Knuckle to shoulder	MKH	MKH + 50.8 cm
Knuckle to reach	MKH	MKH + 88.1 cm*
Shoulder to reach	MKH + 50.8 cm	MKH + 88.1 cm*

*If needed the terminal height was lowered until the subject could place the container onto the platform, at the terminal height.

3. Box Size

The box size was varied in the sagittal plane only and at these levels: 12, 18, and 24 inches. The three box sizes were (width x depth x length): 12"x7"x12", 12"x7"x18", and 12"x7"x24".

4. Environmental Variables

Environmental variables were not varied, but rather they were controlled and maintained constant throughout the experimental phase. It is felt that although environmental conditions are important, any attempt to study their effects in this study would have increased the size of the experiment, making it more difficult to manage. In addition, since the data in the second phase was collected at the participating companies' plant locations, it would have been difficult to control the environmental variables which may have been considerably different at the various work locations.

b. The Task

The subjects were required to perform lifting tasks. Each task was comprised of one level of each of the task variables (frequency of lift, vertical range, and container size). The basic task consisted of lifting various size containers from one height level to another at particular frequencies. There were 72 different possible combinations.

The lifting task required the use of a lifting apparatus, a container with handles, and lead weights. The subject was to lift the container with both hands, in the sagittal plane, using a freestyle lifting technique. The subject would begin the task without prior knowledge of the amount of weight in the container. The subject was free to adjust the weight of the container at any time during the task period until a maximum load the subject could lift repeatedly for a long period of time (a work shift) was reached. The subject was to continue repetition of the task until instructed to stop.

The subject lifted the box, with both hands grasping the handles, from one prescribed level to another, at a set frequency of lift for a specified box size, the lifting apparatus would lower the container to the initial level and the subject lifted the box again at the prescribed signal. During the period between lifts the subject was free to adjust the weight of the load.

The container weight at the end of the 20 minute period was considered the individuals maximum acceptable weight of lift, for that particular task combination (See Appendix B).

c. Experimental Design

The obvious difficulties involved in testing a subject for 72 treatments, wherein each treatment lasts for a minimum of 20 minutes, resulted in the decision to utilize an incomplete randomized block design. A balanced incomplete randomized block design involving 73 treatments and 73 blocks was the closest available design (Cochran and Cox, 1960). In the design chosen, 73 blocks corresponded to 73 subjects. Subjects were treated as blocks to remove differences among subjects. The sample size 73 also represented an acceptable sample size for the regression model.

The incomplete block design resulted in the use of 73 subjects (blocks). Thus it was decided to repeat the experiment, resulting in 146 subjects. These two sets are labeled as design I and design II. (See Appendix C). Since only 72 treatments are available, one of the 73 treatments was randomly chosen in designs I and II, and added in each case as treatment 73. A total of 73 males and 73 females were required, 12 subjects in each sex category (M,F), age category (20-29, 30-39, 40-49) and weight category (above and below median). Two of these categories were chosen at random to have one additional subject each.

Each subject had a code number and was randomly assigned a block number such as I-1, ... I-73, II-1, ... II-73 ... etc. The experiment was conducted in a random order so that both designs I and II would be intermixed. A random number table was used to determine the order in which the experiment was to be performed by a given subject. Each subject under this randomized design performed nine treatment combinations and each treatment combination was tried on nine different subjects. The layout of the experiment is given in an attached computer printout (See Appendix C).

d. Experimental Procedure

The experimental procedure, with respect to the lifting task, was selected to be a modified psychophysical technique.

The lifting procedure associated with this experiment allowed the individual to subjectively adjust, based upon the individual's estimate of his/her working capacity, fatigue, and endurance, the amount that he/she could perform without straining or discomfort and without becoming tired, weakened, overheated, or out of breath. Lead weights were placed in or taken out of the box by the subject, until the maximum weight the subject could lift repetitively was determined. The subject lifted at a specified frequency controlled by the cadence of a light and buzzer signaling the start of each lift.

Following the completion of the personal data and consent forms, the collection of strength and anthropometric data, and a psychological battery the subject was ready to begin the lifting activity.

Each subject was then required to read and listen to a recording of instructions explaining the experiment and the task and what was expected of each subject (See Appendix D).

Each subject was required to perform nine of the 72 task combinations over a 3 hour period wherein each task was performed for approximately 20 minutes (McDaniel, 1972). A brief rest period wqs provided between each 20 minute period while the equipment was being adjusted for the subsequent task combination.

During this 3 hour period cues regarding the elapsed time and the load weight were minimized by removing all time pieces and coding the load weight.

The subject was not provided with any external motivational cues, such as encouragement to lift more or reference made to the affect that the individual was performing better or worse than an arbitrary reference value.

Upon completion of performing the nine task combinations the subject was asked to respond to several questions pertaining to the experiment (See Appendix E).

e. Equipment

The lifting machine (see Figure 1). The lifting apparatus used in this project, in contrast to previous ones used by McDaniel (1972), Dryden (1973), and Knipfer (1973), was nonpowered. It utilized a rubber cup (A) in a 6 foot tube (B) as the main components of this equipment. The tube (B) had a butterfly value on the top (C) and an adjustable value (D). The cup was attached to a movable shelf (E) by means of a steel cable over idling pullies. The entire mechanism was balanced so that when the shelf was empty the rubber cup would slide downwards and the shelf would move upward. During such motion the butterfly valve on top of the tube would open to equalize the pressure on both sides of the cup, thus letting the shelf move upward freely until it stopped against adjustable stops (F). On the other hand, if a box of 8 pounds or more was placed on the shelf, the shelf would move rapidly downwards. During such action, the butterfly valve would close and a pressure would be created inside the tube, depending on the position of valve (D). By adjusting the valve (D) it was possible to cushion the descent of the shelf with any amount of weight on it.

In addition, the equipment had the feature of dumping the box from the moving shelf onto the floor or on an adjustable stationary shelf depending on starting and ending points of the lift. The height level of the stationary shelf was adjustable.

The container box (figure 2); the box was constructed of metal, was equiped with large handles to permit an easy and comfortable fit of the subject's hands. The handles were such that they swiveled to allow the subject to easily grasp and control the load. All handles were so fitted to the box that the point of hold was always above the center of gravity of the load to allow for a more stable condition. The handles on the designed box were 5" above the base of the box.

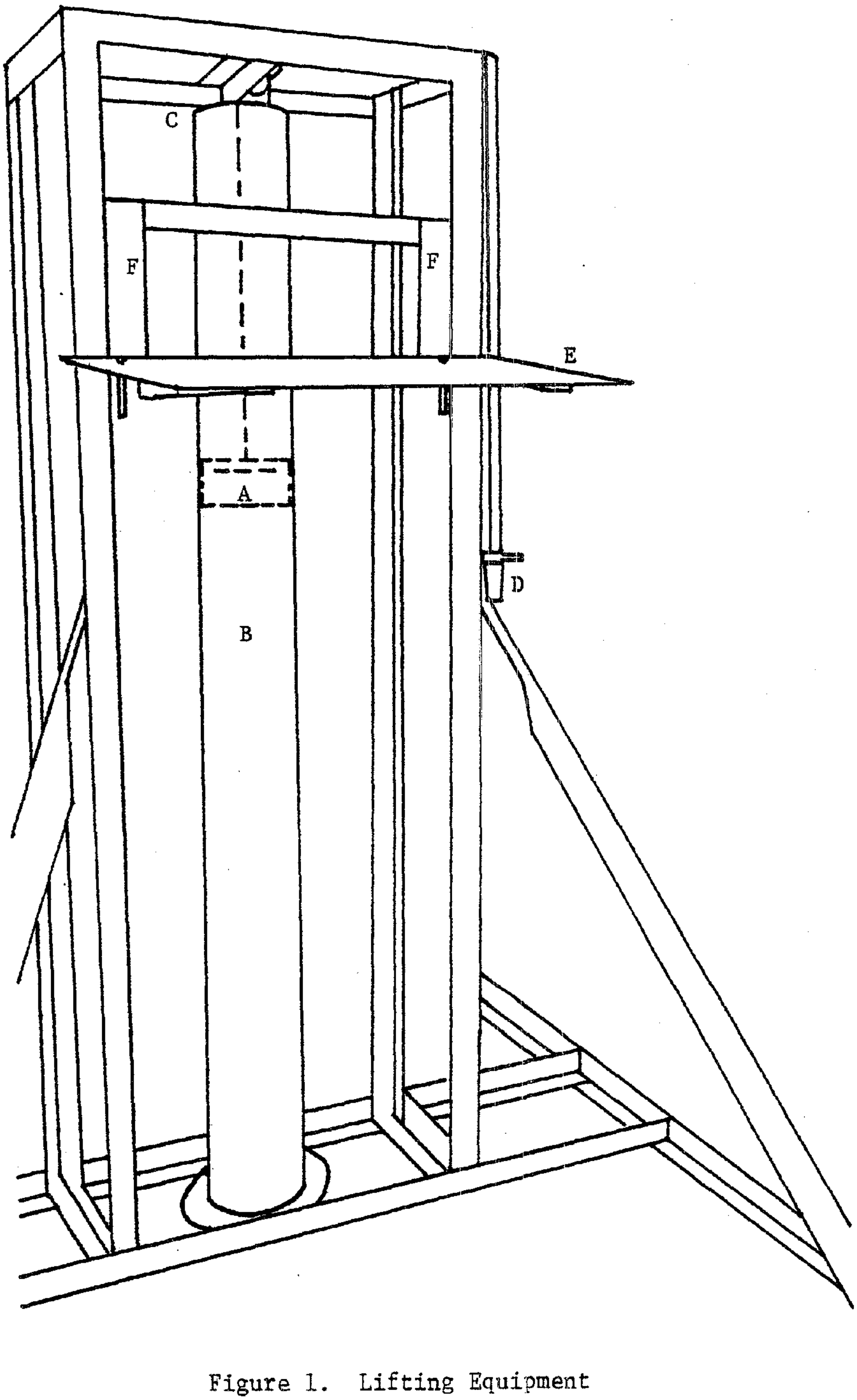

Figure 1. Lifting Equipment

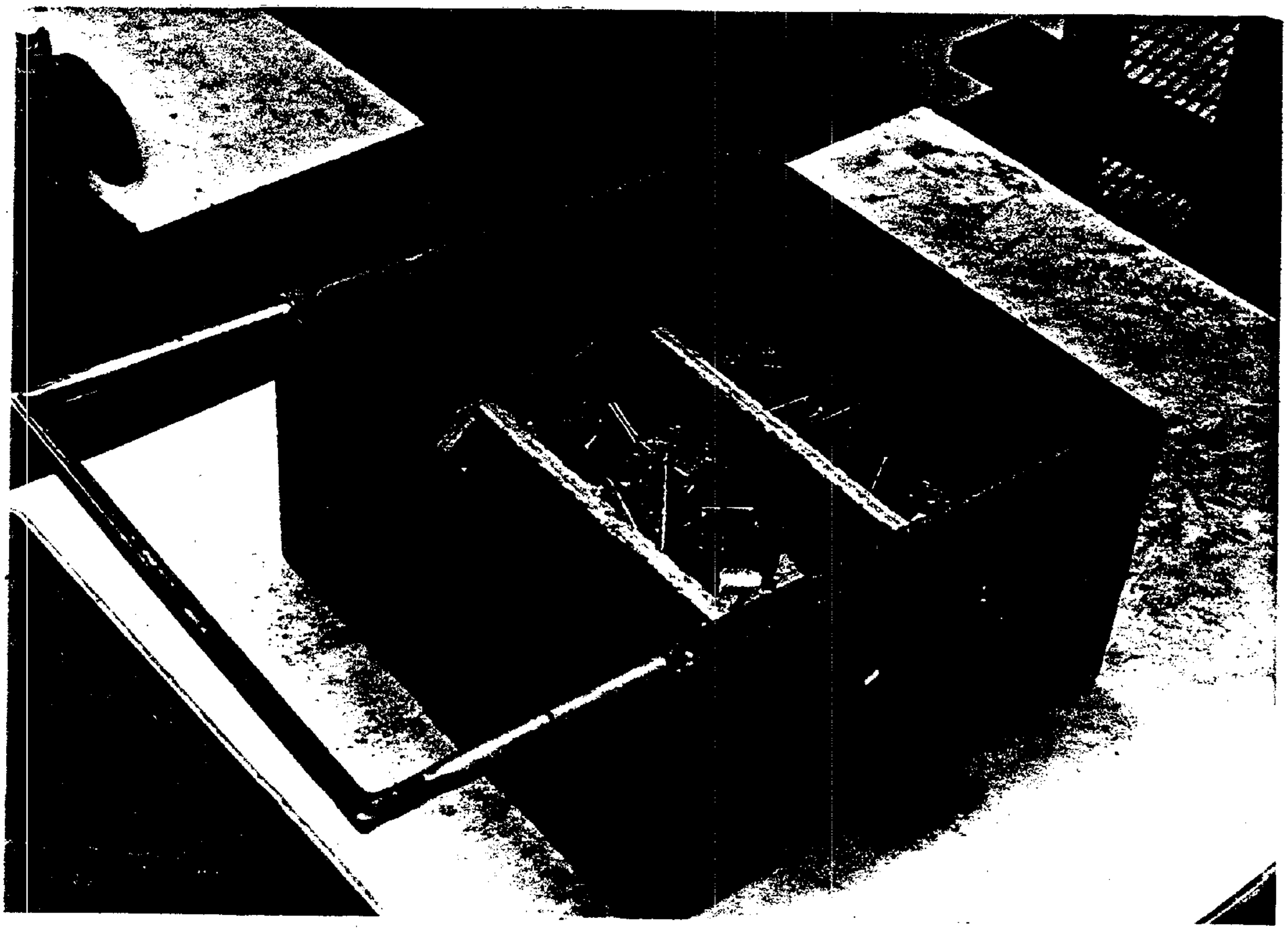

Figure 2. Box with Lead Weights and Extension Piece

An extension rod was used to simulate the variation of the box size in the sagittal plane. The rod was held in place by cotter pins.

The amount of weight lifted was determined by initially weighing the total amount of weight and subtracting the amount remaining in the storage container after the subject had arrived at an acceptable weight of lift. A scale with a capacity of 300 pounds was used for this purpose.

2. The Collection of Strength, Anthropometric and Endurance Data

The development of lifting capacity prediction models based in part on individual variables, necessitated the collection of selected strength, anthropometric, and endurance data for each of the participating subjects.

Each variable was selected on the basis of its supposed correlation with the lifting task. These measures were to be utilized as an independent variables in the development of lifting capacity prediction models.

a. Variables

The anthropometric measurements have been depicted and described in Appendix F. These were: weight, stature, acromial height, knuckle height, standing iliac crest height, knee height, forearm grip distance, chest depth, chest width, and abdominal depth.

The maximum voluntary isometric strength measurements are depicted and described in Appendix F. These were: shoulder strength, arm strength, composite strength, back strength (two different modes), and leg strength.

The endurance measurements, as depicted and described in Appendix F consisted of a static and dynamic arm endurance measurement.

b. Experimental Procedure

As described earlier, 146 subjects (73 male and 73 female) were recruited, screened, and found for participation in the experimental phase of this research.

Upon completion of the personal data and consent form each subject was required to read and listen to a recording of instructions which described the strength, anthropometric, and endurance data collection procedures (See Appendix G). If, at this time, the subject elected to continue with the experiment the appropriate data was collected in accordance with a prescribed sequence (See Appendix H). The data collection seuqence took into consideration that the validity of certain tests is dependent on a reasonable rest period between tests. During those rest periods measuring of nonstressful variables wuch as stature and weight, etc. were made. A typical measurement period was approximately 1 hour.

After completion of the strength and anthropometric data collection, the subjects continued on with the experiment, that is, the psychological battery, the lifting instructions and the lifting tasks, in that order.

c. Equipment

Subject measurements required the use of several pieces of equipment. The equipment could be categorized into three groups: anthropometric, strength, and endurance.

The anthropometric measurements were made using a standard anthropometric measurement kit distributed by Siber Hegner and Company (See Appendix F, Figure F-1). Subject weight was measured using a standard Detecto-Medi scale with a capacity of 300 pounds (See Appendix F, Figure F-4). The accuracy of the scales was checked periodically during the experimental phase.

The various strength measurements were made using a second group of equipment. This group included a metal platform, vertical metal pole with collars, pelvic brace, back board, short handle, long handle, shoulder bar with straps, length of chain, load cell, and the associated load display device (See Appendix F, Figures F-2 and F-3).

The platform served as a base for all strength measurements. It was constructed of metal 30 inches wide, 48.5 inches long, and 1 inch thick. A modified 9/16 inch eye bolt was placed through the platform at its center. This was used during the arm, composite, and shoulder strength measurements as a point of attachment for the chain and load cell assembly.

A second modified 9/16 inch eye bolt was placed through the platform 4 inches from the side (width) and 24.25 inches from either end. This was used during the leg strength measurement as a point of attachment for the chain and load cell assembly.

Force measurement for the strength measurements was accomplished using a load cell and the associated readout device. The load cell used was a Schevitz Engineering AC operated linear variable differential transformer with a range of 1,000 pounds in either tension of compression coupled with a matching digital readout transducer. This device had the tension peak hold option. These two devices were calibrated according to manufacturers specifications prior to the measurement phase of the research and were checked periodically during the experimental phase. The load cell was coupled at one end to the various handles with a hook and to the chain at the other end with a special coupling fixture (See Figure 3).

Both static and dynamic endurance measurements, and static, required the use of a set of weights (See Appendix F, Figure F-19), a tape recorder, and a stop watch. The set of weights consisted of a 1 inch diameter solid steel bar 24-1/2 inches in length. The bar weighed 5.4 pounds. Two tightening collars were used weighing .8 of a pound each. Forty five pounds of iron weights were included, ranging in size from 10 pounds to 1-1/4 pounds each. The tape recorder was a small cassette type tape recorder with AC adapter. The stop watch was a standard Meylan mechanical stopwatch graduated in one hundredths of a minute.

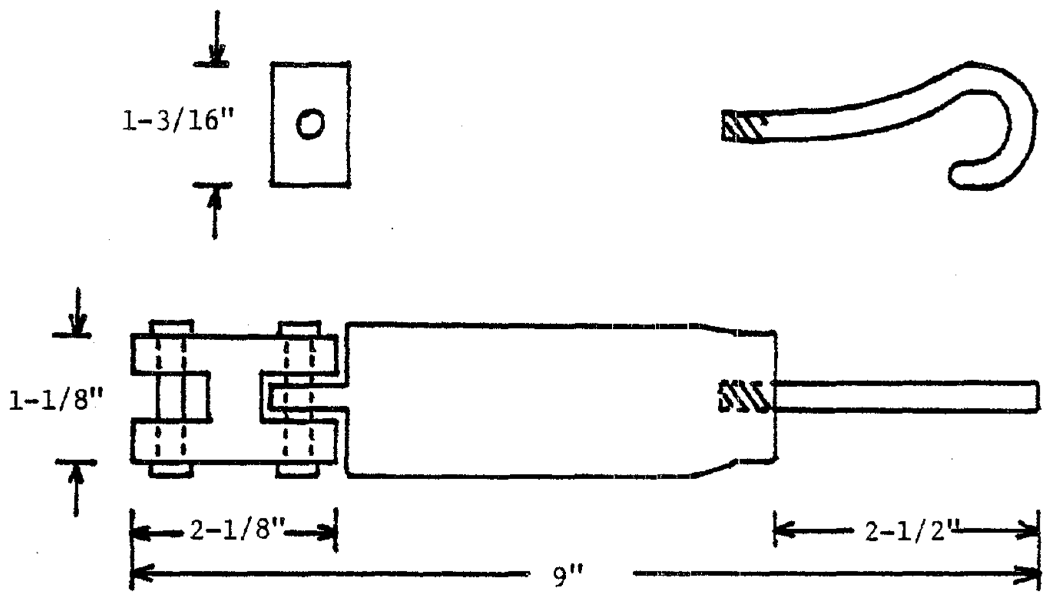

Figure 3. Load Cell, Hook, and Coupling Fixture

3. Predictive Models

The development of effective lifting capacity prediction models, that is, a procedure for successfully estimating an individual's maximum acceptable weight of lift for a given set of task conditions, is based on the correlation between the individual's lifting capacity and individual variables such as sex, strength, anthropometric, endurance, and task variables such as frequency of lift, height, lift, and box size.

In addition to the physical measurements obtained from each subject, a battery of psychological questions (See Appendix I) was administered to each subject. The battery was of interest in that it generated a profile of the subject which could be used to explain any unusual performance.

The objective of the predictive models was to estimate an individual's lifting capacity given a set of task conditions (frequency, height, and box size) and specific information pertaining to the individual, e.g., sex, weight, age, anthropometry, and strength.

a. Variables

Each of the individual and task variables discussed in earlier sections provided the bases for the development of the lifting capacity prediction models.

The individual variables include sex, age, body weight, selected strength measurements, such as, arm strength, leg strength, etc., selected anthropometric measures, such as, age weight, stature, etc., and the two endurance measures, static and dynamic arm endurance.

The task variables include frequency of lift, height and range of lift, and box size.

The psychological profiles of the subjects were not used.

b. Development of the Prediction Models

Development of the lifting capacity prediction models consisted of establishing the correlations between the task and individual variables and the use of regression analysis to develop a given subject. Each subject under this randomized design performed nine treatment combinations and each treatment combination was tried on nine different subjects. The layout of the experiment is given in an attached computer printout (See Appendix C).

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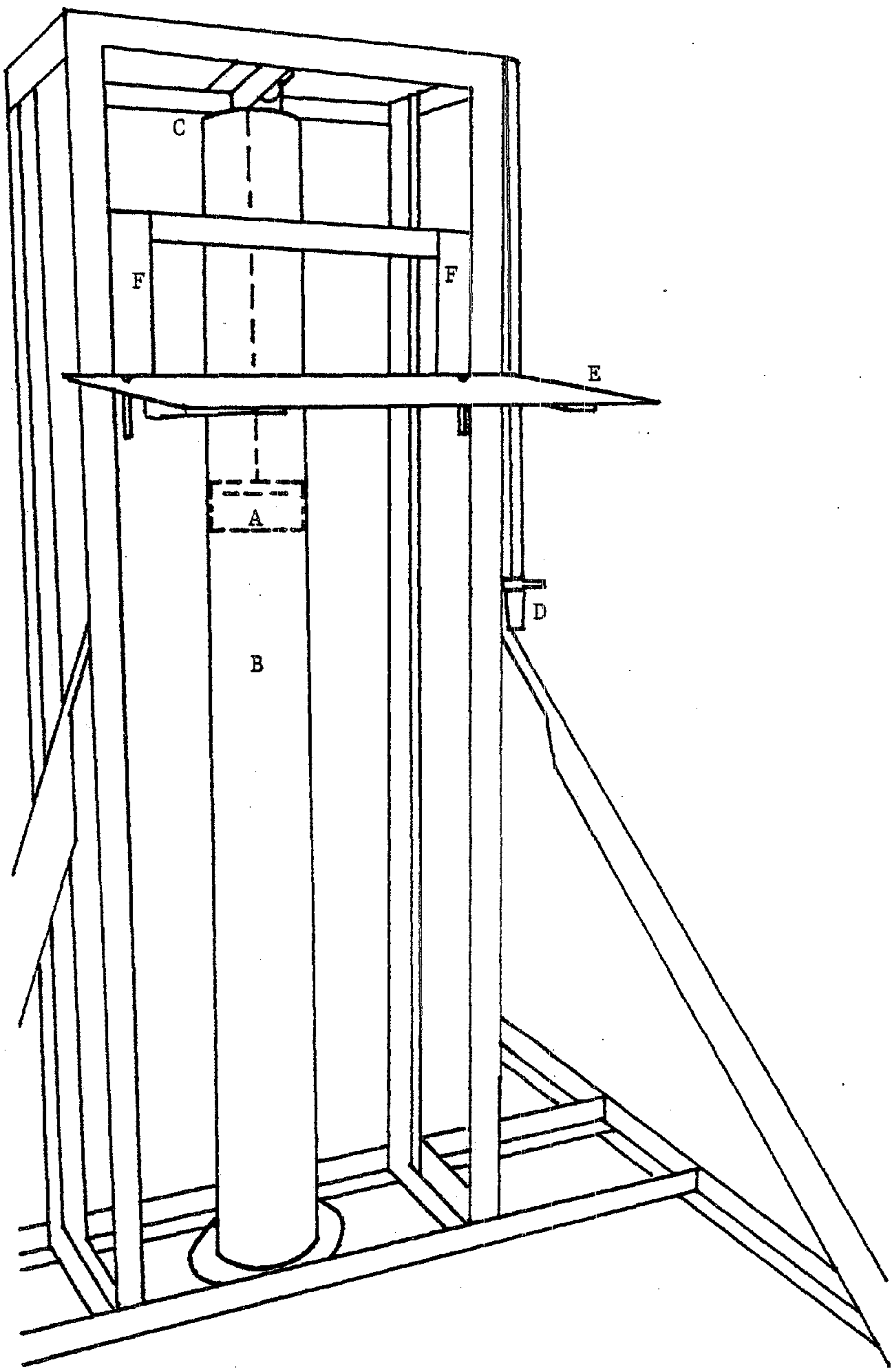

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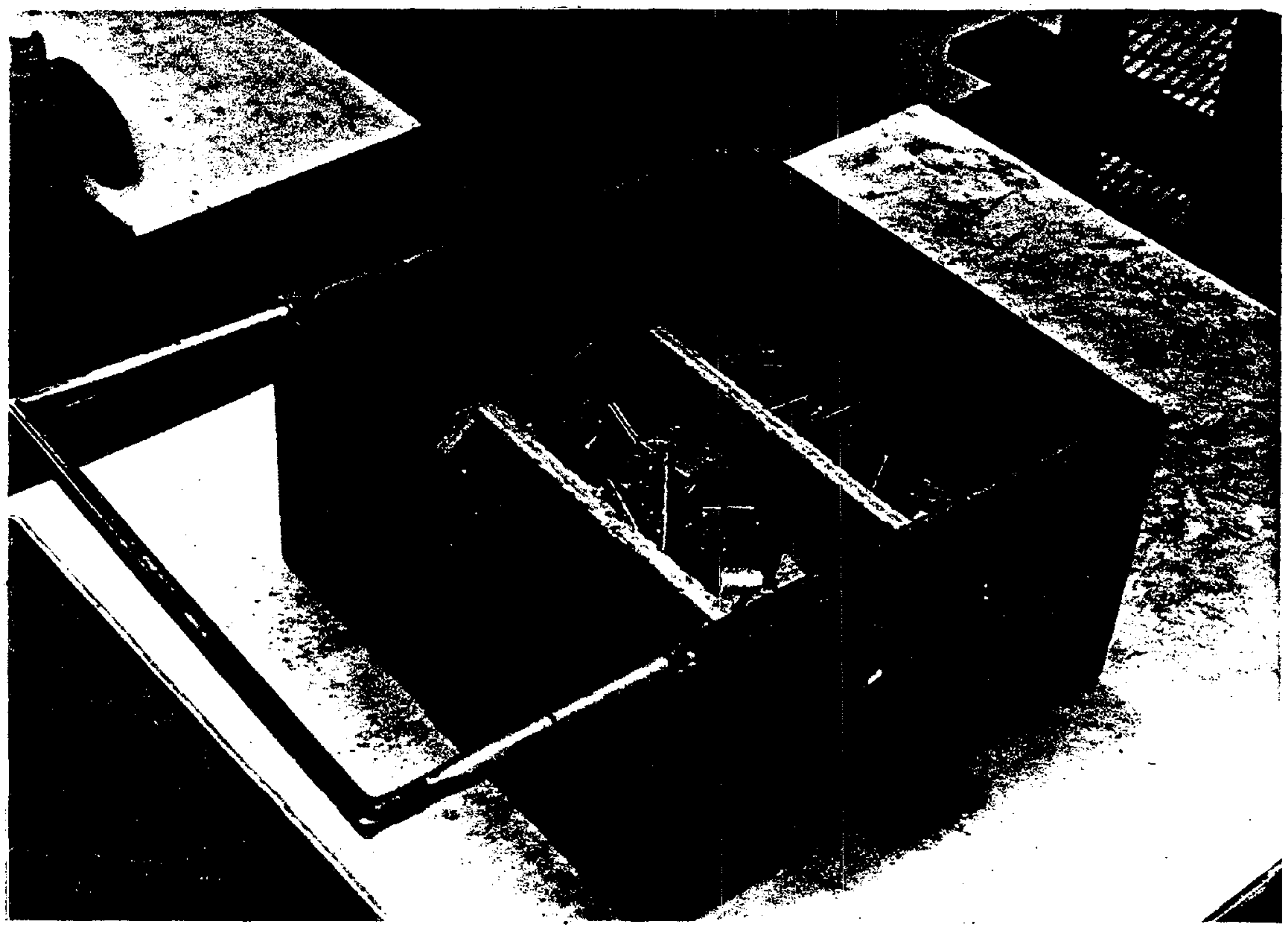

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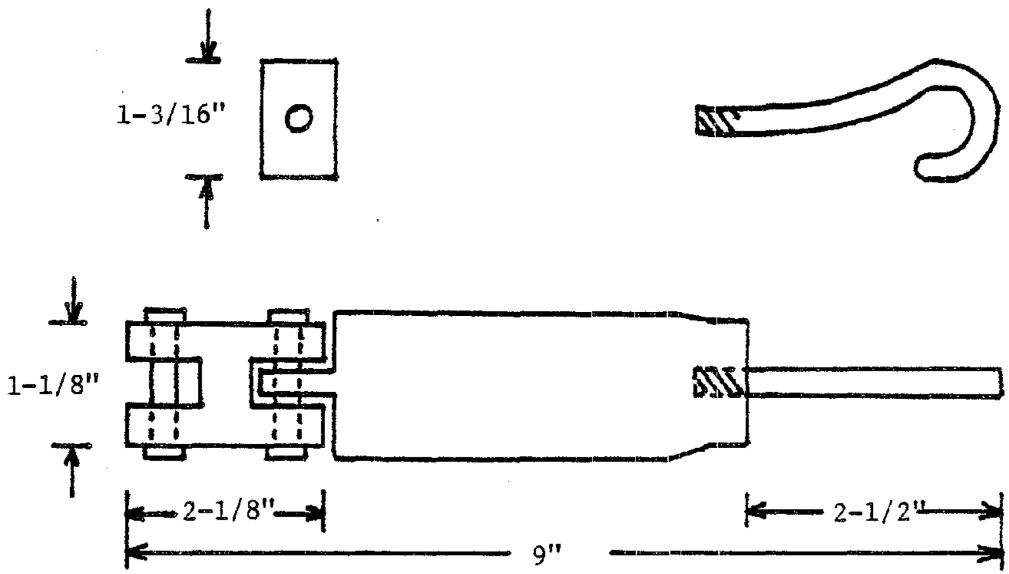

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In addition to the physical measurements obtained from each subject, a battery of psychological questions (See Appendix I) was administered to each subject. The battery was of interest in that it generated a profile of the subject which could be used to explain any unusual performance.

The objective of the predictive models was to estimate an individual's lifting capacity given a set of task conditions (frequency, height, and box size) and specific information pertaining to the individual, e.g., sex, weight, age, anthropometry, and strength.

a. Variables

Each of the individual and task variables discussed in earlier sections provided the bases for the development of the lifting capacity prediction models.

The individual variables include sex, age, body weight, selected strength measurements, such as, arm strength, leg strength, etc., selected anthropometric measures, such as, age weight, stature, etc., and the two endurance measures, static and dynamic arm endurance.

The task variables include frequency of lift, height and range of lift, and box size.

The psychological profiles of the subjects were not used.

b. Development of the Prediction Models

Development of the lifting capacity prediction models consisted of establishing the correlations between the task and individual variables and the use of regression analysis to develop general prediction models. After development, these models were tested.

The statistical technique of regression analysis was used to develop suitable models for predicting the lifting capacity as a function of the predictor variables. The models fitted to the data were of the form

$$Y = \beta_o + \beta_1 Z_1 + 1 + \ldots + \beta_p Z_p + \varepsilon,$$

where

y is the sum of maximum acceptable weight of lift (or lifting capacity) and the body weight. Z_j, $j = 1,2,\ldots, p$, are functions of the predictor variables, e.g., $Z_j = x_j^2, x_j^3, x_j x_k, \log x_j$, etc., where x_j and x_k represent specified task or operator variables, β_o is the intercept (constant) term in the models and is to be estimated, β_j, $j = k,2,\ldots, p$, are coefficients to be estimated, and

ε is a random error assumed to be normally distributed with mean 0 and variance σ^2.

Noted that the independent variables Z_j may be either principal component variables or factor variables which are, of course, themselves linear combinations of the task and individual variables as discussed in the previous section.

The data used in fitting the model (i.e., in estimating the coefficients $\beta_o, \ldots, \beta_p$) were given by $(y_i, Z_{1i}, Z_{2i}, \ldots, Z_{pi})$, $i = 1,2,\ldots, n$, where n was the total number of subjects used.

c. Regression Analysis

The SAS.76 (Barr, et al., 1976) STEPWISE procedure with the maximum R^2 improvement option was used to perform a multiple linear regression analysis to obtain suitable regression models.

Two thirds of the subject's and their lifting capacity and their predictor variable data collected earlier were used for the development of lifting capacity prediction models. A total of six models were developed, one for each height level.

d. Model Verification

Verification or testing of the six lifting capacity prediction models was accomplished through the use of the remaining one third of the lifting capacity and predictor variable data.

B. Field Study Phase

The objectives of this phase were:

1. The collection of historical lifting injury data for many types of manual materials handling jobs, which involved lifting activities. These data were used for determining the relationship between the number of injuries and/or the number of lost week days resulting from those injuries, and the job demands in terms of the amount of weight lifted and the frequency of lift.

2. A determination of the lifting requirements of a select number of jobs, the collection of strength, anthropometric, and endurance data for individuals performing those jobs, and the collection of current injury profiles for the same individuals. These data were utilized to determine the effects of the job stress index (JSI), that is, the ratio between the job demands and the individual's lifting capacity, and lifting injuries both in terms of frequency as well as severity.

3. The development of job stress or severity measures.

1. Data Requirements and Sources

The data collection efforts of this phase were divided into four general areas which correspond to the four types of information needed. These were: (a) historical injury data, (b) the lifting requirements of the job, (c) the lifting capacity of the individual, using the predictive models, and (d) the current injury data on a sample of workers employed in these jobs.

The data collection effort began with the compilation of a list of organizations to be solicited for participation in the project. The name of a responsible person working in each organization to whom an inquiry could be directed was included. This list of organizations and names was accumulated with the help of local insurance agencies dealing in worker's compensation, local chapters of the Texas Association of Business, and personal referrals.

Each organization was initially approached by letter (See Appendix J). The letter briefly explained the research project, outlined the requirements of participation, and asked that participation be seriously considered. If the letter produced no timely response, a follow-up telephone call was made. Plant visits were scheduled with those company representatives who expressed a interest in the project. During these initial visits, in most cases, prelinimary decisions were made as to whether specific lifting jobs were appropriate for study.

If, at the end of this initial visit, the company was still willing to participate and if one or more jobs were deemed adequate for study, a second visit was scheduled. This second visit was used to obtain a detailed job description and to collect historical injury data for each of these jobs.

2. Selection of Jobs for the Study

a. Job Qualifications for Inclusion

An appropriate job was one which required a significant amount of repetitive lifting and showed at least some similarity to the "ideal" lifting jobs which were used for the formulation of the maximum acceptable weight of lift equations. These ideal lifting jobs were described as having specific weights of lift, specific frequencies of lift, specific lifting ranges, and a constant box size. The "ideal" job also exhibited no carrying, pushing or pulling. Obviously, few, if any, actual lifting jobs exactly met these specifications. It was, therefore, necessary to include many jobs that were less than ideal.

b. Job Sources

This data was obtained through the cooperation of 22 private companies and governmental entities, operating in the Dallas-Ft. Worth metropolitan area, where 63 jobs required lifting task were studied.

c. Job Requirement Analysis

The job requirements for each of the jobs tentatively selected for study were determined using a detailed job description procedure. The job description requirements and procedures are explained below.

It was necessary to determine, for each job, the actual weight or weights lifted and the job factors necessary to predict an individual's lifting capacity. It was originally thought that the final set of lifting capacity prediction models would include the predictive variables; frequency of lift, range of lift, and box size as well as various individual characteristics. The final set of models did not use frequency of lift or box size. However, it was necessary to accomplish the job description activity prior to the final determination of the models. As a result, each job studied was described in terms of actual weight of lift, frequency of lift, box size, and range of lift.

The lack of constant parameters exhibited by many of the jobs selected, required that the job description procedure be designed to accommodate a certain amount of variability. This was accomplished by dividing each job into a number of components tasks. Tasks were selected so that each could be described with constant or near constant parameters. This procedure was devised to enable the accurate description of each job as well as to facilitate the Job Severity Index (JSI) calculations.

The initial step in the job description procedure (See Appendix K) was to complete a master job description form (See Appendix L). The information recorded of this form included; the job code, the job title or name, the average length of the work week, the average length of the work day or shift, the number of shifts per day, a general written description of the job, and additional comments.

A five digit code was assigned to each job in the study for purposes of identification. The first three digits of this code identified the company where the particular job was found and the final two digits pertained to the job itself. The job title or name information included both the official job title and the informal name used, if any. This informal name was often more descriptive than the official title. It was also found, in some cases, that two or more different lifting jobs could have the same official or organizational title. The average length of the work week, measured in days per week, and the average length of the work day, measured in hours per day, were recorded. This information was needed to determine the employees average job exposure time. The number of shifts during which the job was performed was recorded for use in subject measurement scheduling. The general written description included a short qualitative summary of the activity involved to be used for communication with the company management and with the subjects. The additional comments section was included to record any unusual aspects of the job such as adverse environmental conditions. When determined, the number of lifting and non-lifting tasks required by the job were also recorded on the master job description form.

The lifting activities required in a job were described through a series of lifting tasks, each of which could be described by constant or nearly constant parameters. A lifting task form (See Appendix M) was completed for each lifting task. The information recorded on this form included the job code, the task code, the amount of time actually spent doing the task, the lifting range, the box size or dimension, the lifting frequency, the actual weight of lift, and any pertinent additional comments. Prior to actual task description, each task was assigned to a task group consisting of other tasks which were performed during the same time period. For instance, if a certain job required the performance of four unique tasks, two of which were performed in the morning and two of which were performed in the afternoon the two morning tasks were grouped together and the two afternoon tasks were grouped together. This method allowed a more accurate description of jobs that required different activity on different days of the week. The task groupings were recorded in the comments section of the lifting task form. In addition, the amount of time that a task was performed was estimated in relation to other tasks within a group. For example, if two tasks were performed with equal lifting frequency for 4 hours per day, 3 days per week, the time estimated was 50 percent of 4 hours, 3 days per week. This estimate was recorded on the task description form for each task.

The lifting requirements of range, dimension, frequency and weight of lift were then determined and recorded for each task. To make the job descriptions usuable for any person working in that job, it was decided to define the range of lift in terms of lift initiation level and lift termination level. The vertical distance, in inches, from the floor to the hand at the lift initiation level was measured and recorded. This was called the "FROM" point. The vertical distance, in inches, from the floor to the hand at the lift termination level was also measured and recorded. This was called the "TO" point. If one or both of these points were not constant, the mean and the upper and lower limits of variation were recorded. Any variation in these parameters was assumed to have a uniform distribution. This allowed, for instance, the stacking or unstacking of pallets to be described using a single task description. If the variation in one or both of the two parameters was obviously bi-modal, additional tasks were defined. The box size or dimension was defined as the dimension of the box or other load, measured in inches along a line perpendicular to the frontal plane of the body of the person doing the lifting. If this parameter displayed variation, the mean and upper and lower limits of variation were recorded. The lifting frequency was recorded as the average number of lifts per minute required by the particular task. These average frequency estimates were made using production records. Variations in frequency of lift were handled using additional task descriptions. The actual weight of lift was measured and recorded in pounds. Variation was again handled by recording the mean and upper and lower limits of an assumed uniform weight distribution.

During job selection, those jobs requiring a significant amount of carrying, pushing, or pulling were excluded. Therefore, the job description procedure did not provide for the description of these activities. It was found, however, that most jobs requiring lifting activities also required some significant amount of lowering. The job description procedure explained above was also applied to all lowering activities. It was assumed, that during analysis, lowering would be separated from lifting and weighted differently.

3. Historical Injury Data

a. Types and Sources

The historical injury data profile was job oriented, that is, an injury profile was determined for a job versus an individual by collecting injury data pertaining to those aspects of the job that involved lifting.

Injury history information was collected for 54 jobs covering the previous 3 year period. Several of the injury histories were actually combined histories pertaining to two or more jobs within a single organization. In these instances the jobs had similar lifting requirements and insufficient injury records to discriminate whether the injury pertained to one job versus the other. However, when adequate historical records existed, unique injury profiles were determined regardless of job similarity. In several cases, historical profiles could not be compiled because of a combination of insufficient records and dissimilar lifting requirements. These cases were not included in the 54 jobs reported in the study.

b. Procedure

The injury histories were obtained from organizational records. The information collected included: the date of injury; the name of the injured person; number of lost work days; work termination, or death of the employee; the nature of the injury in terms of injury type, affected area of the body, and required medical attention; and a narrative description of the incident or accident. In addition, an estimate was made of the employee exposure hours for the 3 year time period coincident with the collection of the historical injury data. This information was reduced in volume using an injury history summary for each job. The procedures and forms for the injury history data collection and summary are presented in Appendix N.

4. Subject Measurements

a. Variables

The individual measurements required in this phase were specified by the final selection of individual predictor variables used in the lifting capacity models. However, subject measurement for this research began prior to the above final selection. It was, therefore, decided to make measurements of all variables most likely to be included in the final models. The final set of variables used to predict lifting capacity included only a few of the variables actually measured. The following discussion describes the actual measurements taken.

The measurements required and taken were a sub-set of the set of measurements taken in the experiment used to formulate the predictive equations. Ayoub, et al. (1977), described the measurements (See Appendix F) used in the earlier experiment. The following is a list of the actual measurements taken during the field effort:

TABLE 2

List of Subject Measurements Taken
in Field Study Phase

Sex	Knuckle Height	Shoulder Strength
Age	Knee Height	Arm Strength
Weight	Abdominal Depth	Composite Strength
Height	Chest Depth	Back Strength
Shoulder Height	Grip Distance	Dynamic Endurances

b. Subjects and Subject Sources

Two hundred and forty-four (244) individuals (220 males and 24 females) were selected who were assigned to the 63 jobs identified as appropriate for this study. The subjects volunteered to participate in the study but were paid their normal wage by the employer. No additional compensation was given for participation in this study.

c. Subject Data Collection

The measurement sessions were accomplished at the employees place of employment and were scheduled so as to minimize any possible disruption in the work place. In most cases a small private room was provided. When a private room was not available, additional precautions were taken to reduce the influence of onlookers. Environmental conditions varied. Several of the measurement sessions were conducted in rooms or areas that were not air conditioned. In those cases, the subjects were asked to take longer rest periods between measurements to reduce the effects of heat fatigue.

The subjects measured were all volunteers selected from the people working on the lifting jobs selected for the study. Preliminary selection was made by management prior to the day of measurement. The company representatives were asked to solicit volunteers from among their employees based upon three selection criteria. Each volunteer was required to have been working on one of the jobs for at least 3 months, to be between the ages of 18 and 55, and not have a serious medical or injury condition. Final screening and selection was made by the experimenter prior to actual measurement.

The measurement procedure described below was patterned after the laboratory procedure used for the model formulation experiment at Texas Tech Ergonomics Laboratories.

The measurement session began when the subject was brought to the measurement site by his or her supervisor. After introductions, the subject was given a short explanation of the research. This and most subsequent explanations and instructions were presented orally using a cassette recording which was played as the subject was reading the instructions in written form (See Appendix O). All instructions and explanations were available in both Spanish and English. It should be noted that the title of the research and parts of the explanation given to the subjects differ slightly from the actual title and objectives stated earlier. The removal of any mention that injury data would be collected after measurement was required for two reasons: (1) an accurate description of the research may have biased the results by influencing the subject population by suggestion, and (2) reservations were expressed by most of the companies involved, that complete disclosure might cause a "rash of injuries."

Final screening was accomplished using a pre-test questionnaire (See Appendix P) administered by the experimenter. After the subject's name, address, and phone number were recorded, he or she was asked to give a short description of his or her job. This was to insure that the person was indeed working in one of the described jobs. Each person was asked how long they had been working on the job. If the answer was less than 3 months and if the person's previous job required no lifting, that person was excluded from the study. Several pertinent questions were asked to determine the subject's physical and medical acceptability. A subject was excluded from the study if one or more of the following was true.

1. History of back surgery.
2. Current back, leg, shoulder, neck, or arm pain.
3. History of uncontrolled or uncorrected high blood pressure.
4. Measured blood pressure in excessive of 140/90 on the day of the measurement session (each subjects blood pressure was taken by the experimenter at that time).
5. Uncorrected abdominal hernia.
6. Corrective surgery for an abdominal hernia within the past ten years.
7. Any history of heart attack or heart condition.
8. Less than 3 hours sleep the night prior to measurement.
9. Taking medication that might inhibit muscle action in any way.

These precautions were taken to reduce the possibility of subject injury during measurement. This screening also reduced the number of people included in the study likely to be injuried or re-injured for reasons other than job severity.

If a person was found acceptable for study, he or she was asked to read and sign an informed consent. As in the case of the initial instructions, the consent form was available in two languages and was recorded on tape for playback as the subject was reading. (The text of the informal consent is included as part of the subject questionnaire in the Appendix P).

Prior to signing, the subject was asked if he or she had any questions and if he or she fully understood what they were about to sign. After the subject had read and signed the consent form, the investigator signed and dated the form. The signature of a witness, usually the subject's supervisor, was also obtained.

The measurements taken were recorded on a data sheet (See Appendix Q). Each subject was assigned a three digit numerical code. This code, along with the subject's name, age, sex, and job code was recorded. The date and time of measurement were also recorded.

The measurements were made in the following sequence.

1. Shoulder Strength
2. Weight
3. Arm Strength
4. Height
5. Shoulder Height
6. Knuckle Height
7. Knee Height
8. Composite Strength
9. Forearm Grip Distance
10. Back Strength
11. Abdominal Depth
12. Chest Depth
13. Dynamic Endurance

It should be noted that the strength and endurance measurements were each separated by at least one anthropometric measurement. This was done to allow sufficient rest periods for the subjects without unnecessarily extending the time required to complete the measurement session. Using this sequence the measurement session, including the completion of the quetionnnaire and explanation, took between 30 and 45 minutes.

Special instructions were given to the subjects immediately prior to each measurement. Each instruction consisted of written directions accompanied by a photograph (See Appendix F). The anthropometric measurements required only passive participation on the part of the subject. Therefore, these instructions were not recorded on tape and are not presented here. The strength and endurance measurements, however, did require active subject participation. Therefore, recordings of these instructions were presented in conjunction with the written instructions (See Appendix E) and photographs.

The four strength measurements were each repeated until a minimum of three measurements were observed. The subjects were required to rest for a minimum of 30 seconds between each repetition. The average of the three strength measurements was recorded.

The four strength averages and the weight of the subject were recorded to the nearest whole pound. The height, depth, and other linear measurements were made and recorded to the nearest tenth of a centimeter. The endurance measurement was made and recorded to the nearest one hundredth of a minute.

d. Equipment for Subject Measurement

Subject measurements required the use of several pieces of equipment. This measurement equipment was equivalent to that used in the previous model formulation study conducted in the laboratory at Texas Tech University. A number of equipment changes, however, were required due to the fact that the subjects used in this research were measured at their place of employment.

The equipment had to be portable and easily assembled and disassembled. Therefore, a few modifications were made to make the equipment easier to transport, assemble, and disassemble.

5. Current Injury Data Collections

a. The Various Data Collected

The injury data was collected and classified according to its cause and injury type. The two injury cause classifications were simply lifting and non-lifting. A lifting injury was defined as any injury not classified as a lifting injury. Because of inadequate accident reporting the distinction between lifting and non-lifting injuries was sometimes difficult to make. These injuries were recent enough, however, that in many of those cases additional clarification could be obtained from first line supervision. If, after clarification, there remained doubt, regarding the injury classification, the injury was classified as non-lifting. The determination of injury type was less difficult. Each injury, regardless of cause, was classified as one of the five injury types described below.

Type 1 - Musculoskeletal injuries (strains, sprains, broken bones, etc.) involving the lower back.

Type 2 - Musculoskeletal injuries to parts of the body other than the lower back.

Type 3 - Surface tissue injury due to impact (cuts, bruises, etc.).

Type 4 - Surface tissue injury due to causes other than impact (chemical and thermal burns).

Type 5 - Injuries not classified as one of the other four types.

b. Sources of the Injury Data

The current injury data was collected on those 244 subjects identified earlier. Each subject was employed by one of the 22 organizations participating in the project. The injury data was obtained from the organizational records and, when needed, through interviews of the first-line supervisors.

c. Injury Data Collection Procedures

The current injury data was collected in one of two methods. If a company provided fewer than 10 subjects, injury report questionnaires were mailed to the company and completed by an appropriate person working there. If, however, the company had provided more than 10 subjects, the information was collected by the experimenter during an on-site visit using the same injury reports (See Appendix R)

Injury data was collected from these workers for a 9 month period beginning with the day when the individual lifting capacity predictor variables were measured. However, for subjects measured during early stages of the subject measurement phase, injury data was collected for two time periods. The first time period was 4 to 6 months after measurement. The second time period was at the end of the study (9 months). Subject injury information for those subjects measured later in the measurement phase was collected once at the end of the study.

Each injury sustained by one of the subjects subsequent to measurement was fully documented. The information requested included the date of injury, the amount of lost time involved, the type and location of injury, and the injury cause. The number of hours worked by the individual between injuries or between measurement and the first injury was determined. Additional information collected included: the date of transfer or termination, if any, and the reason for that transfer or termination; the total of hours worked by the individual during the study period; and the number of hours worked between the date of the most recent injury prior to measurement and the date of measurement. If there was no record of previous injury, the number of hours worked between the date of employment on the job and the date of measurement was determined.

6. Measures of Job Stress

a. <u>Assumptions</u>

The determination of the job severity index for each person required certain information about the person and about the job in which the person was working. The job severity index was defined as the actual weight lifted on the job divided by the predicted capacity of maximum acceptable weight of lift of the person doing the lifting.

The measure of lifting capacity used in this study is maximum acceptable weight of lift. The maximum acceptable weight of lift is not an absolute measure of what an individual can lift but rather a measure of a person's capacity of lift. Equation to predict maximum acceptable weight of lift capacity were developed in the experimental phase of this project. There are six predictive equations, one for each of the six common ranges of lift (i.e., floor to knuckle, etc.). Subsequent mention of individual lifting capacity refers to the maximum acceptable weight of lift predicted by one or more of these six equations.

The requirements of a job, as used in this study, were confined exclusively to the lifting requirements. As stated earlier, the jobs selected for study required a minimal amount of carrying, pushing or pulling. However, many of the jobs did require substantial lowering of loads. For the purposes of this study, load lowering was not considered.

The simple Job Stress Index (JSI) formulation was not directly applicable to actual lifting jobs found in industry. Most jobs had no single lifting requirement. A given job may have required that several different weights be lifted over several different ranges of lift. It therefore seemed necessary to assume that any index used, be devised so as to account for this variability. Three of the four job severity indices were formulated on that basis. A fourth index was presented which does not account for job variability. This index was investigated to check the validity of the assumption.

The job description procedure, as explained earlier, facilitated the accounting for job variability. Each job was defined as a series of tasks. Each task had a unique maximum required weight of lift, a unique set of lifting ranges required, and a unique average lifting frequency. The tasks were, in turn, grouped according to when they were performed. Tasks, for example, performed only in the morning were separated from those performed only in the afternoon. Each group had an average frequency of lift which was equal to the sum of the lifting frequencies of the tasks in the group.

The job descriptions specified the point of lift initiation and the point of lift termination, or the range of each, for all tasks. A given required lift may start or stop at any point from the floor to the full extended reach of the individual performing the lift. The predictive equations, however, used only four points of lift initiation or termination and provide for only six unique ranges of lift. These six lifting ranges are:

1. From floor level to knuckle level,
2. From floor level to shoulder level,
3. From floor level to reach level,
4. From knuckle level to shoulder level,
5. From knuckle level to reach level, and
6. From shoulder level to reach level.

Knuckle level is equal to the measured knuckle height of the individual performing the lift. Shoulder level and reach level are 20 inches and 40 inches above knuckle level respectively. Obviously, some procedure was necessary to assign actual observed lifting ranges to one of the above six so that individual capacities could be predicted. Such a procedure was devised.

b. Types

The first of the four job severity indices investigated essentially the time and frequency weighted average of the task severities. The task severities were equal to the maximum weight of lift required divided by the average of the capacities predicted for the lifting ranges required by the tasks. This definition was restated as follows:

$$JSI1_y = \sum_{j=1}^{M} \left[\frac{DAYS_j}{DAYS_T} + \frac{HRS_j}{HRS_T}\right] \sum_{i=1}^{N_j} \frac{F_i}{F_{Tj}} \left[\frac{1}{R} \sum \frac{WT_i}{CAP_{ky}}\right] \quad \text{(eq. 1.0)}$$

M = Number of task groups.

N_j = Number of tasks in group j.

$DAYS_j$ = Number of days per week that group j is performed.

$DAYS_T$ = Number of days per week that the job is performed.

HRS_j = Number of hours per day that group j is performed.

HRS_T = Number of hours per day that the job is performed.

F_i = Lifting frequency of task i.

F_{Tj} = Total lifting frequency of group j = $\sum_{i=1}^{N_j} F_i$.

R = Number of different ranges required by task i.

WT_i = Maximum weight of lift required by task i.

CAP_{ky} = Predicted capacity of individual y to lift over range k.

The second index investigated did not account for job variability. It was simply defined as the maximum weight of lift required by the job divided by the average capacity of the individual.

$$JSI2_y = \frac{WT}{CAP_y} . \qquad \text{(eq. 2)}$$

Where

WT = Maximum weight required by the job.

CAP_y = Average of six capacities predicted for individual y.

The third index defined was similar to the first except the capacity used was the smallest of the predicted capacities for the ranges required by a given task. This third index used, as a control, the worst or most stressful task situation. The additional step of averaging the required range capacities was removed.

$$JSI3_y = \sum_{j=1}^{M} \left[\frac{DAYS_j}{DAYS_T} \times \frac{HRS_j}{HRS_T} \right] \sum_{i=1}^{N_j} \left[\frac{F_i}{F_{Tj}} \times \frac{WT_i}{CAP_{iy}} \right] . \qquad \text{(eq. 3)}$$

Where

CAP_{iy} = The smallest of the one or more capacities for the ranges required by task i for individual y.

Other symbols = Same as for JSI^1.

The fourth and final index was again similar to the first except the capacity was equal to the average of the six capacities for each individual. This index, in effect, ignored the differences in lifting range.

$$JSI4_y = \sum_{j=1}^{M} \left[\frac{DAYS_j}{DAYS_T} \times \frac{HRS_j}{HRS_T} \right] \sum_{i=1}^{N_j} \left[\frac{F_i}{F_{Tj}} \times \frac{WT_i}{CAP_y} \right]. \quad \text{(eq. 4)}$$

Where

CAP_y = Average of six lifting capacities for individual y.

Other symbols = Same as for JSI1.

Work Rate (WR), a measure of absolute job demand, was defined as the number of inch-pounds per minute that an individual was required to do. This measure, like the ones described above, disregarded any lowering requirement. For purposes of computation, the points of lift initiation and termination were assigned to one of six regions. The boundaries of these regions were one-half knuckle height, knuckle height, knuckle height plus 10 inches, knuckle height plus 20 inches, and knuckle height plus 30 inches. All lifts were assumed to initiate or terminate at the mid-points of these regions, or in the case of the two extreme regions, at a point 5 inches from the boundary. It is assumed, in addition, that a lift from one region to the next higher region required a movement of 10 inches. A lift within the same region was assumed to require a movement of 1 inch. This measure, as was obvious, ignores individual differences.

$$WR = \sum_{j=1}^{M} \left[\frac{DAYS_j}{DAYS_T} \times \frac{HRS_j}{HRS_T} \right] \sum_{i=1}^{N_j} \frac{F_i}{F_{Tj}} \left[\frac{1}{R} \sum_{R} (WT_i \times F_i \times DIST) \right]. \quad \text{(eq. 5)}$$

Where

DIST = Lifting distance in inches.

Other symbols = Same as for JSI1.

Another measure of absolute job demand, Average Maximum Weight, (AWT), was similar to work rate in that it also ignored lowering requirements and individual differences. Average maximum weight was the time and frequency weighted average of the task maximum weights.

$$AWT = \sum_{j=1}^{M} \left[\frac{DAYS_j}{DAYS_T} \times \frac{HRS_j}{HRS_T} \right] \sum_{i=1}^{N_j} \frac{F_i}{F_{Tj}} \times WT_i . \qquad \text{(eq. 6)}$$

Where all symbols are as previously defined.

The final independent variable considered was simply the average of the six predicted lifting capacities for each individual ($ACAP_y$).

$$ACAP_y = \frac{1}{6} \sum_{k=1}^{6} CAP_{ky} . \qquad \text{(eq. 7)}$$

c. Procedure

A total of four job severity indices, two measures of absolute job demand, and one measure of individual capacity were compared through the use of correlation and linear regression analysis to the injury measures. The job severity indices were all variations of the simple relationship:

$$\text{Job Severity Index (JSI)} = \frac{WT}{CAP} .$$

Where

WT = Maximum weight of lift required, and

CAP = Predicted lifting capacity of individual.

The two absolute measures of job demand were work rate, measured in inch-pounds per minute, and average maximum weight lifted. The measure of individual capacity was the arithmetic average of the six predicted maximum acceptable weights of lift for each individual.

IV. RESULTS

The results are presented in two parts. The first part is a presentation of the results of the experimental phase while the second part is a presentation of the results of the field study.

A. Experimental Results

The experimental phase results include: subject data, lifting capacity data, frequency effect, effect of box size, combined box size and frequency effect, effect of age, and prediction models and their use. The data presented is for both males and females unless otherwise noted.

1. Subject Data

Strength and anthropometric measurement means and standard deviations for the male and female subjects used in the experimental phase and field study phase are given in Tables 3 and 4. Although these means were not tested statistically, the difference does not appear to be significant.

2. Lifting Capacity

Lifting capacity, in this context, is defined as the maximum acceptable weight of lift at the rate of one lift per minute for the different height levels. The maximum acceptable weight lifted by male and female subjects for the different frequencies was adjusted to one lift per minute assuming a linear frequency effect, to determine the lifting capacity. Table 5 is a presentation of the lifting capacity means and standard deviations (assume normal distribution) for the six different height levels. Lifting capacity bar diagrams are presented in Figures 4 and 5. The lifting capacity histograms for each height of lift are presented in Appendix S.

Table 6 is a presentation of the mean lifting capacities for different frequencies. The effect of box size was ignored to obtain these values. Similarly, the mean lifting capacity for different box sizes (Table 7) were obtained by ignoring the effect of frequency.

TABLE 3: Strength and Anthropometric Measurement Means and Standard Deviations for Field Study Data Subjects

	Male (N=220)		Female (N=24)	
Age	Mean	Std. Deviation	Mean	Std. Deviation
Age	27.99	9.59	31.29	7.43
Weight	171.38	35.16	147.46	22.46
Height	174.53	7.30	162.69	7.64
Shoulder Height	144.58	6.61	133.95	6.32
Knuckle Height	77.78	4.05	72.47	4.48
Knee Height	46.51	3.09	43.30	2.50
Abdominal Depth	20.39	3.62	19.88	3.59
Chest Depth	20.95	2.66	18.56	2.48
Grip Distance	25.77	2.04	32.77	1.72
Shoulder Strength	108.05	26.66	50.33	17.93
Arm Strength	86.60	24.28	44.58	13.88
Composite Strength	244.63	69.59	115.00	44.73
Back Strength	142.53	41.56	81.67	25.81
Dynamic Endurance	2.36	1.33	2.42	1.41

TABLE 4: Strength and Anthropometric Measurement Means and Studied Deviations for Experimental Data Subjects

	Male (N=73)		Female (N=73)	
Age	Mean	Std. Deviation	Mean	Std. Deviation
Age	33.61	10.58	34.08	10.06
Weight	172.83	32.82	141.53	26.18
Height	173.82	7.55	161.65	5.52
Shoulder Height	142.51	6.47	132.79	4.49
Knuckle Height	75.65	4.63	71.58	3.04
Abdominal Depth	22.07	3.77	20.07	4.48
Chest Depth	21.61	2.57	19.07	2.05
Grip Distance	34.16	2.14	31.09	1.82
Shoulder Strength	110.16	28.08	60.72	14.79
Arm Strength	81.45	21.29	51.58	13.15
Composite Strength	249.10	59.79	142.20	39.92
Back Strength	185.74	52.65	118.42	30.94
Dynamic Endurance	2.55	1.42	2.63	1.62

TABLE 5: Distribution of Maximum Weights (lbs.) of Lift Acceptable to Male and Female Industrial Workers* (Corrected for one lift/min.)

Height of Lift	Sex	Mean	Std. Devia.	PERCENT OF POPULATION										
				95	85	75	65	55	50	45	35	25	15	5
Floor to Knuckle	Male	61.17	16.86	33.43	43.67	49.62	54.66	59.06	61.17	63.47	67.67	72.71	78.66	88.90
	Female	37.12	6.76	26.00	30.12	32.50	34.52	36.27	37.12	37.96	39.72	41.73	44.11	48.20
Floor to Shoulder	Male	51.21	12.11	31.29	38.64	42.91	46.53	49.69	51.21	52.72	55.88	59.50	63.77	71.13
	Female	31.08	6.54	20.32	24.29	26.60	28.55	30.26	31.08	31.78	33.60	35.56	37.86	41.83
Floor to Reach	Male	49.12	11.20	30.69	37.50	41.45	44.79	47.72	49.12	50.52	53.44	56.79	60.74	67.54
	Female	28.14	5.41	19.24	22.52	24.43	26.05	27.46	28.14	28.81	30.23	31.84	33.75	37.04
Knuckle to Shoulder	Male	57.75	14.67	33.33	42.25	47.42	51.80	55.63	57.47	59.30	63.13	67.52	72.69	81.60
	Female	31.97	6.55	21.19	35.17	27.48	29.44	31.15	31.97	32.78	34.50	36.45	38.76	42.74
Knuckle to Reach	Male	53.54	10.70	35.93	42.44	46.21	49.40	52.20	53.54	54.87	57.67	60.87	64.64	71.14
	Female	26.22	4.86	18.22	21.17	22.89	24.35	25.61	26.22	26.83	28.09	29.55	31.26	34.21
Shoulder to Reach	Male	43.62	10.45	26.43	32.77	36.46	39.58	42.31	42.62	44.92	47.65	50.77	54.46	60.81
	Female	25.78	4.17	18.92	21.45	22.92	24.17	25.26	25.78	26.30	27.39	28.63	30.10	32.64

*Assuming a normal distribution

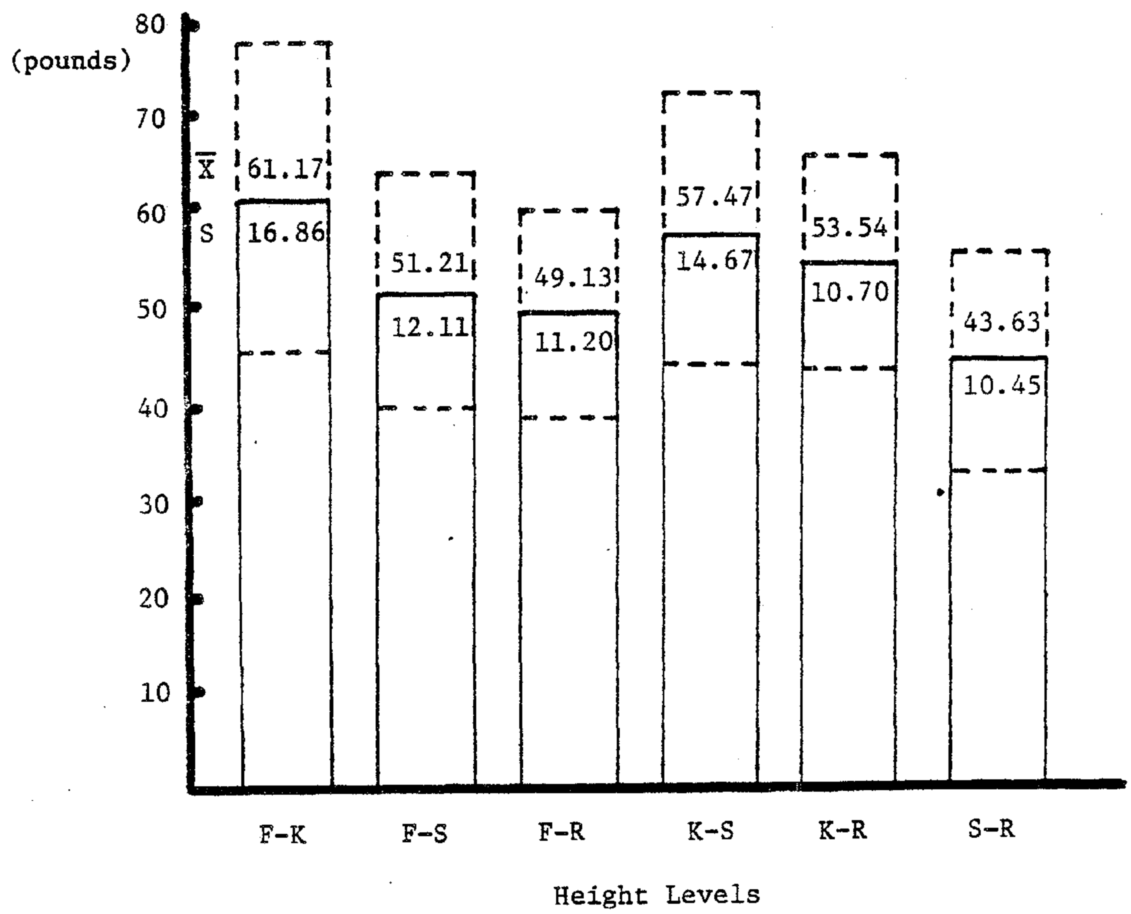

Figure 4: Lifting Capacity for Males for Various Height Levels

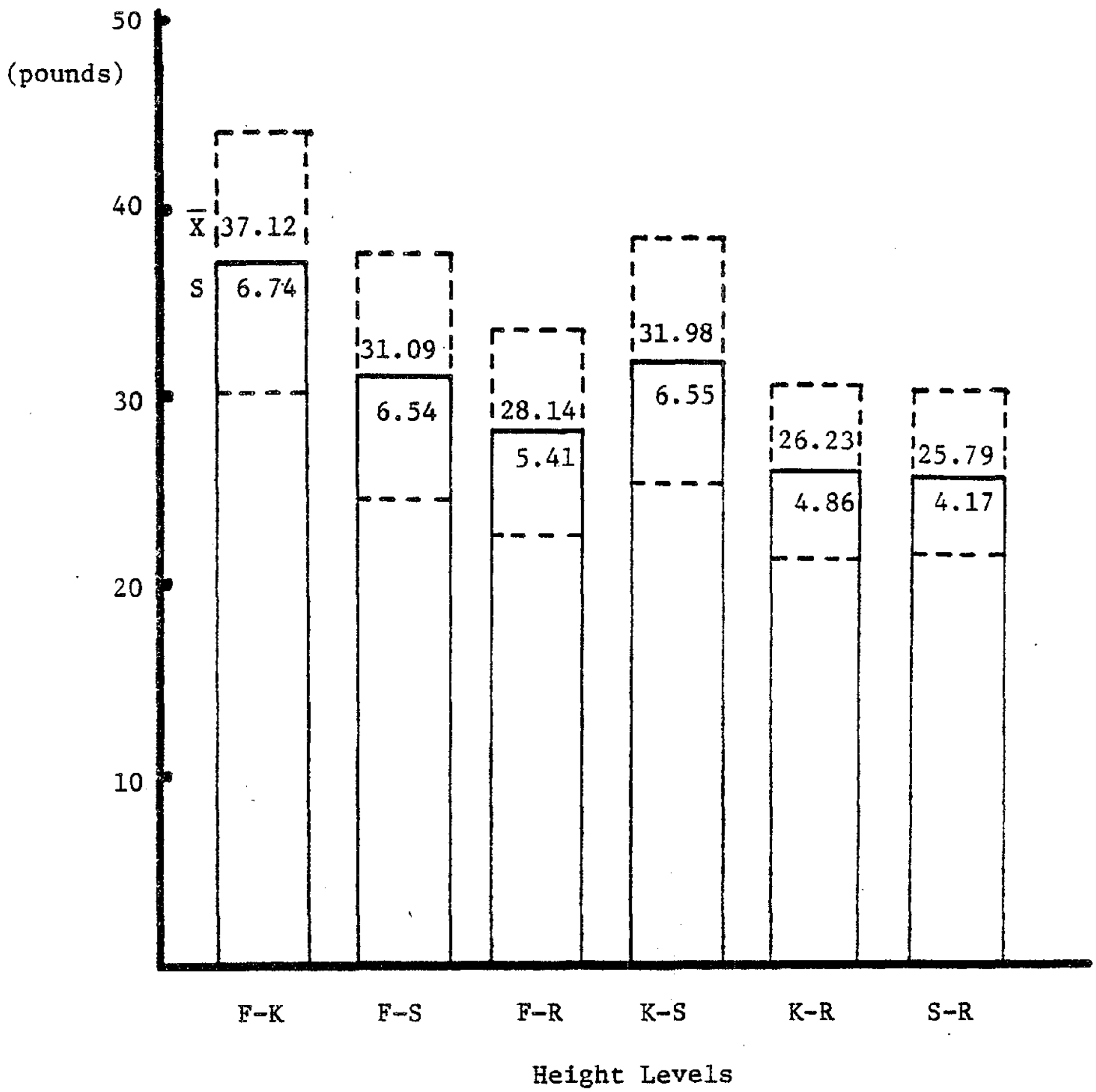

Figure 5: Lifting Capacity for Females for Various Height Levels

TABLE 6: Mean and Standard Deviation of the Maximum Weight (lbs.) Acceptable to Male and Female Industrial Workers for Different Frequencies (lifts/min.)

Height of Lift	Sex	Frequency=2		Frequency=4		Frequency=6		Frequency=8	
		Mean	Std. Deviation	Mean	Std. Deviation	Mean	Std. Deviation	Mean	Std. Deviation
Floor to knuckle	Male	59.71	18.40	56.79	16.62	55.14	15.50	52.30	17.01
	Female	29.93	5.64	32.20	8.23	28.92	6.60	30.44	5.97
Floor to shoulder	Male	50.05	10.43	47.73	11.47	47.00	11.76	44.25	13.87
	Female	29.68	6.50	26.87	5.97	26.48	7.52	26.02	5.79
Floor to reach	Male	47.52	12.85	44.31	12.45	42.91	8.44	36.08	8.79
	Female	27.21	5.11	25.35	6.17	23.86	5.38	23.52	4.05
Knuckle to shoulder	Male	55.60	13.98	51.86	15.15	51.67	15.28	48.09	13.90
	Female	30.22	7.24	26.71	5.23	29.63	5.25	24.73	6.64
Knuckle to reach	Male	50.45	12.00	44.27	8.85	41.82	8.47	38.55	8.68
	Female	26.00	5.54	25.55	5.11	26.05	3.89	24.11	5.06
Shoulder to reach	Male	43.15	9.55	42.20	10.51	39.26	11.37	35.60	9.33
	Female	24.72	4.64	22.59	3.70	23.22	3.17	23.51	5.19

TABLE 7: Mean and Standard Deviation of the Maximum Weight (lbs.) Acceptable to Male and Female Industrial Workers for Different Box Sizes (in.)

Height of Lift	Sex	Box Size=12		Box Size=18		Box Size=24	
		Mean	Std. Deviation	Mean	Std. Deviation	Mean	Std. Deviation
Floor to knuckle	Male	60.40	17.45	56.96	16.50	50.70	15.59
	Female	32.04	6.53	30.62	7.85	28.16	4.92
Floor to shoulder	Male	46.35	13.26	48.87	11.68	45.24	11.25
	Female	29.05	5.70	28.28	7.22	25.42	6.18
Floor to reach	Male	45.24	10.30	41.39	12.99	40.61	9.71
	Female	26.17	5.17	24.86	4.73	24.40	6.05
Knuckle to shoulder	Male	53.06	12.28	52.40	14.66	49.64	16.86
	Female	28.51	7.06	27.83	6.50	27.06	6.23
Knuckle to reach	Male	42.81	11.39	45.94	11.19	43.34	9.47
	Female	25.61	6.12	25.38	3.76	25.56	4.78
Shoulder to reach	Male	39.37	10.56	39.33	11.02	40.86	9.93
	Female	25.00	4.50	22.90	3.84	22.53	3.83

The means and standard deviations for each combination of frequency and box size for the six height levels are given in Table 8.

The lifting capacity data can be interpolated to arrive at the lifting capacity for other frequencies and box sizes. Extrapolation can also be used within close value used in the data development (within 15 lifts per minute and 1 lift every 5 minutes).

Lifting capacity data, based on the psychophysical approach, have also been generated by several other researchers (McDaniel, 1972; Dryden, 1973; Knipfer, 1974; and Snook, 1978), but due to certain experimental differences it is not possible to compare all the data. However, for the common height levels (floor to knuckle, knuckle to shoulder, and shoulder to reach height levels), the lifting capacity data are similar for both males and females. The exception is in the case of male data generated by Dryden (1973) and Knipfer (1974). The values in these two cases are much higher than those generated by Snook (1978) or in the present study. It should be noted that in this study, the data were generated using a large industrial subject population making the data more reliable than the Dryden and Knipfer studies.

3. Frequency Effect

As the frequency of lift per minute increased, the amoung of work done (in foot pounds) also increased. As expected, the maximum weight of lift decreased with the increase in frequency of lift. The amount of weight lifted for different frequencies is tabulated in Table 6 and the main effects are plotted and shown in Figures 6 through 11 for all six height levels. Regression equations, for the amount of weight lifted for different frequencies, were developed and are indicated on each figure. These equations should be used to determine the effect of frequency on the lifting capacity.

When the effects of frequency were considered over all box sizes and height levels, no significant difference ($p<.05$) was found in the lifting capacity for females, between frequencies of 4 and 6 lifts per minute and 6 and 8 lifts per minute. All other levels (males and females), however, were significantly different (Figure 12).

TABLE 8: Means and Standard Deviations of the Maximum Weights (lbs.) Acceptable to Male and Female Industrial Workers for Different Box Size (in.) and Frequency (lifts/min.) Combinations

Height of Lift	Sex		Frequency=2 Box Size 12	18	24	Frequency=4 Box Size 12	18	24	Frequency=6 Box Size 12	18	24	Frequency=8 Box Size 12	18	24
Floor to Knuckle	Male	X̄	60.80	61.50	54.90	53.80	60.80	55.90	63.10	55.10	46.20	61.30	51.10	45.30
		S	20.70	18.90	14.90	12.80	20.90	16.50	17.60	12.70	11.40	17.30	13.90	17.60
	Female	X̄	33.00	29.60	27.80	35.00	32.30	26.10	30.50	27.50	28.30	29.10	32.30	29.90
		S	3.30	7.10	5.20	5.60	10.80	3.50	7.80	6.80	4.40	7.10	4.50	5.90
Floor to Shoulder	Male	X̄	50.50	53.10	46.20	45.20	48.50	48.50	49.50	47.70	50.00	41.90	46.80	44.70
		S	13.50	7.00	11.20	12.10	12.70	9.50	13.40	10.60	8.30	13.70	14.90	14.00
	Female	X̄	29.10	31.50	28.90	28.40	28.50	22.80	31.40	26.40	24.40	27.70	25.90	24.90
		S	7.20	6.20	6.20	3.40	7.40	4.30	7.20	10.30	5.40	4.30	4.70	7.90
Floor to Reach	Male	X̄	47.20	53.90	40.70	47.50	36.40	47.10	46.20	43.50	40.30	39.50	32.70	36.60
		S	11.10	13.60	11.60	12.70	12.90	8.18	6.90	8.60	8.80	8.10	8.10	9.60
	Female	X̄	27.30	27.80	26.40	27.10	24.20	25.40	26.40	22.40	22.70	23.80	24.10	22.70
		S	4.80	4.50	6.30	5.80	4.80	7.40	6.20	4.10	5.00	3.80	4.20	4.30
Knuckle to Shoulder	Male	X̄	53.50	57.10	56.60	53.00	54.80	49.80	51.80	54.00	48.40	54.10	44.30	46.40
		S	11.90	15.60	16.20	13.90	19.30	16.50	12.80	14.20	19.20	11.90	11.80	16.10
	Female	X̄	32.40	30.80	27.80	27.10	27.30	25.00	29.90	28.30	30.10	24.50	25.10	24.30
		S	7.50	8.30	5.80	3.30	4.90	7.10	4.90	4.90	6.30	8.00	6.70	5.20
Knuckle to Reach	Male	X̄	46.90	52.60	52.20	46.70	51.50	40.00	41.40	31.90	56.20	36.40	39.60	39.80
		S	14.50	8.70	13.20	8.90	8.40	7.30	10.70	7.00	4.50	7.70	11.40	7.50
	Female	X̄	27.90	25.90	24.60	24.30	24.50	28.60	25.90	26.80	25.30	24.20	24.30	23.60
		S	7.70	3.60	4.90	5.90	3.00	6.00	4.70	4.10	2.70	6.90	4.10	4.80
Shoulder to Reach	Male	X̄	48.60	41.20	40.40	42.90	43.90	38.00	36.10	38.30	42.60	33.30	33.20	41.00
		S	5.00	9.60	11.30	14.40	7.60	9.60	6.10	17.10	10.70	8.50	9.10	9.10
	Female	X̄	26.30	22.90	24.50	23.00	22.70	22.10	23.80	22.70	23.20	28.40	23.10	20.10
		S	4.80	4.20	4.60	3.80	3.30	4.00	3.40	3.60	2.10	4.80	4.70	3.00

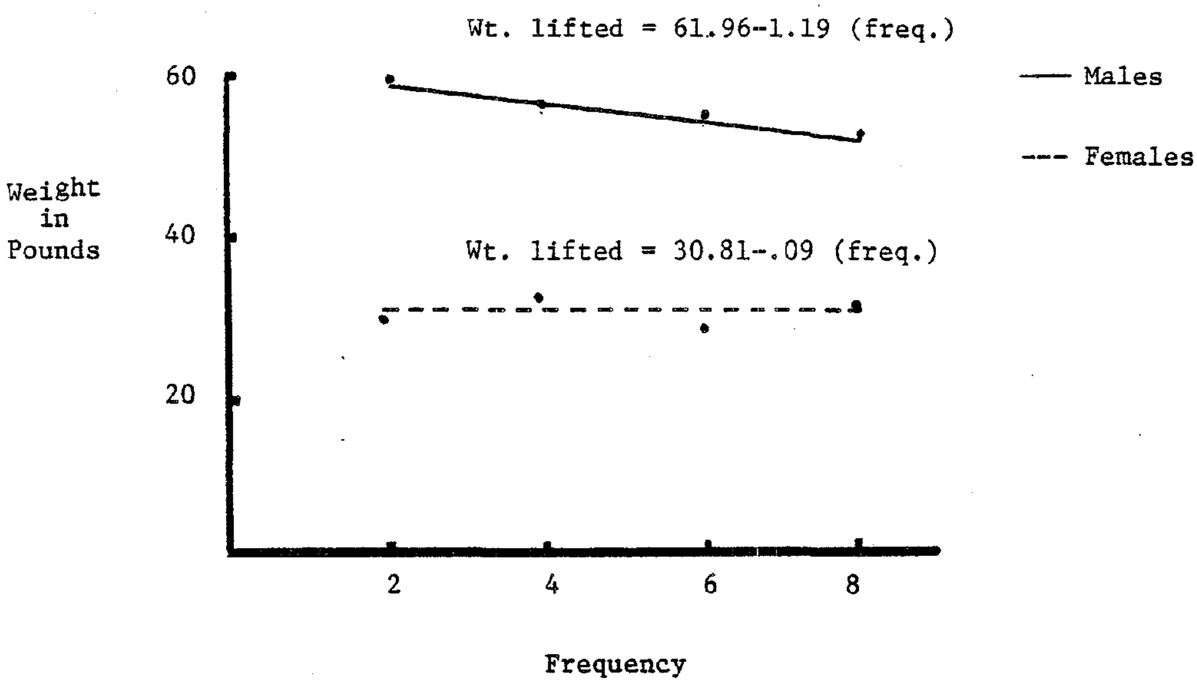

Figure 6 : Height Level 1
(Floor to Knuckle)

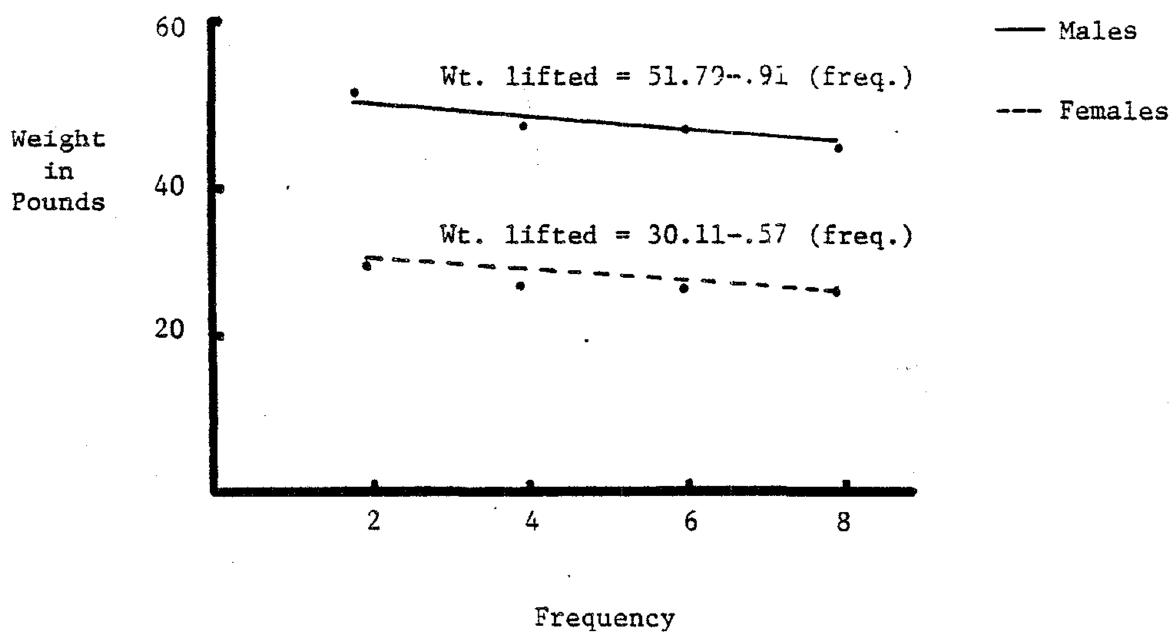

Figure 7: Height Level 2
(Floor to Shoulder)

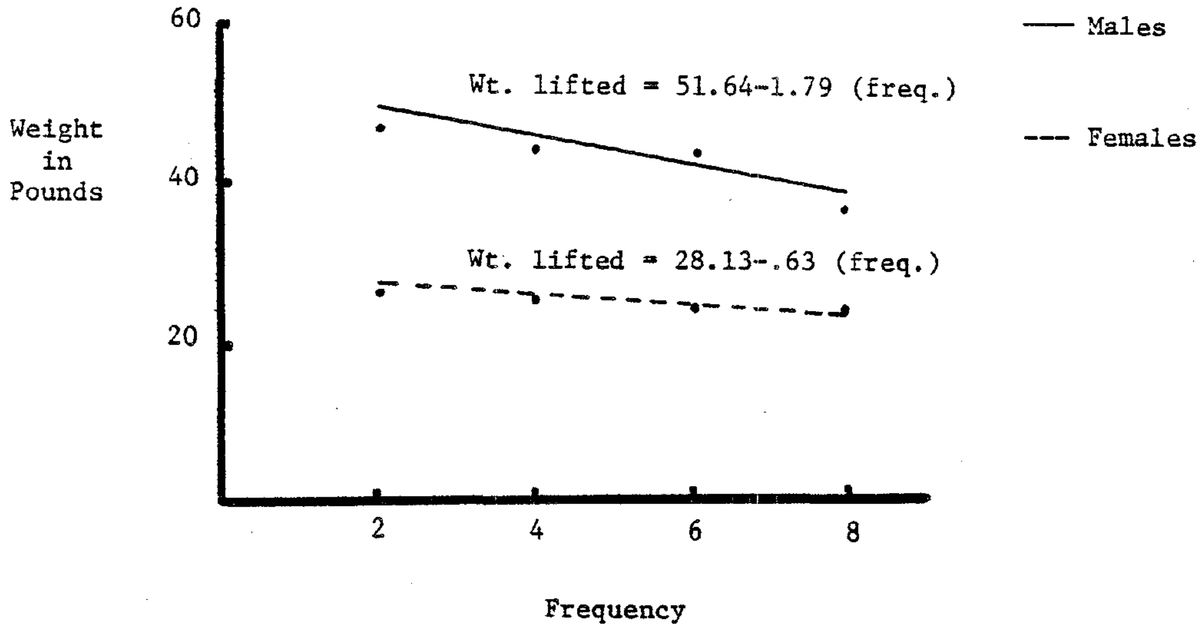

Figure 8 : Height Level 3
(Floor to Reach)

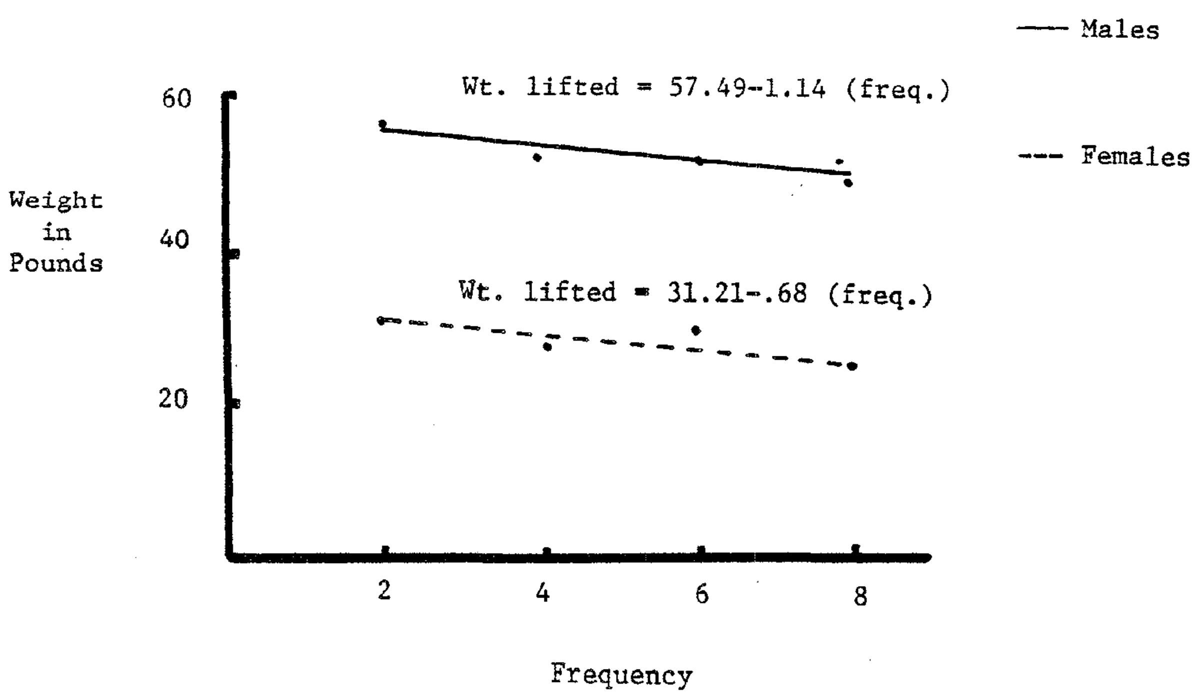

Figure 9 : Height Level 4
(Knuckle to Shoulder)

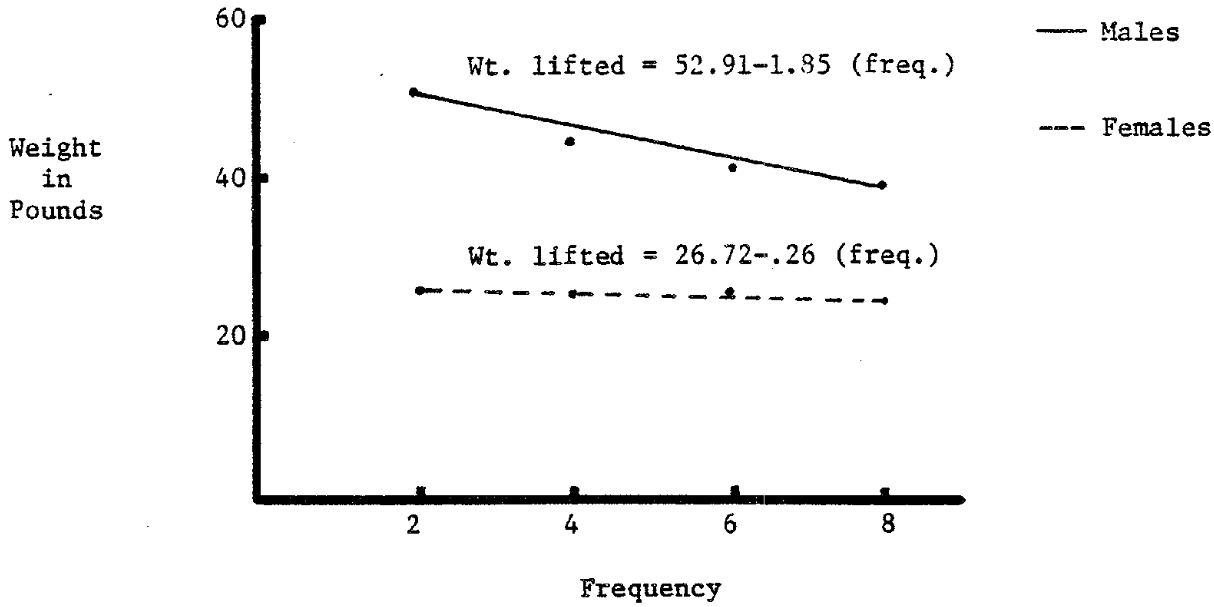

Figure 10: Height Level 5
(Knuckle to reach)

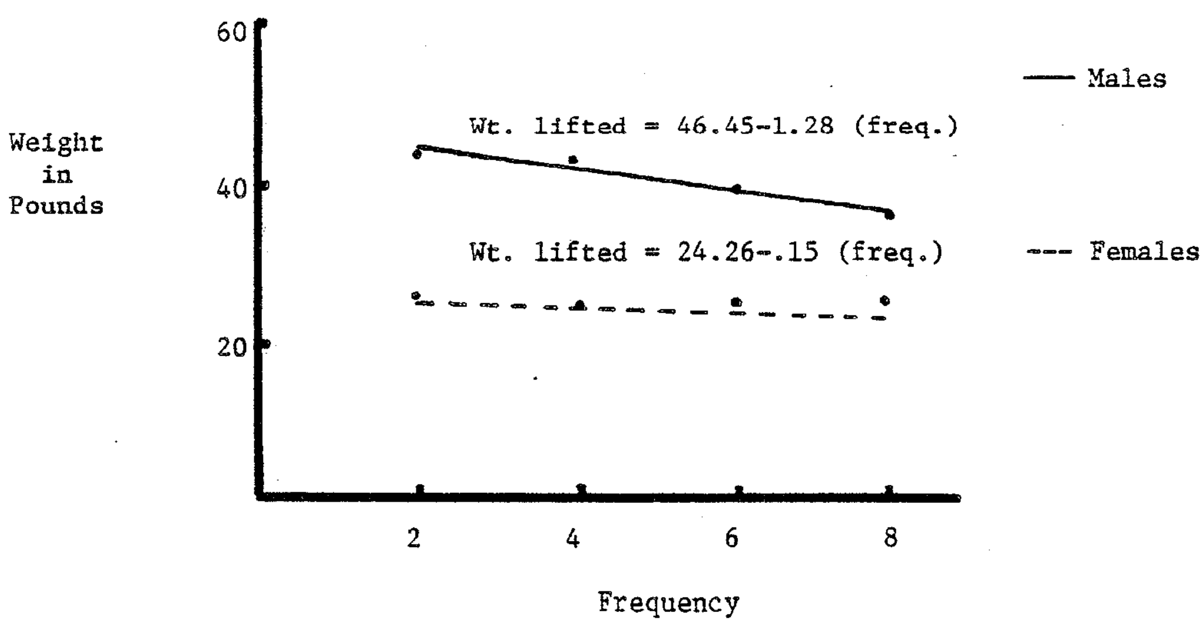

Figure 11: Height Level 6
(Shoulder to Reach)

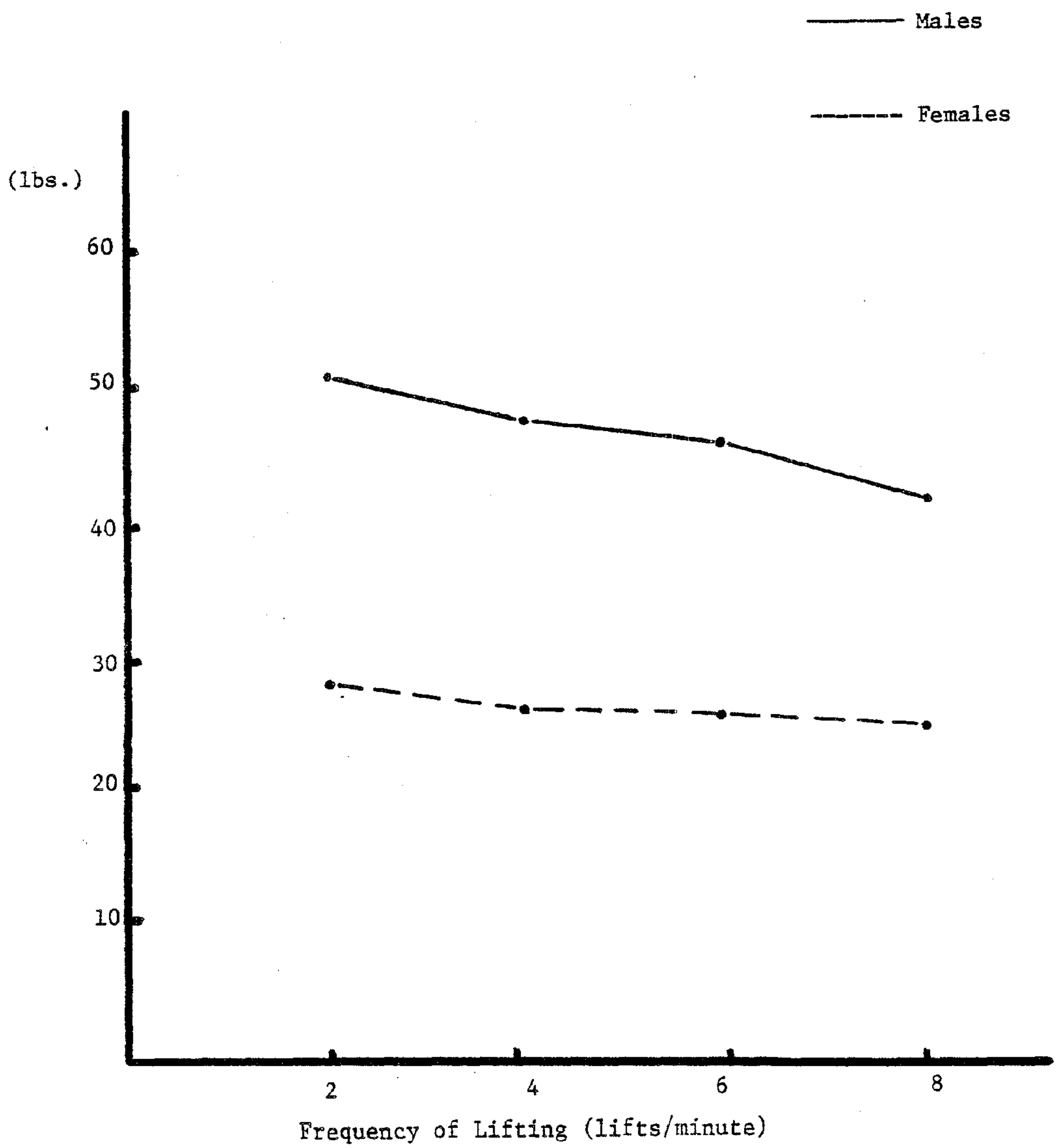

Figure 12: Effect of Frequency on Lifting Capacity

4. Effect of Box Size

The box size in this study refers only to a variation of the box dimension in the sagittal plane. A 12 inch box with a tube projection was used as discussed in the equipment section, to move the center of gravity in the sagittal plane, away from the subject 3 inches or 6 inches, thereby simulating an 18 inch and 24 inch box size. The general box size effect was analyzed ignoring the frequency effect. The means and standard deviations of the maximum acceptable weight of lift for each box size and each height level are presented in Table 7. The main effects are plotted in Figures 12 through 18. Regression equations (Figures 13 through 18) were developed to show the effect of box size on the lifting capacity. It should be noted that for the knuckle to reach and the shoulder to reach height levels, for males, there is an increase in the lifting capacity with the increase in the box size. Causation of this phenomenon is not known at this time.

When the effects of height level and frequency were ignored, no significant differences ($p<.05$) were found in the lifting capacity for box sizes of 12 inches and 18 inches for males. However for the remainder of the box sizes, the differences in the lifting capacity, for both males and females, were significantly different (Figure 19).

5. Combined Box Size and Frequency Effect

The interaction effect of the box size and frequency was analyzed. Table 8 is a presentation of the means and standard deviations of the maximum acceptable weights of lift for each box size-frequency combination for each height level.

The data was fitted with straight lines (manual estimation) without the use of statistical regression analysis methods. The effects, general trends, are plotted in Figures 20 through 25 and in Figures 26 through 31 for females. As the box size and frequency of lift increased, the amount of weight lifted decreased.

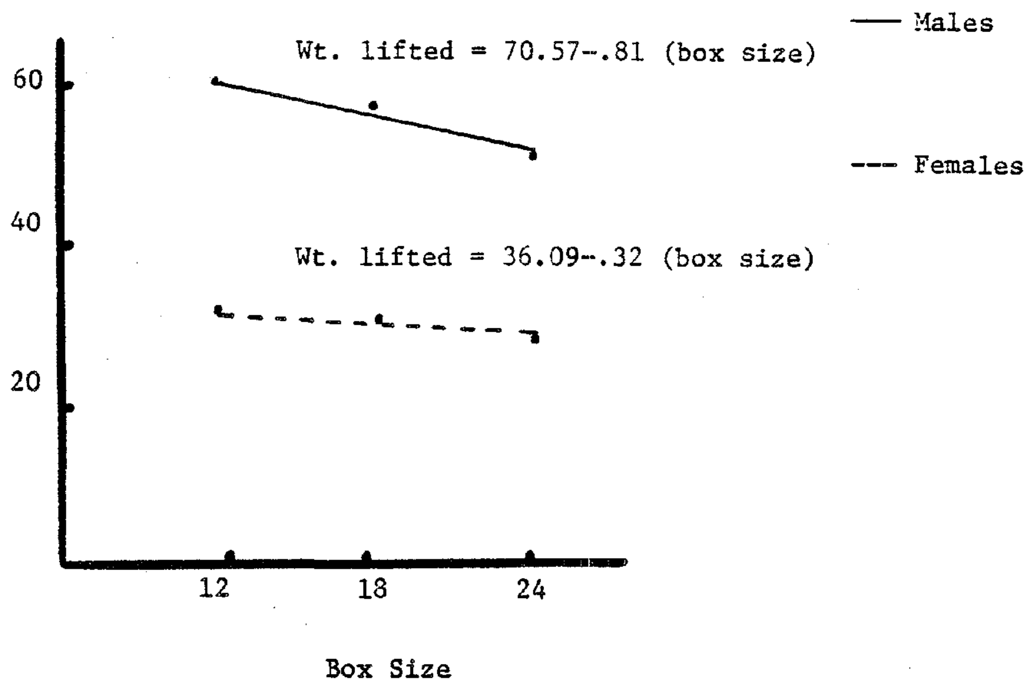

Figure 13 : Height Level 1
(Floor to Knuckle)

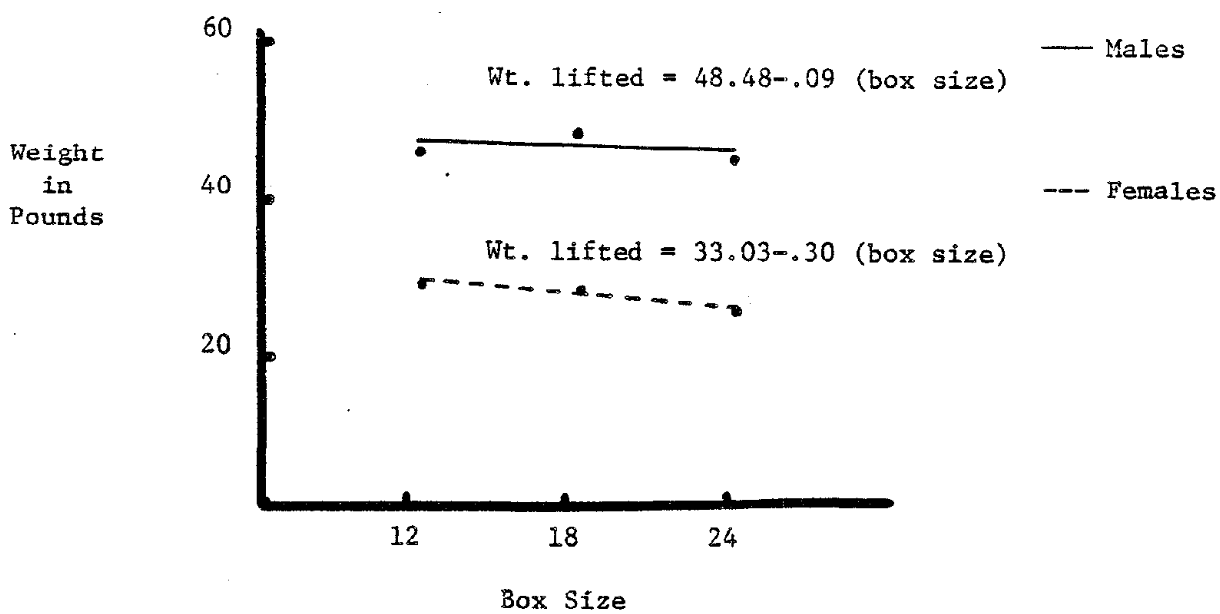

Figure 14 : Height Level 2
(Floor to Shoulder)

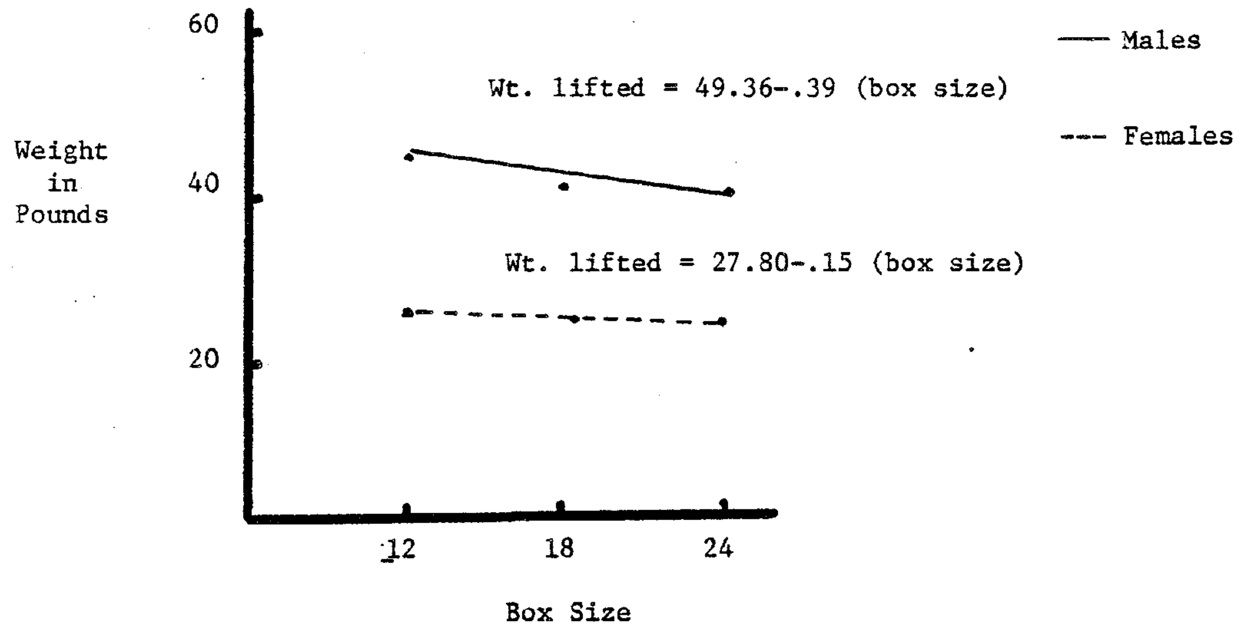

Figure 15: Height Level 3
(Floor to Reach)

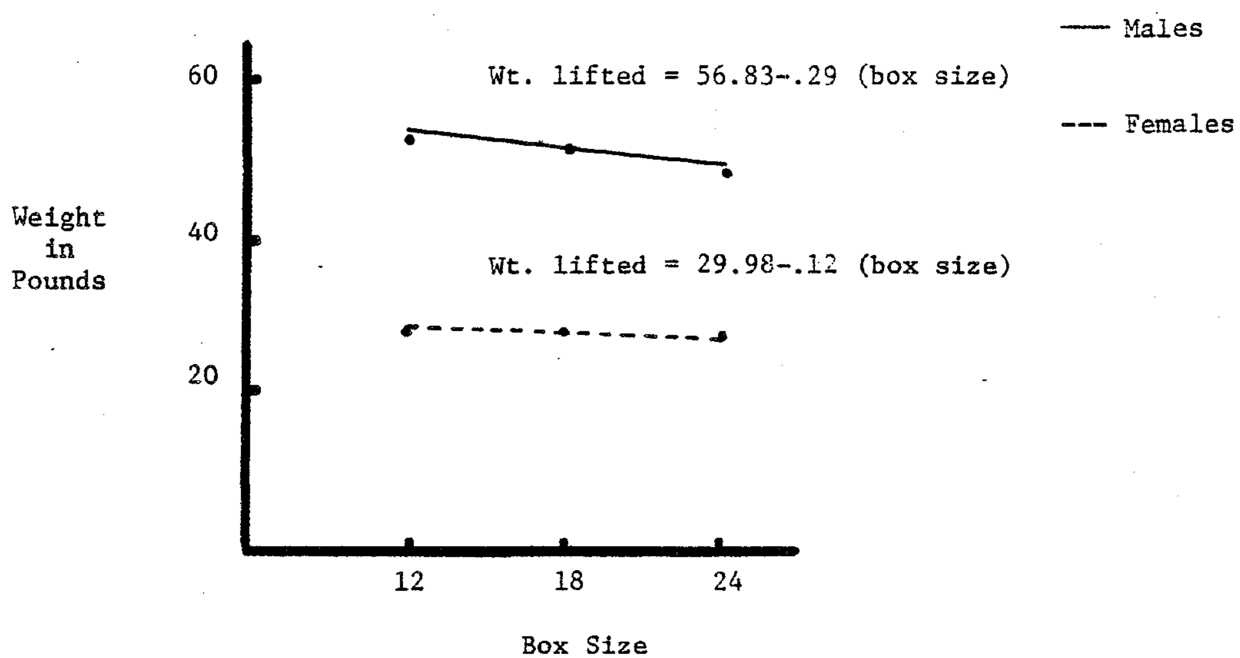

Figure 16: Height Level 4
(Knuckle to Shoulder)

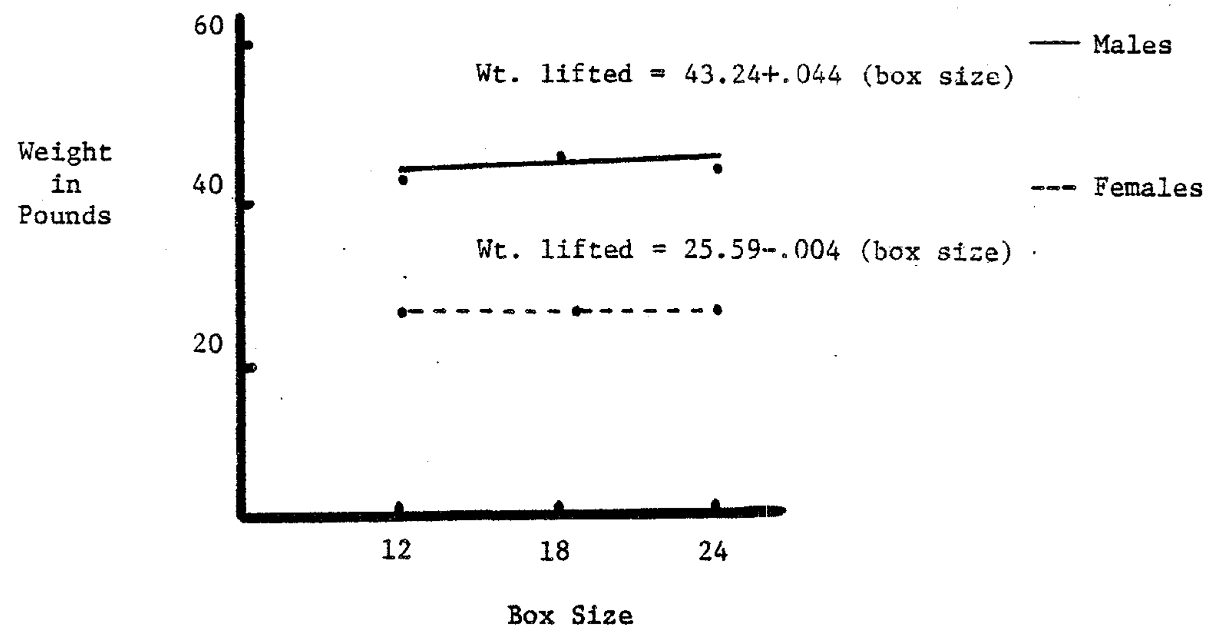

Figure 17: Height Level 5
(Knuckle to Reach)

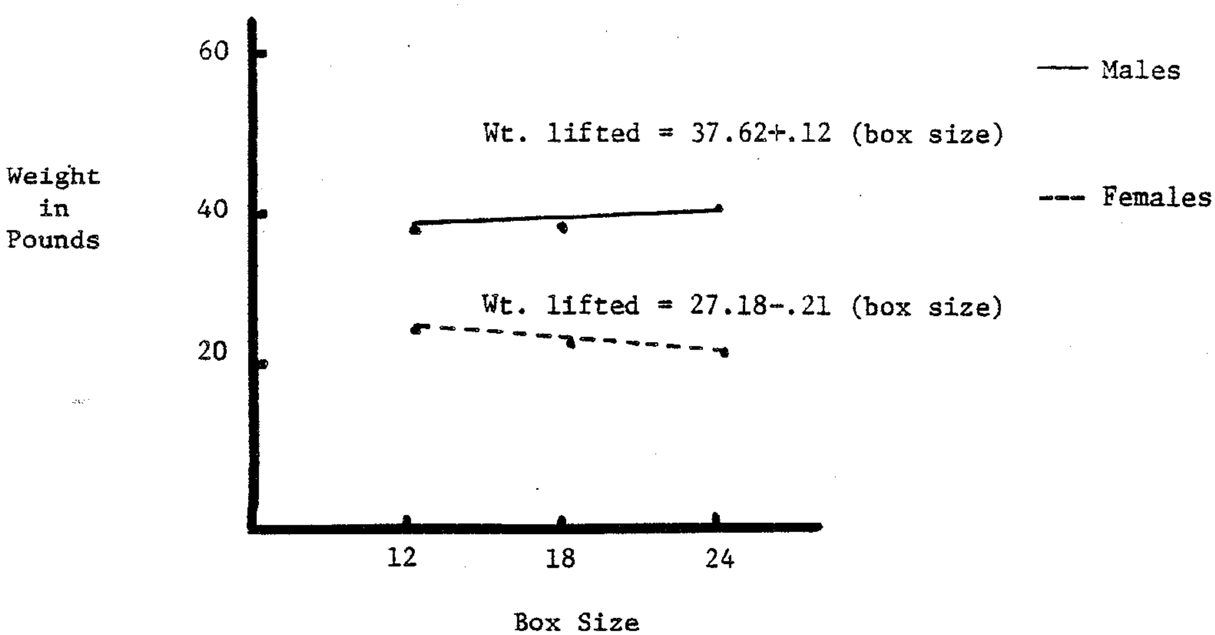

Figure 18: Height Level 6
(Shoulder to Reach)

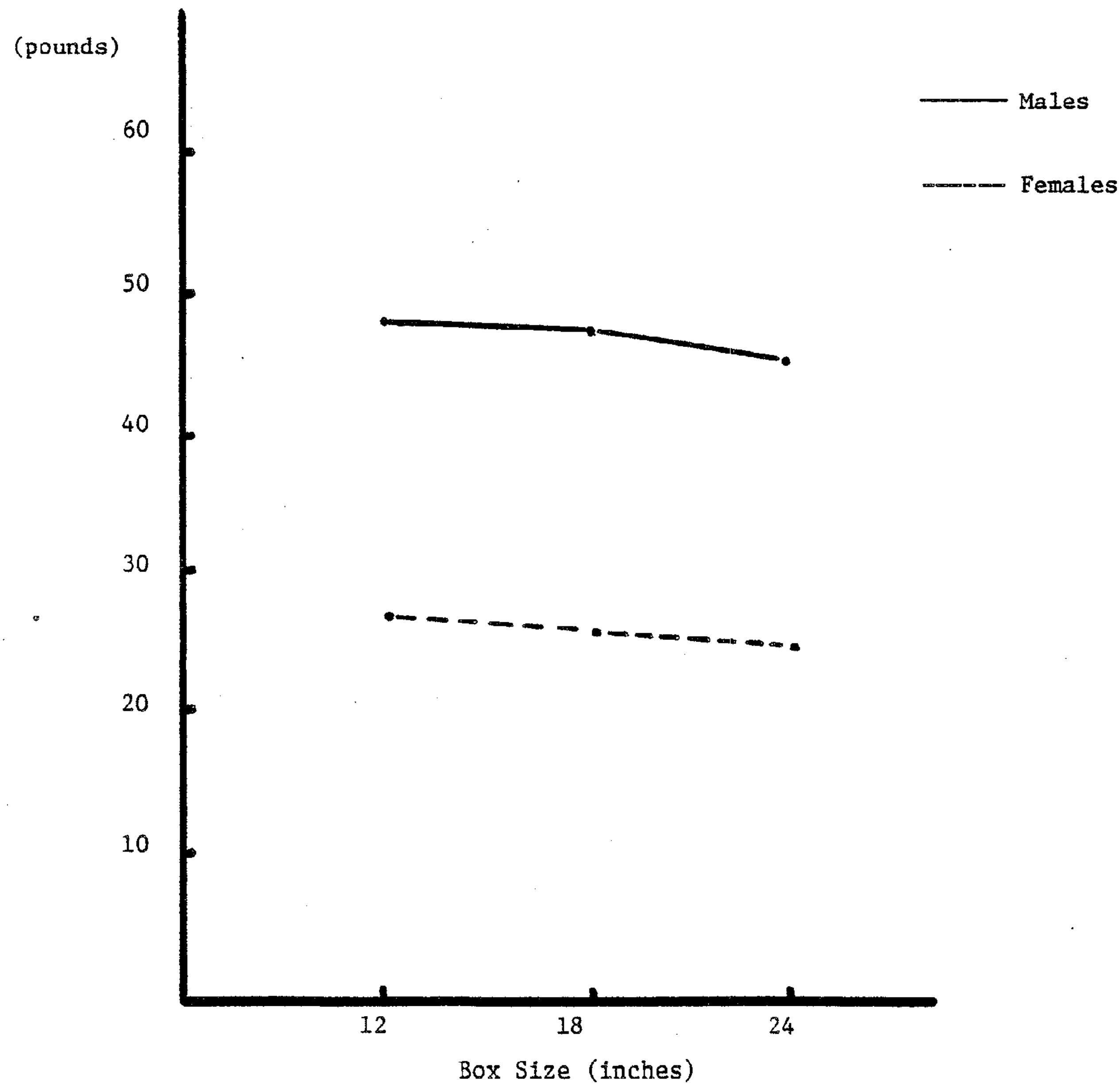

Figure 19: Effects of Box Size on Lifting Capacity

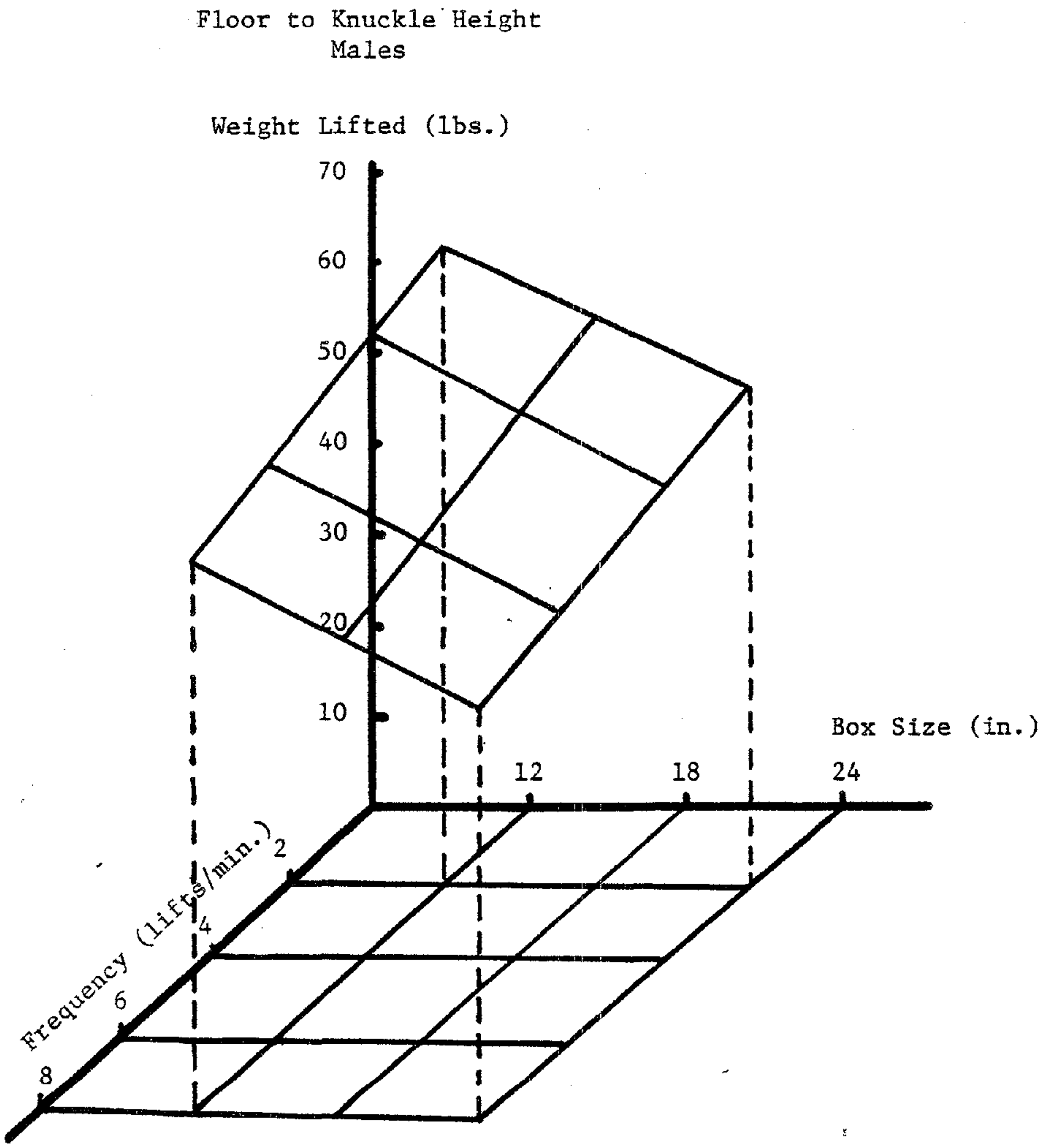

Figure 20: Interaction Effects of Box Size and Frequency

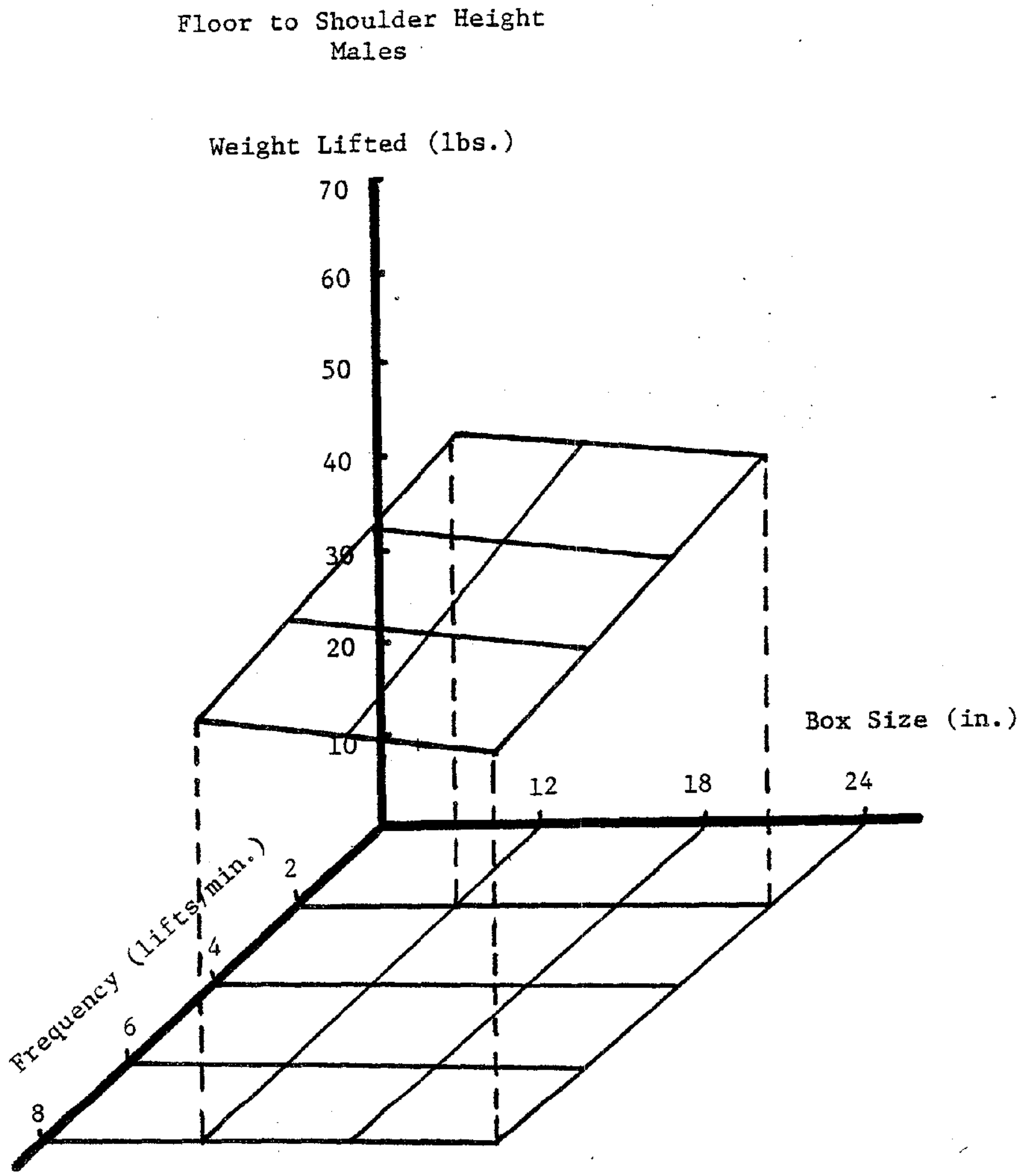

Figure 21: Interaction Effects of Box Size and Frequency

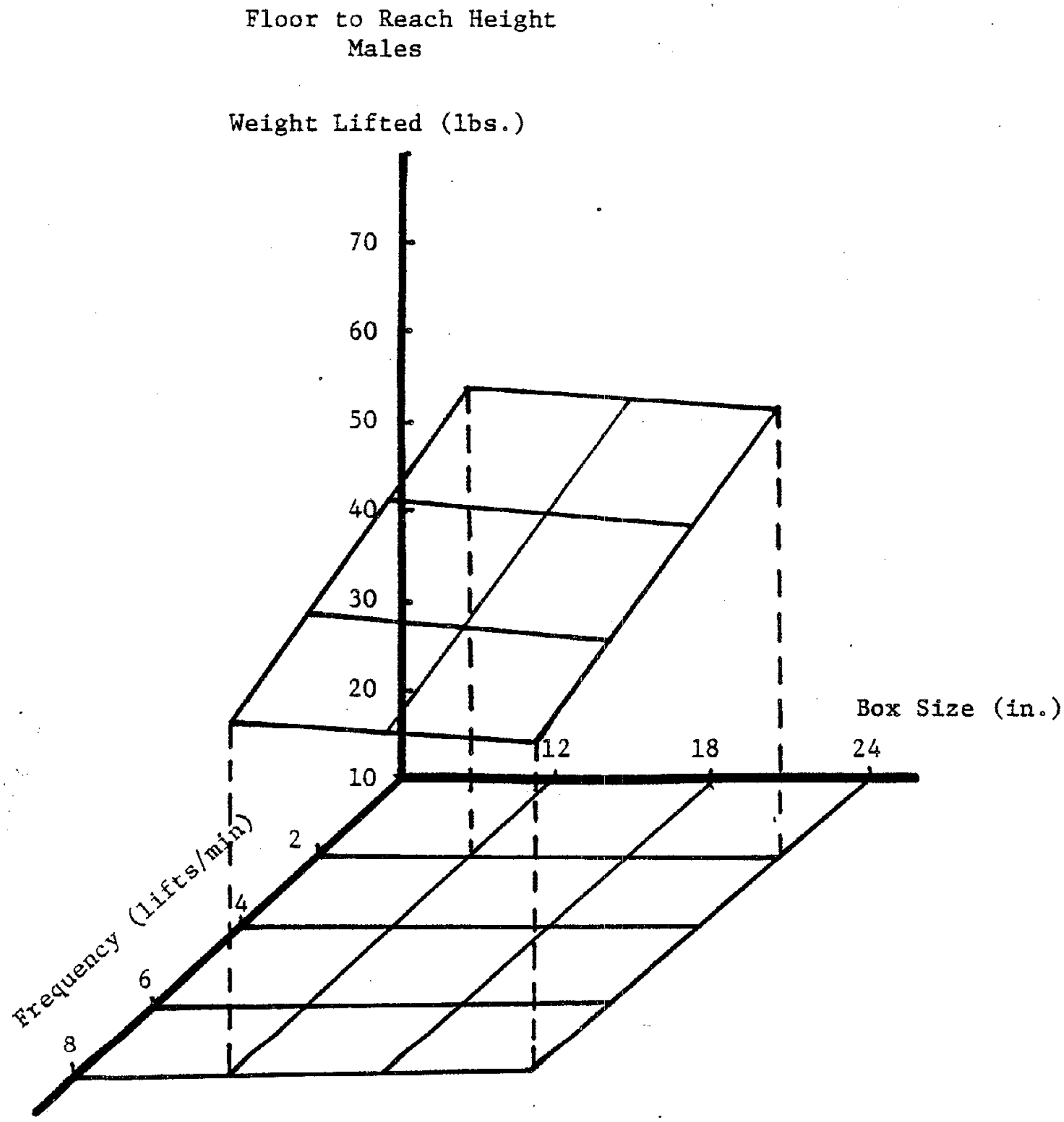

Figure 22: Interaction Effects of Box Size and Frequency

Knuckle to Shoulder Height
Males

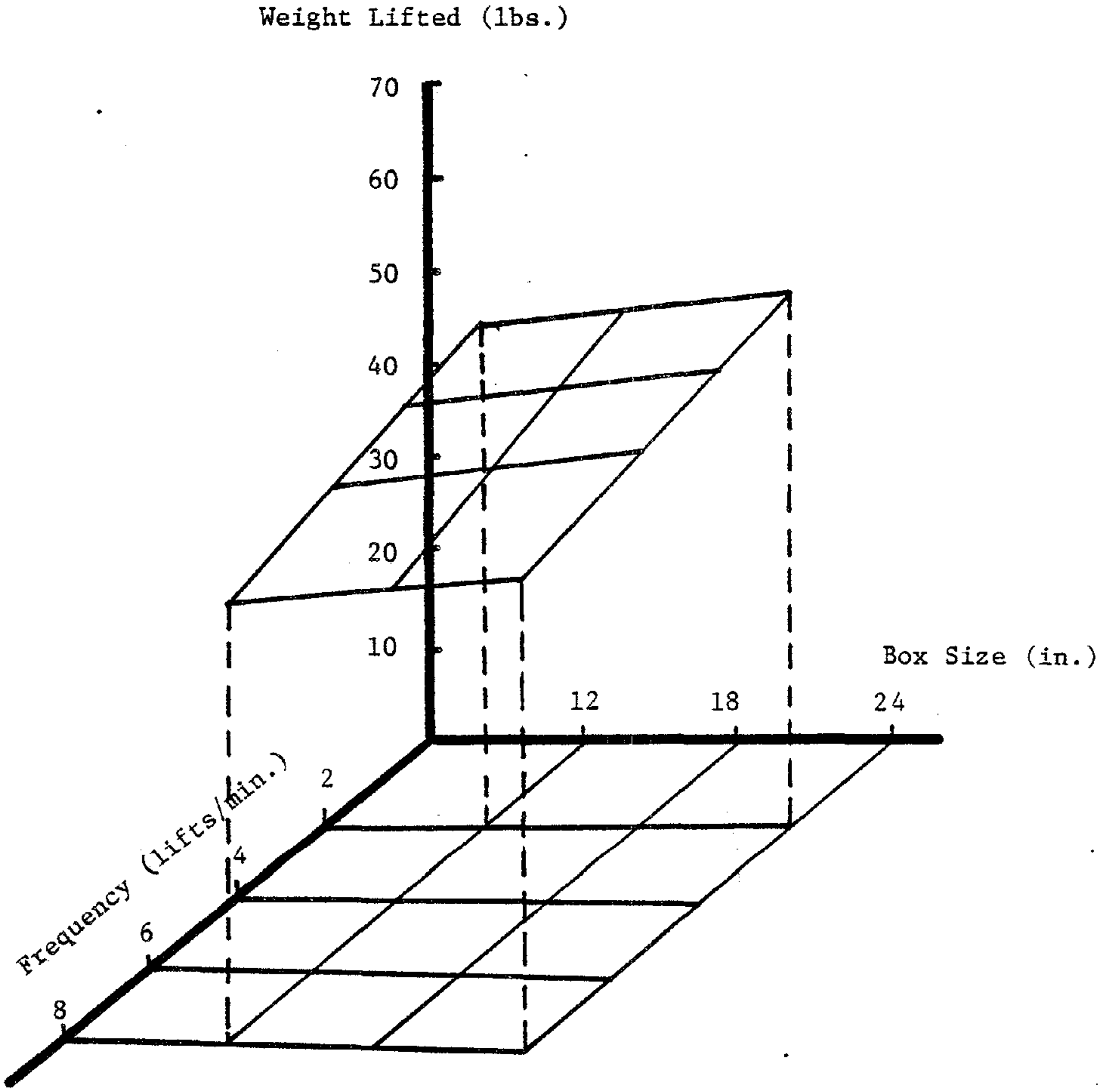

Figure 23: Interaction Effects of Box Size and Frequency

Knuckle to Reach Height
Males

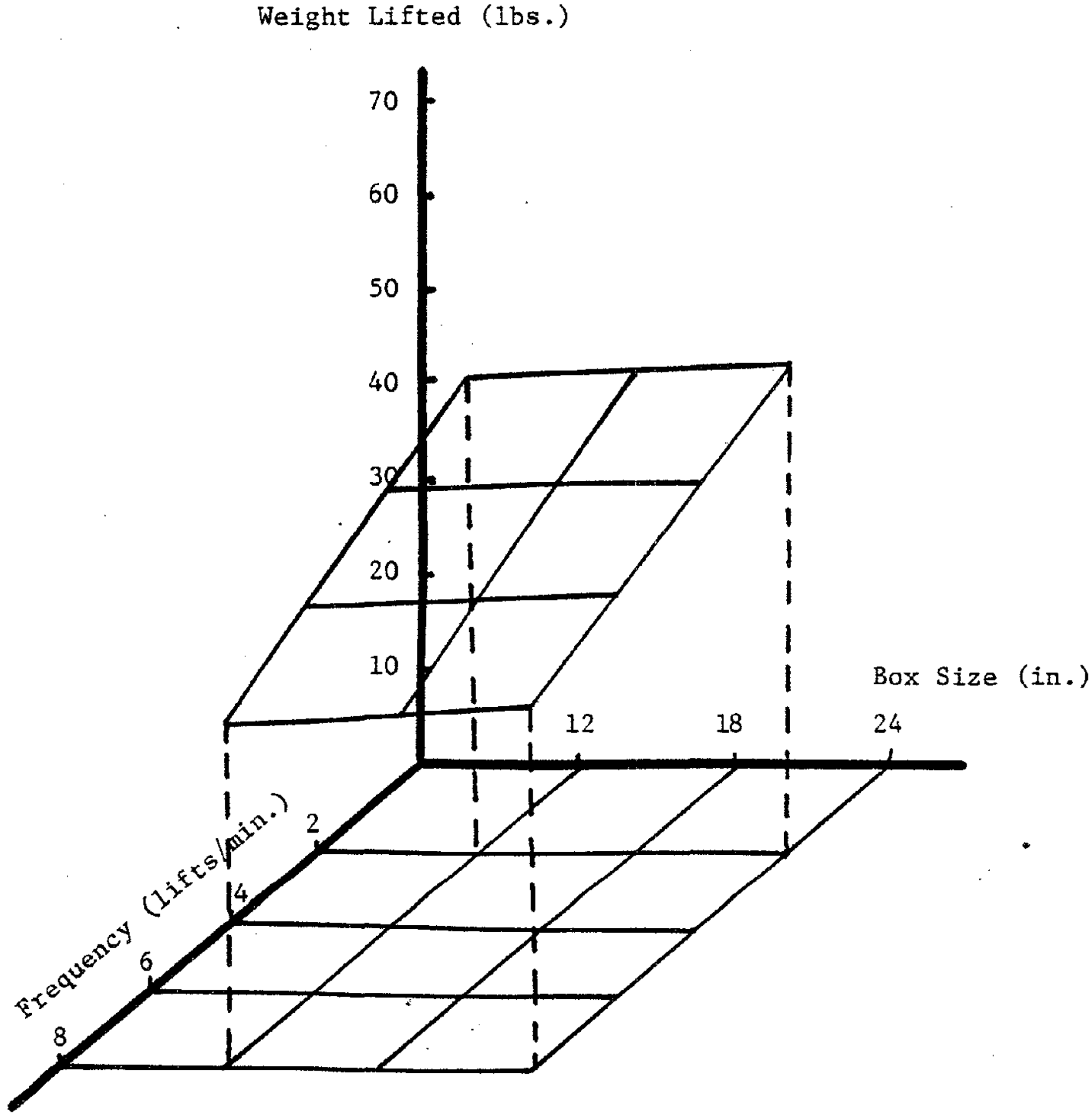

Figure 24: Interaction Effects of Box Size and Frequency

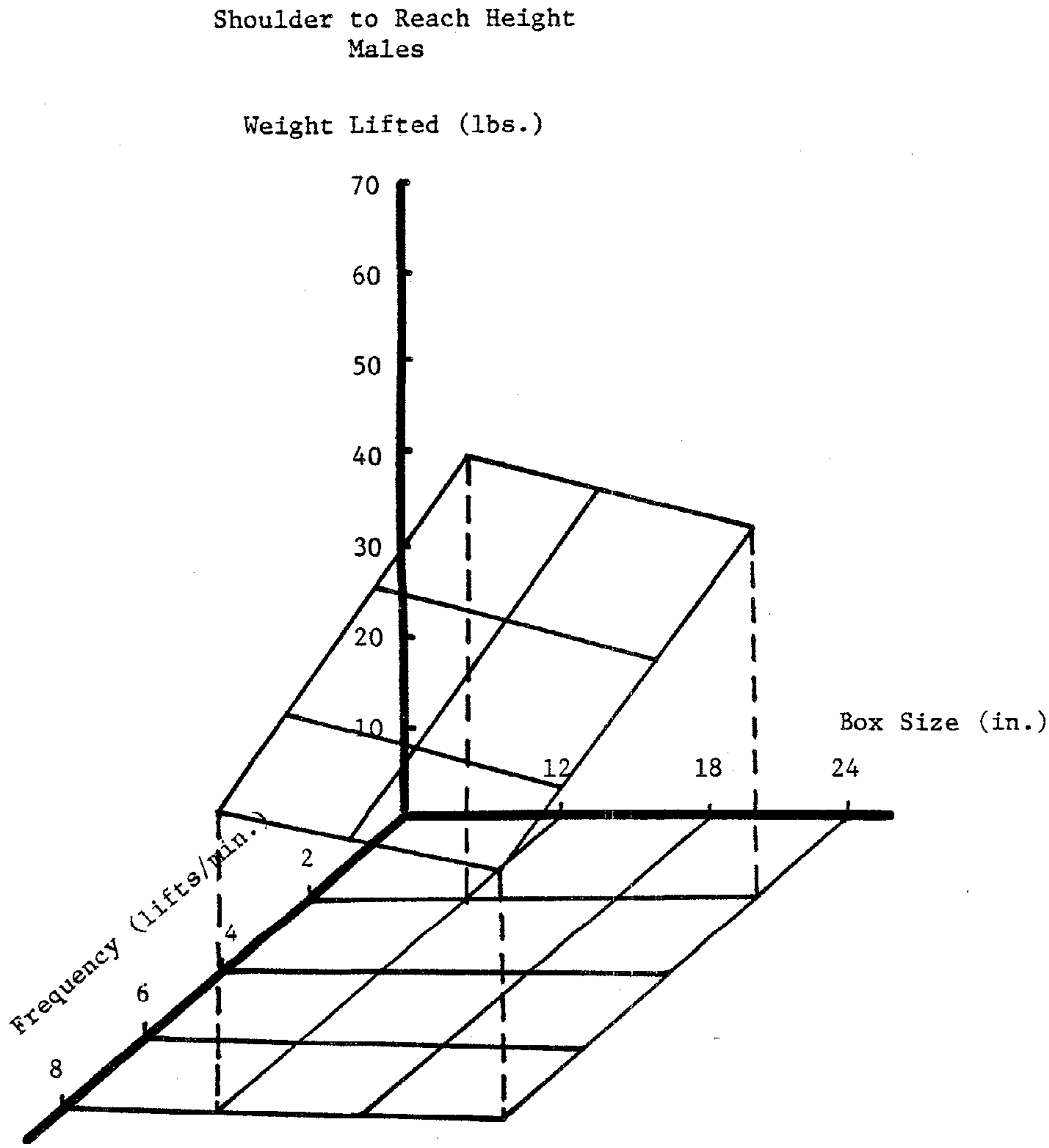

Figure 25: Interaction Effects of Box Size and Frequency

Floor to Shoulder Height
Females

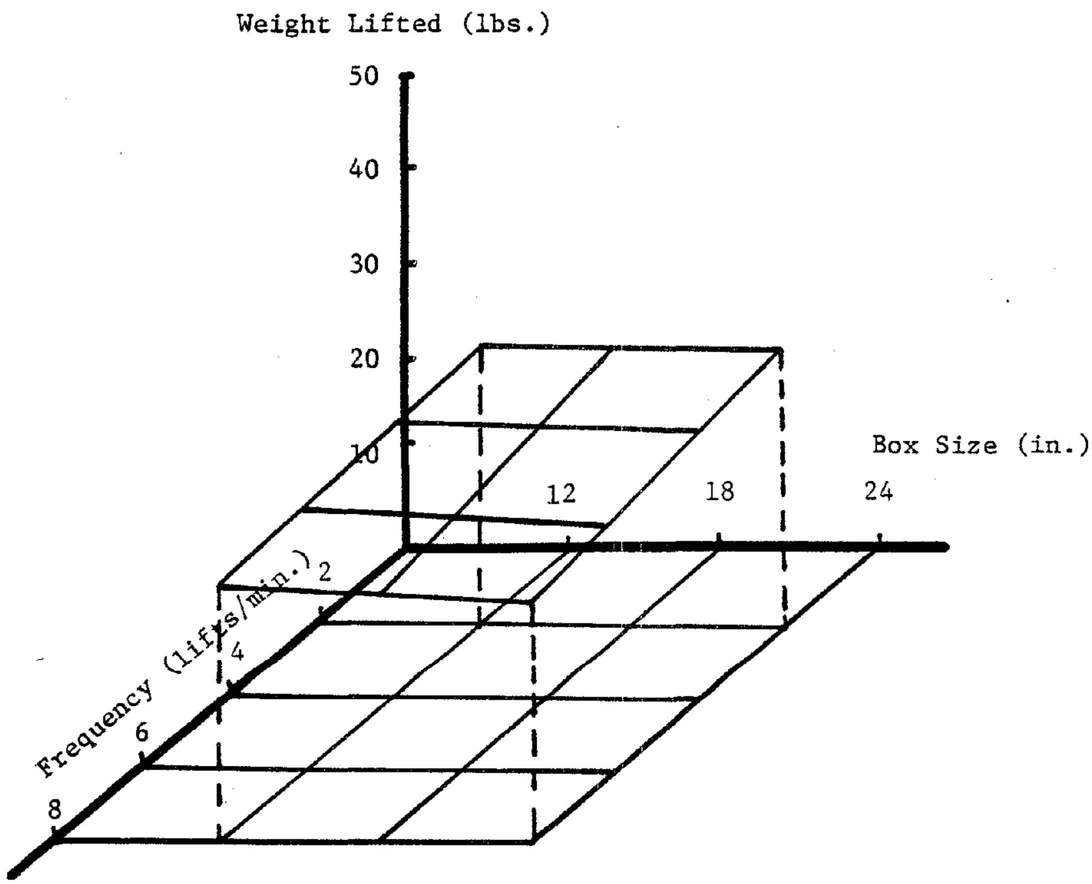

Figure 27 : Interaction Effects of Box Size and Frequency

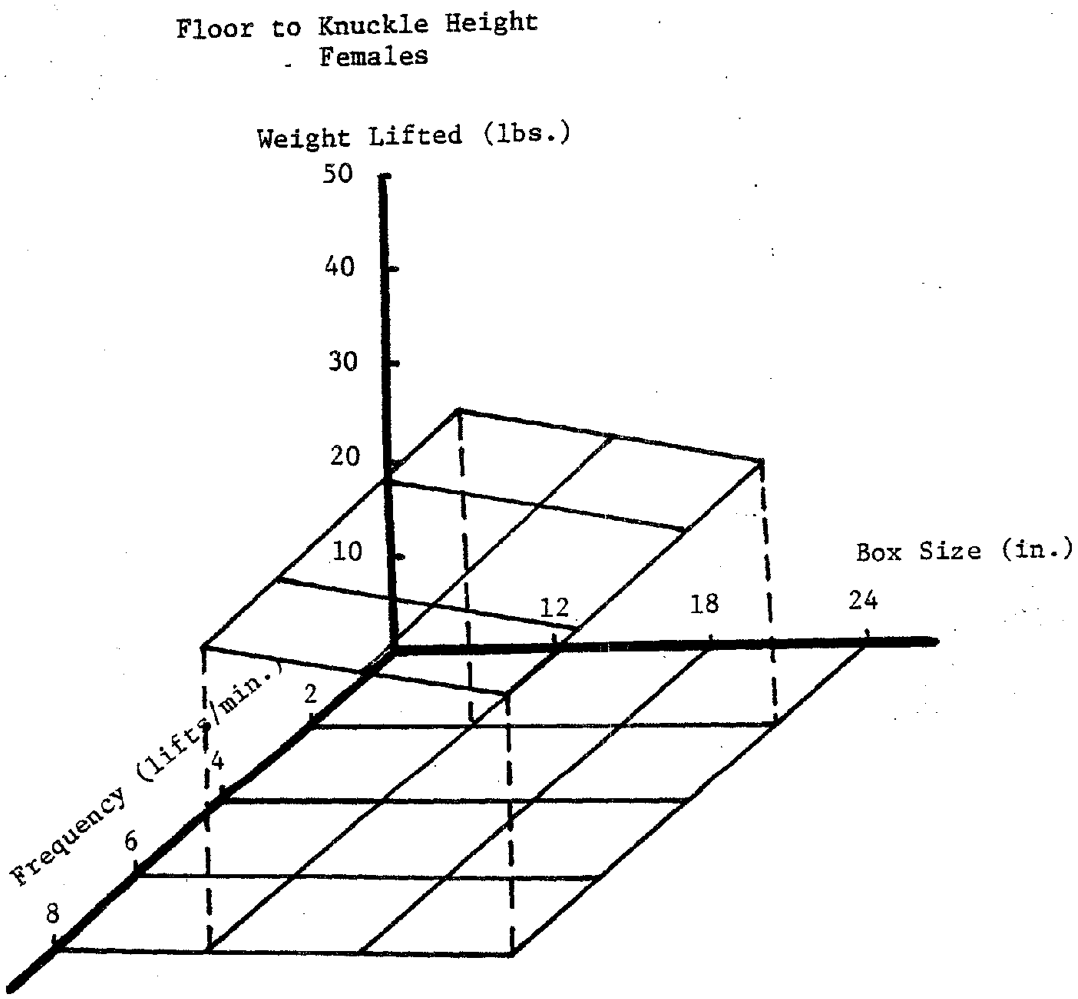

Figure 26 : Interaction Effects of Box Size and Frequency

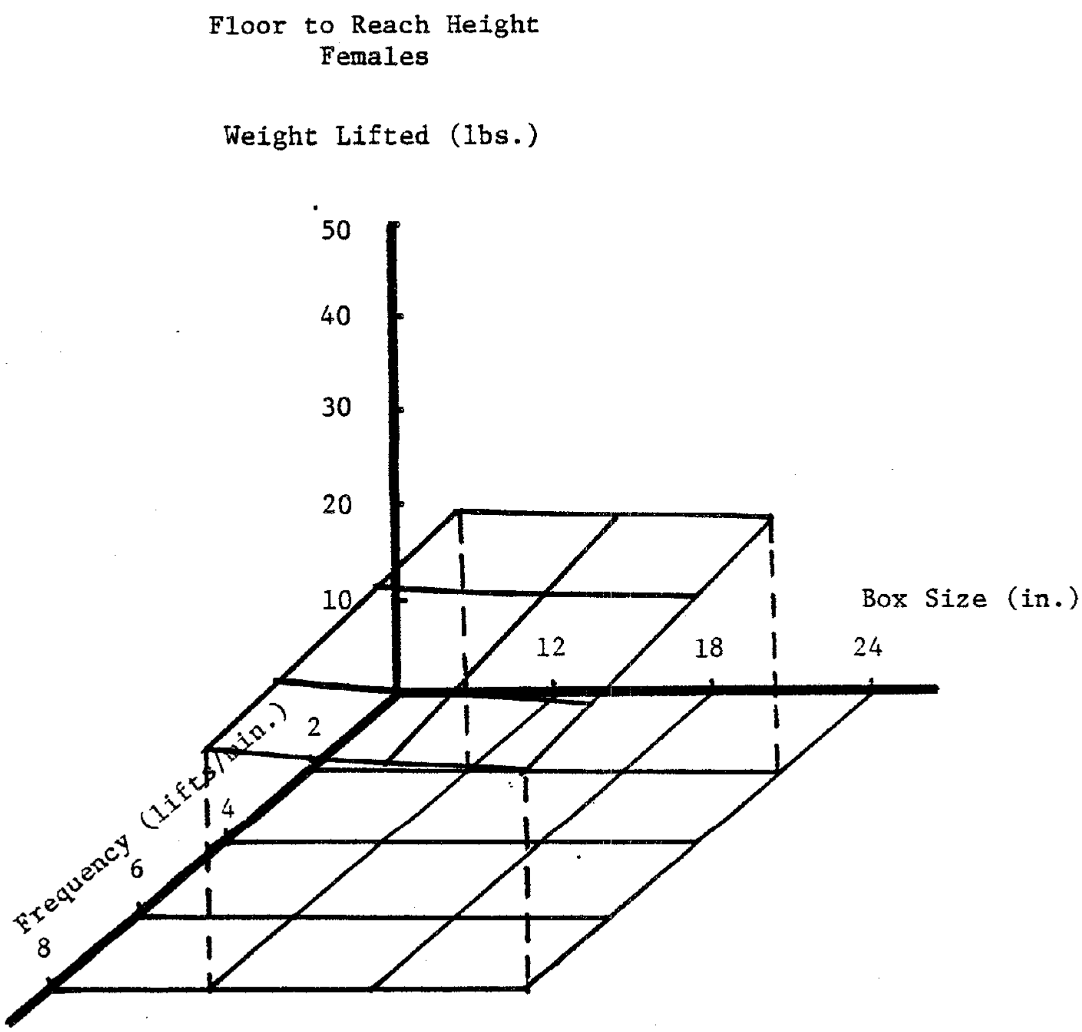

Figure 28 : Interaction Effects of Box Size and Frequency

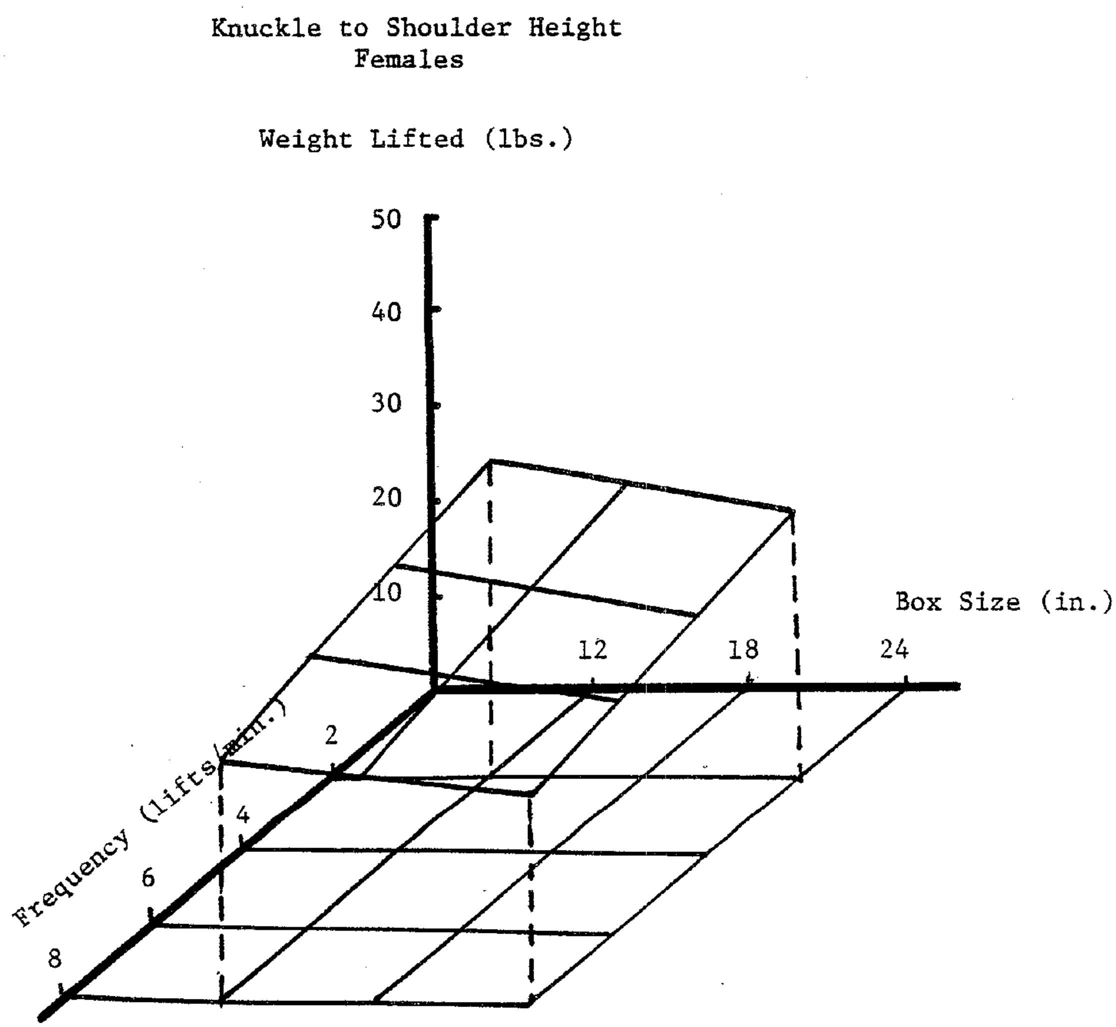

Figure 29: Interaction Effects of Box Size and Frequency

Knuckle to Reach Height
Females

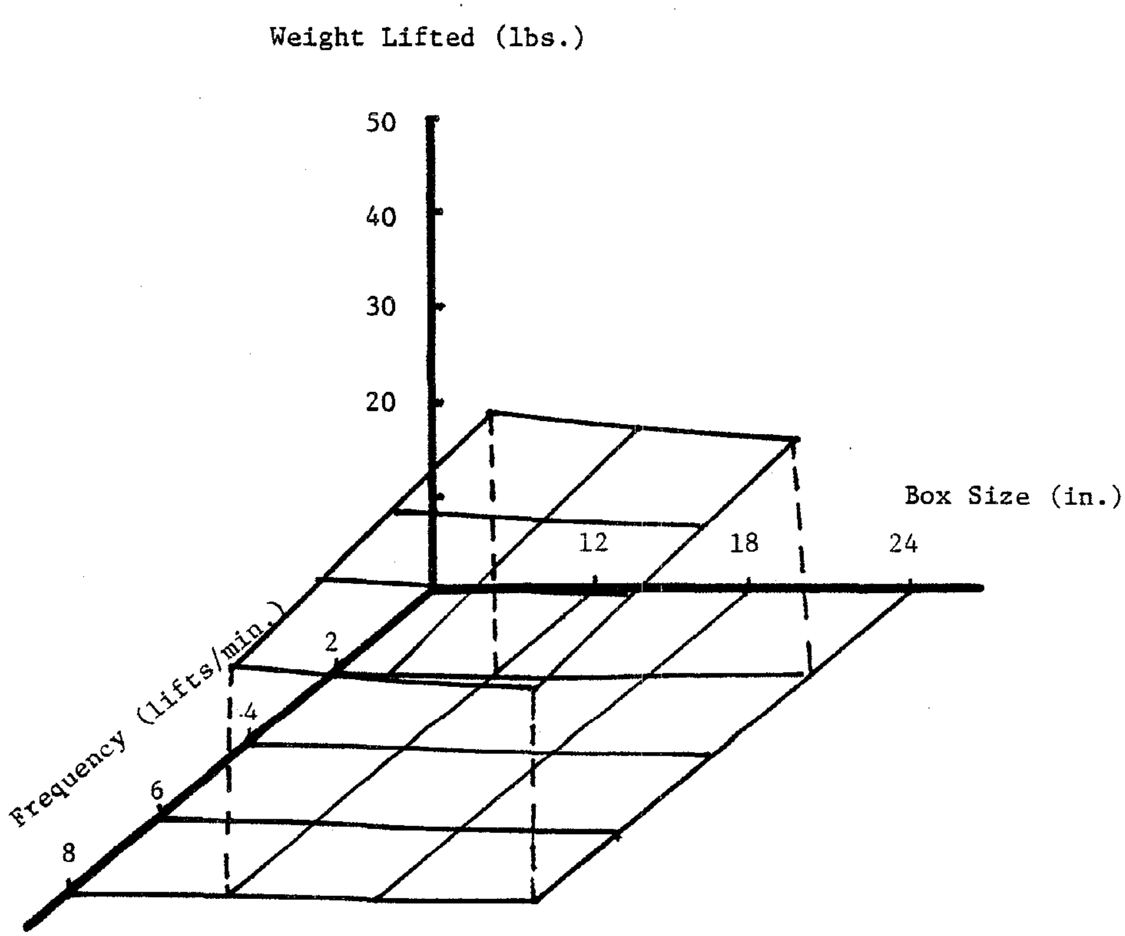

Figure 30: Interaction Effects of Box Size and Frequency

Shoulder to Reach Height
Females

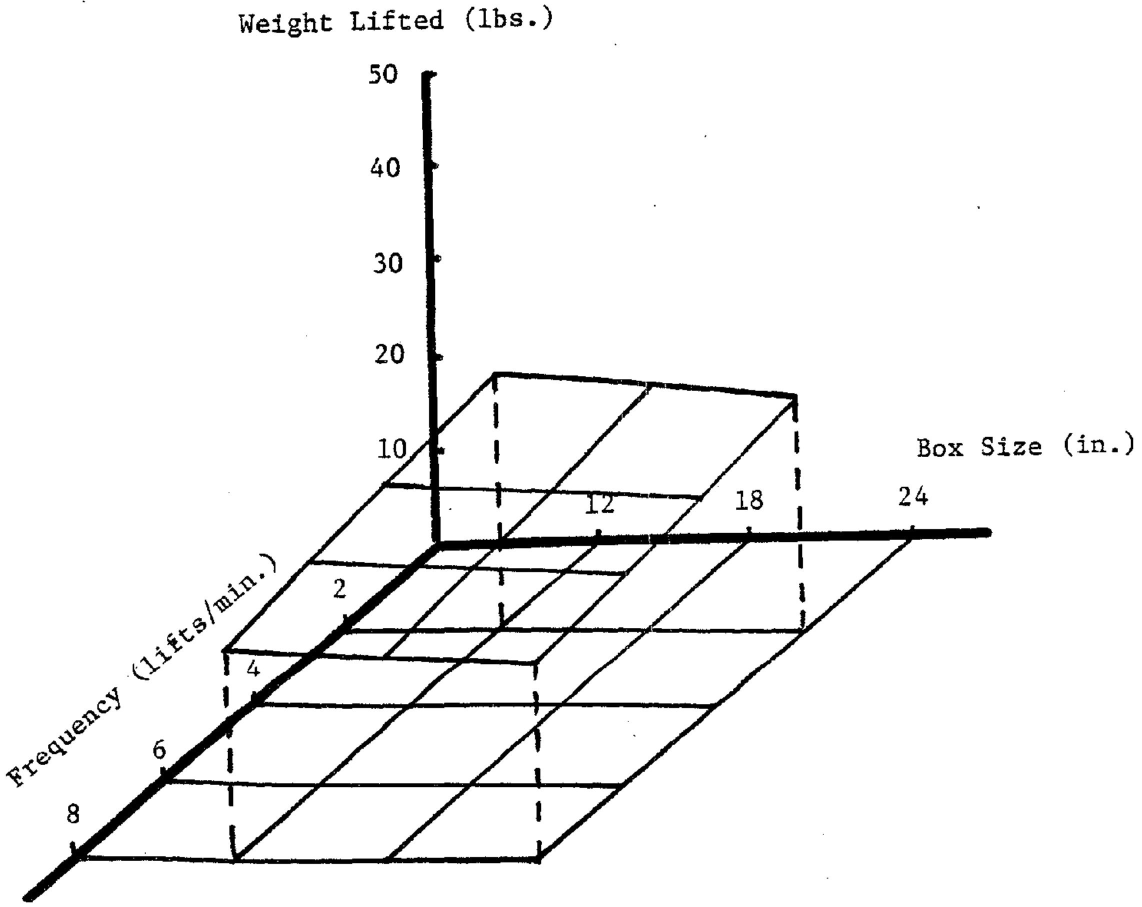

Figure 31 : Interaction Effects of Box Size and Frequency

6. Effect of Age

The subjects in this study were divided into three groups: age 18 to 29 years; 30 to 39 years; and 40 years and above. The means and standard deviations of the maximum acceptable weight of lift for each age group are presented in Table 9. The effect of age did not have any significant effect on lifting capacity for both males and females.

7. Lifting Capacity Prediction Models

In the development of the prediction models several approaches were used before a final set of models were selected. In the development of these models, attempts were made to:

(i) Use various transgenerations composed of the independent variables (logs, exponents, quadratic functions, ... etc.).

(ii) Develop male/female as well as combined male-female models.

(iii) Use the maximum acceptable weight of lift as the sole independent variable or use the maximum acceptable weight of lift plus body weight as the dependent variable.

(iv) Use all the task variables as independent variables in the models.

The final models selected are presented in Table 10. The selection was based primarily on the smallest number of variables in the models since the performance statistics on these models were not significantly different from each other. The statistics for the selected set of models are given in Table 11. The verification of these models were made on one third of the data set not used for model development. Figure 32 shows the model performance.

Models to predict lifting capacity have been developed by several other researchers (McConville and Hertzberg, 1968; Poulsen, 1970; McDaniel, 1972; Dryden, 1973; and Knipfer, 1974). These models have limitations in that they are applicable to only one or two height levels for lifting in the sagittal plane, and are developed in this by collecting data at only one frequency of lift. Many of these limitations have been overcome in the models developed in this study. The models are for six different height levels

TABLE 9 : Mean and Standard Deviation of the Maximum Weights (lbs.) Acceptable to the Three Age Groups of Males and Females

	Age Groups					
	Up to 29 years		30 to 39 years		40 years and above	
Sex	Mean	Std. Deviation	Mean	Std. Deviation	Mean	Std. Deviation
Male	47.29	11.92	46.17	15.35	47.19	14.52
Female	24.79	6.19	27.27	6.21	26.61	5.98

TABLE 10: Prediction Models for Maximum Acceptable Weight of Lift Plus Body Weight (lbs.) Both for Males and Females

Height Level H	Constant Term	Sex Code Coefficient V1	Weight Code Coefficient V3	Arm Strength Coefficient V8	Age Coefficient V15	Shoulder Height Coefficient V18	Back Strength Coefficient V28	Abdominal Depth Coefficient V34	Dynamic Endurance Coefficient V36
1(F-K)	-72.165	-28.334	24.243	0.143	-0.553	1.225	0.056	4.914	1.757
2(F-S)	-145.412	-16.165	11.928	0.185	-0.597	1.438	0.077	6.472	2.608
3(F-R)	-41.267	-19.453	16.176	0.210	-0.842	0.759	0.068	6.220	1.426
4(K-S)	-55.160	-18.452	11.700	0.265	-0.606	0.768	0.105	6.290	1.415
5(K-R)	-79.193	-18.917	17.273	0.297	-0.499	1.092	0.018	5.154	2.120
6(S-R)	-37.439	-19.584	20.352	0.096	-0.592	0.886	0.099	4.731	1.090

TABLE 11: Model Statistics for Prediction Equations Given in Table 10

Height Level H	R^2	Mean Error in W	Std. Deviation of Error for W	Maximum Error in W	Std. Error of Mean for W
1(F-K)	0.868	-1.078	16.910	-36.230	1.940
2(F-S)	0.877	4.600	15.490	39.430	1.950
3(F-R)	0.850	-1.660	17.390	44.990	2.150
4(K-S)	0.861	-4.790	18.460	46.820	2.120
5(K-R)	0.877	-5.600	14.190	-31.090	1.640
6(S-R)	0.863	-2.750	13.820	-29.310	1.570

VW = -72.165 - 28.334 * sex + 24.243 * wt. code + .143 * arm st. -0.553 * age + 1.225 * shoulder ht. + 0.056 * back st. + 4.914 *abdominal depth + 1.757 * dynamic endurance

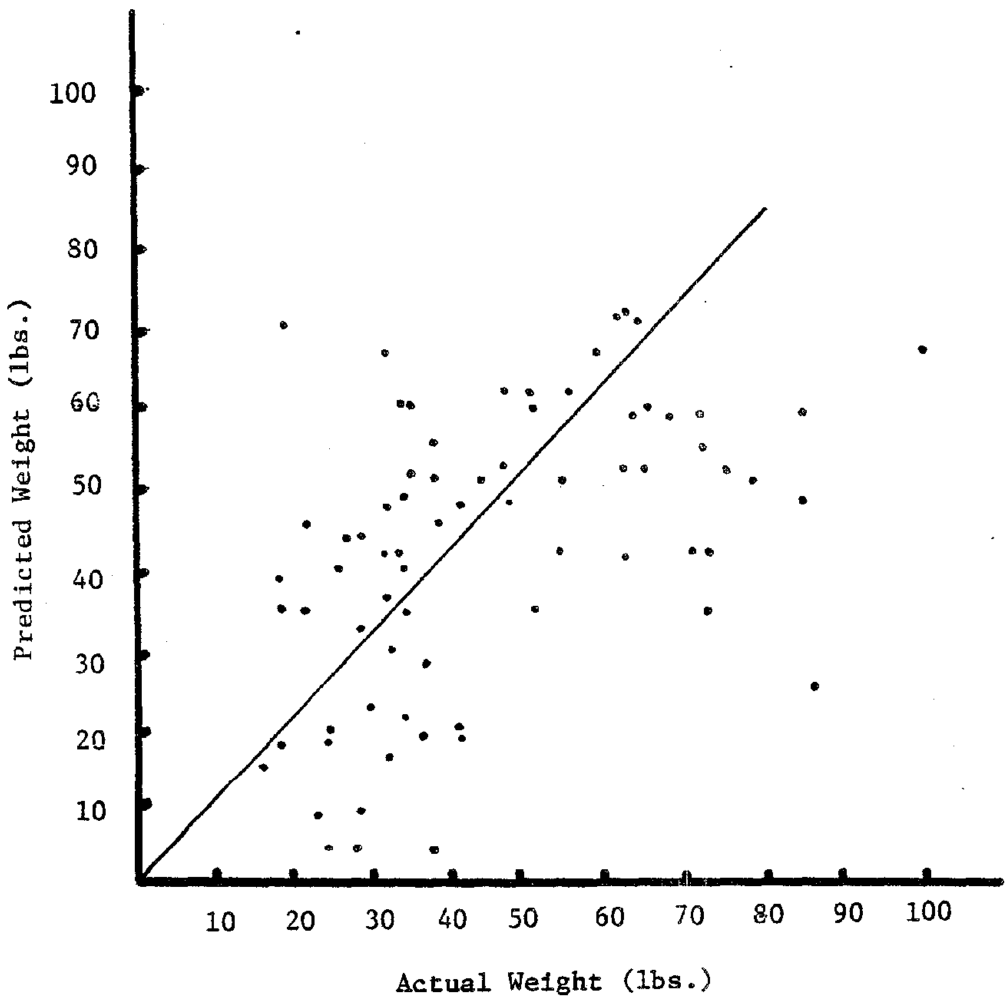

Figure 32: Model Performance for the Floor to Knuckle Height (Males and Females)

and are based on the data collected at different frequency of lift with different box sizes.

In many respects the models given in Table 9 are consistent with other past models. Back strength, arm strength, age, and dynamic endurance are the common independent variables in most of these models. The models in Table 9 are combined models (both for males and females) and predict the lifting capacity better than individual models (high R^2 and low mean error). This inference is different from the one drawn by McDaniel (1972), Dryden (1973), and Knipfer (1974).

8. Model Usage

Usage of the final models is relatively simple. The units and multipliers for the different variables are given as follows:

1. Sex Code: V_1 = 0, for males, and
   1, for females.
2. Weight Code: V_3 = 0, if the body weight is equal to or below the median, and
   = 1, if the body weight is above the median.

   Median Weight = 135 pounds, for females, and
   170 pounds, for males.
3. Arm Strength V8: units are pounds.
4. Age, V15: units are years.
5. Shoulder Height, V18: units are centimeters.
6. Back strength, V28: units are pounds.
7. Abdominal Depth, V34: units are centimeters.
8. Dynamic Endurance, V36: units are minutes.

If the above variables are measured in the units indicated and those values are utilized in the models (See Table 10), the maximum acceptable weight of lift plus body weight, in pounds, can be calculated. By subtracting the individual's body weight from the calculated value, the maximum acceptable weight of lift for that individual can be determined.

B. Field Study Results

Data associated with the determination of the effects of the JSI (ratio between the lifting demands of the job and the individual's lifting capacity) on occupational injuries are presented in this section. Specifically, the results include subject data collected, injury data, the analysis of the injury data, job design, and employee placement procedures.

The field study was achieved by (1) collecting history injury information to determine the relationship between job demands and potential injury (Historical Injury Data) and (2) collecting on the job injury frequency and severity to determine the relationship between the ratio of job demands to capacity and potential injury (Current injury data). The relationship between frequency and severity of injury and some acceptable measure of relative job stress was defined for this purpose. This relationship was used as the basis for developing job design and employee placement procedures.

The measure of job severity was the Job Stress Index (JSI) and in its simplest form is the ratio of weight of lift required by the job and the lifting capacity of the individual performing the lift under the considerations of the job.

The establishment of the relationships between the JSI and the frequency and severity of injuries required the collection of the following data:

1. The lifting requirements of the job in which the person was working,

2. The maximum acceptable weight of lift for the particular individual, and

3. An injury profile describing that person's on-the-job injury experience.

Those jobs, from a number of organizations in the Dallas-Ft. Worth area, which required a significant amount of repetitive lifting, were selected. Each job was described in terms of actual weight of lift, frequency of lift, box size, and range of lift.

The lack of constant parameters exhibited by many of the jobs required that the job description procedure be designed to accommodate a certain amount of variability. This was accomplished by dividing each job into a number of component tasks. Tasks were selected so that each could be described with constant or near constant parameters.

Prior to actual task description, each task was assigned to a task group consisting of other tasks which were performed during the same time period. For instance, if a certain job required the performance of four unique tasks, two of which were performed in the morning and two of which were performed in the afternoon, the two morning tasks were grouped together and the two afternoon tasks were grouped together.

i. Injury Data Collection

The injury-data collection was divided into two parts: (a) the first part was to determine an injury history profile for each job. A total of 54 jobs were studied. (b) The second part, information was gathered pertaining to any injury that may have been sustained by a subject during the 9 month period after the various strength and anthropometric measurements on the subject were made. A total of 63 jobs (220 male and 24 female workers) were studied.

a. Historical Injury Data and Analysis

Injury history information was collected for a total of 54 jobs. Several of the reported injury histories were actually combined histories pertaining to two or more jobs within a single company. Combining the injury histories was done when the jobs had similar lifting requirements and when injury records were insufficient to discriminate between an injury pertaining to one job from an injury pertaining to another.

Each injury, regardless of cause, was classified as one of the five injury types described below.

Type I - Musculoskeletal injuries (strains, sprains, broken bones, etc.) involving the lower back.

Type II - Musculoskeletal injuries to parts of the body other than the lower back.

Type III - Surface tissue injury due to impact (cuts, bruises, etc.).

Type IV - Surface tissue injury due to causes other than impact (chemical and thermal burns).

Type V - Injuries not classified as one of the above four types.

Combining of the injury histories reduced the total number of jobs to 41 involving 250 persons. The historical injury information was collected for a 3 year time period beginning immediately prior to the day of subject data collection. From the historical injury data it was shown that 271 lifting injuries accounted for 1034 days lost. Of these 271 injuries there were 93 back injuries that resulted in 842 days lost. Eighty five of these back injuries were caused by lifting which accounted for 681 of the days lost. Table 12 is a summary presentation of the historical injury data. Figures 33 and 34 are scatter diagrams of the back injuries vs. work days lost for the different amounts of weight lifted on the job. Figures 35 and 36 are scatter diagrams of work rate vs. the number of back injuries and work days lost.

The total number of injury exposure hours (man hours worked), for the study jobs, during this 3 year period was 1.4819 million hours. Based on these historical data, models were developed to predict the number of back injuries and the work days lost. The dependent and independent variables used in developing the prediction equations were:

Variables	Description	Variable Number
Dependent	Number of lifting injuries per 1000 man hours worked.	1
	Number of work days lost due to lifting injuries per 1000 man-hours work.	2
	Number of strains-sprains per 1000 man-hours worked.	3
	Number of work days lost due to strains-sprains per 1000 man-hours worked.	4
Independent	Maximum weight lifted on job (pounds).	5
	Overall frequency of lift (lifts per minute)	6
	Work rate (weight*frequency*range-in pounds per minute).	7

TABLE 12: Summary of Historical Injury Data Based on 41 Jobs Utilizing 250 Male Workers

Job #	Max.[M] Weight Lifted on the Job (lbs.)	Work Rate* (in.-lbs./min.)	# Back Injuries Per 1000 Man-hrs.	# Work Days Lost Per 1000 Man-hrs.
1	60.00	8133	0.00	0.00
2	60.00	8625	0.20	0.00
3	60.00	9000	0.00	0.00
4	60.00	3240	0.02	0.10
5	26.00	8562	0.18	0.16
6	26.50	438	0.00	0.00
7	18.00	630	0.03	0.00
8	32.00	2640	0.06	0.00
9	22.00	126	0.00	0.00
10	80.00	9600	0.15	1.48
11	60.00	3779	0.00	0.00
12	70.00	1434	0.10	0.00
13	90.00	948	0.06	0.41
14	45.00	819	0.00	0.00
15	45.00	1375	0.00	0.00
16	45.00	5095	0.00	0.00
17	50.00	204	0.00	0.00
18	75.00	603	0.12	0.60
19	50.00	73	0.00	0.00
20	75.00	519	0.05	1.06
21	85.00	126	0.03	0.25
22	83.00	2386	0.00	0.00
23	85,99	840	0.00	0.00
24	90.00	1215	0.38	0.12
25	42.00	35	0.13	0.00
26	40.00	54	0.00	0.00

TABLE 12: Summary of Historical Injury Data Based on 41 Jobs Utilizing 250 Male Workers (Continued)

Job #	Max.^{M} Weight Lifted on the Job (lbs.)	Work Rate* (in.-lbs./ min.)	# Back Injuries Per 1000 Man-hrs.	# Work Days Lost Per 1000 Man-hrs.
27	60.00	26	0.00	0.00
28	40.00	33	0.00	0.00
29	100.00	41	0.00	0.00
30	25.00	1240	0.00	0.00
31	70.00	605	0.00	0.00
32	100.00	4788	0.25	1.25
33	50.00	4000	0.00	0.00
34	14.50	464	0.00	0.00
35	14.50	464	0.13	0.00
36	100.00	17460	0.29	1.80
37	56.00	2963	0.02	1.45
38	25.00	488	0.02	0.09
39	15.00	272	0.00	0.00
40	15.00	88	0.01	0.07
41	100.00	1337	0.02	0.11

$$\text{*Work Rate} = \sum_{\text{All tasks}} \text{Task Max. Wt.*Task Frequency*Task Max. Range**}$$

**Task Max. Range = Greatest Lifting Distance (in.) Required by a Task.

Historical Injury Data

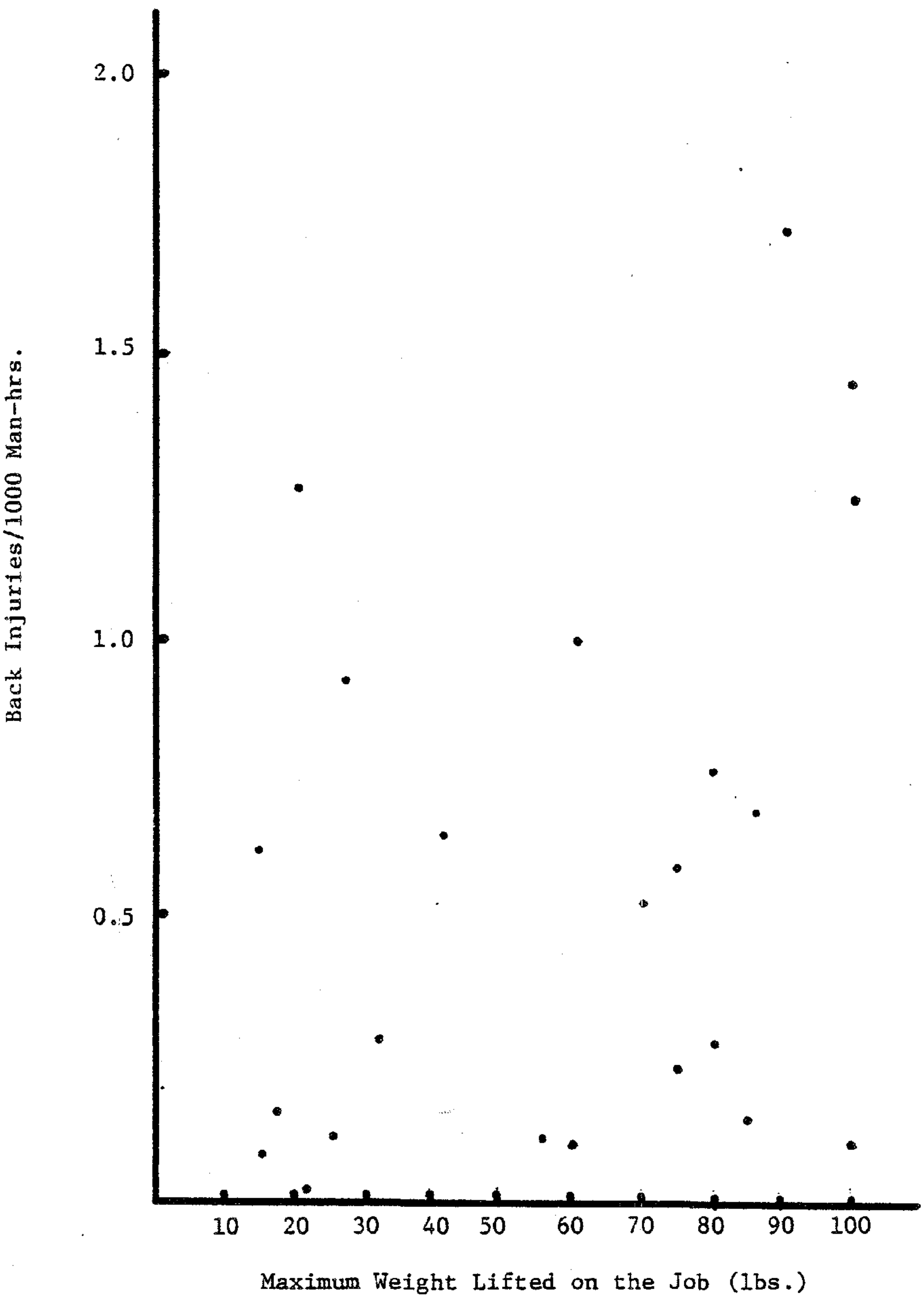

Figure 33 : Scatter Diagram of the Number of Back Injuries Per 1000 Man-hrs. and the Maximum Weight Handled on the Job

Historical Injury Data

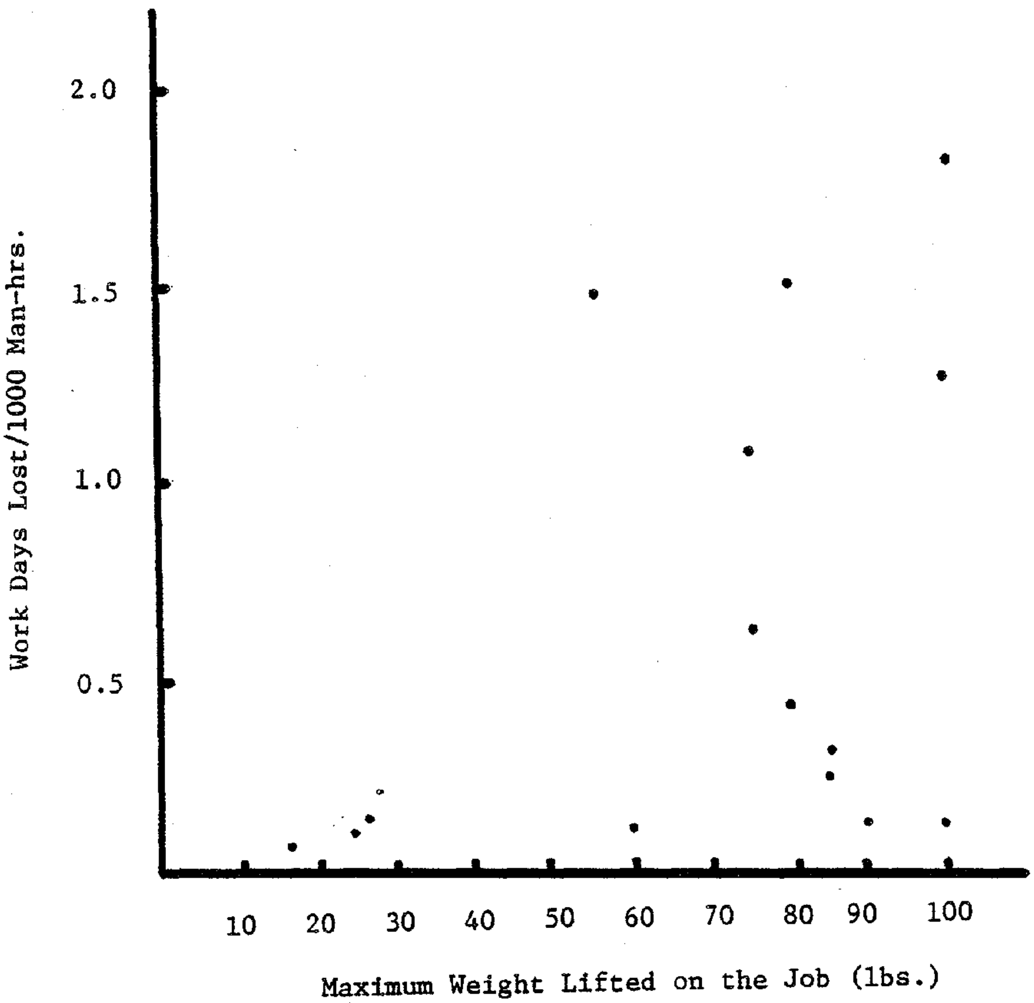

Figure 34: Scatter Diagram of the Number of Work Days Lost Due to Back Injuries and the Maximum Weight Handled on the Job

Historical Injury Data

No. of Lifting Back Injuries/1000 Man-hrs. = 0.02455 + 0.00014 * (work rate)

R = 0.488

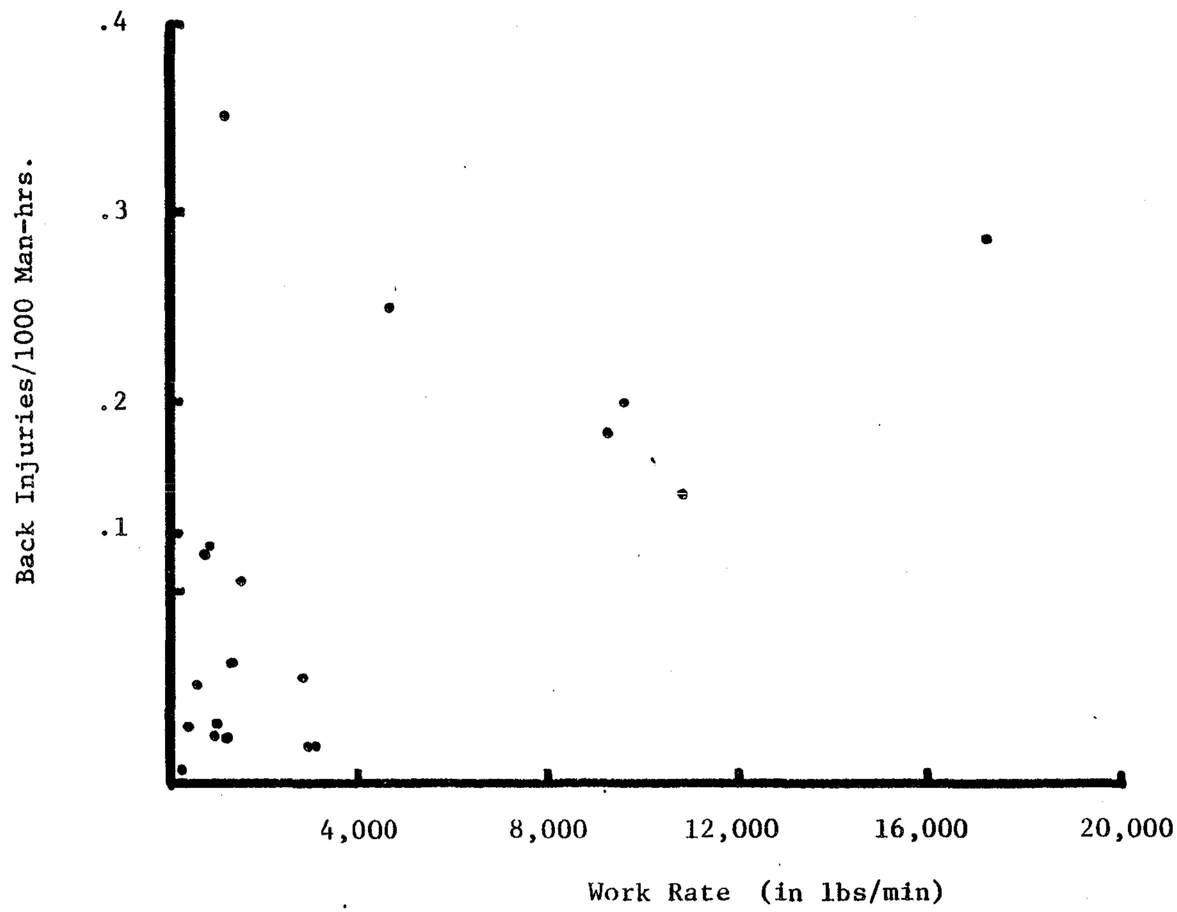

Figure 35: Scatter Diagram of the Number of Back Injuries Per 1000 Man-hrs. and the Work Rate

Historical Injury Data

Work Days Lost Due to Lifting Back Injuries/1000 Man-hrs.
= 0.04844 + 0.0008 * (work rate)

R = 0.5203

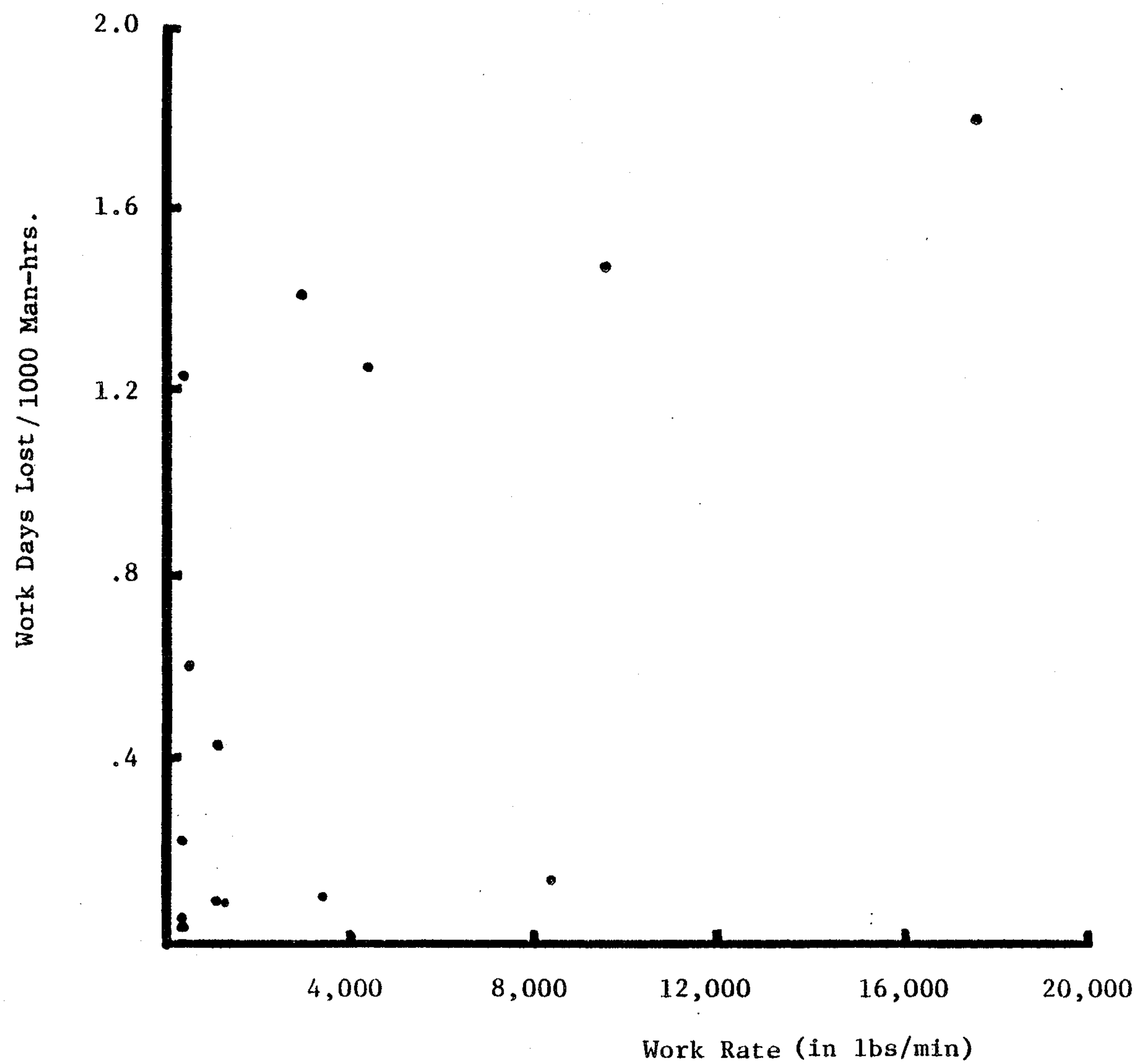

Figure 36 : Scatter Diagram of the Number of Work Days Lost Due to Back Injuries and the Work Rate

Variables 1, 2, 3, and 4 were used as dependent variables and variables 5, 6, and 7 as independent variables in the regression analysis. The prediction equations developed were:

One variable models:

$$[\text{No. of lifting back injuries/1000 man-hrs.}] = [0.02455 + 0.00014^* \text{work rate}] \quad (1)$$

$R = 0.488$

$$[\text{No. of work days lost due to lifting back injuries/1000 man-hrs.}] = [0.04844 + 0.0008^*\text{work rate}] \quad (2)$$

$R = 0.5203$

Two variable models:

$$[\text{No. of lifting-back injuries}/10^6 \text{ man-hrs.}] = [-14.06026 + 0.77983^*\text{weight of lift} + 0.11986^*\text{work rate}] \quad (3)$$

$R = 0.5376$

$$[\text{No. of work days lost due to lifting back injuries}/10^6 \text{ man-hrs.}] = [1.13799 + 427.66968^*X_1 + 0.0013^*X_2] \quad (4)$$

where

$X_1 = 1$, if the weight of lift $\geq$ 75 pounds
0, otherwise

$X_2 = (\text{work rate})^{1.9}$; work rate in foot pounds per minute

$R = 0.6996$

b. Current Injury Data

For each of the subjects measured, injury information was collected for a 9 month time period, commencing the day the measurements were made. As in the case of injury histories, this information was taken from company records. Each injury was classified according to its cause (lifting and non-lifting) and type.

Various strength and anthropometric measurements (described earlier in the report) were recorded for each of the 220 male and 24 female subjects.

Table 13 provides the complete injury breakdown, for a total of 195,690 man-hours worked, according to injury type and cause. Forty-nine of the subjects experienced some type of injury. A total of 67 injuries of all types were reported.

2. Analysis of the Current Injury Data

Before the development of the relationship between a suitable measure of injury and Job Stress Index (JSI) is presented, the injury measures used are defined:

1. Frequency rate - number of reported injuries per million exposure hours.

2. Severity rate - number of days lost per million exposure hours.

3. Average days charged - average number of work days lost/ number of injuries.

4. Proportion of workers injured - Number of people injured/ number of people in the group.

a. Measures of Job Stress

Lifting job stress is measured in terms of JSI, which is defined, in general, as a comparison of the lifting requirements of a given job to the ability of capacity of a given person to perform the required lifting. A total of four job severity indices (two measures of absolute job demand and one measure of individual capacity) were compared to the injury measures described above. The following procedures were used in the development of the JSI's:

1. All lowering requirements were ignored because:
    a. the capacity prediction models (Table 10) are restricted to lifting activities only.
    b. Lowering is considered less stressful than lifting (negative work).

TABLE 13: Injury Breakdown by Type and Cause

Type	Number of Lifting Injuries	Work Days Lost Due to Lifting Injuries	Number of Non-Lifting Injuries	Work Days Lost Due to Non-lifting Injuries	Number of People Injuried	
					Lifting	Non-lifting
1	9	201*	0	0	8	0
2	5	5	6	29**	5	5
3	13	5	21	8	13	18
4	0	0	1	0	0	1
5	0	0	12	1	0	11
Total	27	211	40	38	26	35

*One Injury Accounted for 189 days.

**One Injury Accounted for 25 days.

2. Each of the 63 jobs were described as a series of lifting tasks only. The description consisted of:

   a. Weight(s) of lift - uniform variation in weight was described using a single task (mean, upper limit, and lower limit were determined).

   b. Range(s) of lift - the range(s) of lift was determined for each task (if there was uniform variation in the range, then average, upper and lower limits were determined).

   c. Frequency of lift - average number of lifts per minute for each task.

   d. Box size - measured but not used (See Table 10).

3. The tasks were grouped according to when they were performed, i.e., tasks 1 and 2 performed in the morning were in group 1 and tasks 3 and 4, if performed in the afternoon, were in group 2.

Group frequency = sum of the frequencies of tasks in the group.

4. Determination of lifting range - there were basically six lifting ranges for which lifting capacity prediction equations were developed (Table 10), but since jobs did not always fit properly into those six ranges, a method was devised to assign the lifting ranges. Table 14 describes this assignment.

b. Job Stress Indices

The first of the four JSI's investigated is essentially the time and frequency weighted average of the task severities. The task severities are equal to the maximum weight of lift required divided by the average of the capacities predicted for the lifting ranges required by the tasks.

$$JSI^1{}_y = \sum_{j=1}^{M} \left[\frac{DAYS_j}{DAYS_T} * \frac{HRS_j}{HRS_T} \right] \sum_{i=1}^{N_j} \frac{F_i}{F_{Tj}} \left[\frac{1}{R} \sum_{R} \frac{WT_i}{CAP_k} \right] \qquad (5)$$

TABLE 14: Starting and Terminating Points of Lift (in.) and the Height Level (See Table 10) Assignment

Initial Point of Lift	Termination Point of Lift	Height Level Assigned
0 to (knuckle/2)	0 to (knuckle+10)	Height Level 1 (F-K)
	(knuckle+10) to (knuckle+30)	Height Level 2 (F-S)
	(knuckle+30) to Above	Height Level 3 (F-R)
(knuckle/2) to knuckle	(knuckle/2) to knuckle	Height Level 1 (F-K)
	knuckle to (knuckle+30)	Height Level 4 (F-S)
	(knuckle+30) to Above	Height Level 5 (K-R)
knuckle to (knuckle+10)	knuckle to (knuckle+30)	Height Level 4 (K-S)
	(knuckle+30) to Above	Height Level 5 (K-R)
(knuckle+10) to (knuckle+20)	(knuckle+10) to (knuckle+20)	Height Level 4 (K-S)
	(Knuckle+20) to Above	Height Level 6 (S-R)
(knuckle+20) to Above	(knuckle+20) to Above	Height Level 6 (S-R)

where:

M = Number of task groups.

N_j = Number of tasks in groups.

$DAYS_j$ = Number of days per week that group j is performed.

$DAYS_T$ = Number of days per week that the job is performed.

HRS_j = Number of hours per day that group j is performed.

HRS_T = Number of hours per day that the job is performed.

F_i = Lifting frequency of task i.

F_{Tj} = Total lifting frequency of group j = $\sum_{i=1}^{N_i} F_i$

R = Number of different lifting ranges required by task i.

WT_i = Maximum weight of lift required by task i.

CAP_{ky} = Predicted capacity of individual y to lift over the range k.

The second index (JSI^2_y) investigated does not account for job variability. It is simply defined as the maximum weight of lift required by the job divided by the average capacity of the individual.

$$JSI^2_y = \frac{WT}{CAP_y} \qquad (6)$$

Where:

WT = Maximum weight required by the job.

CAP_y = Average of six capacities predicted for individual y.

The third index is similar to the first except the capacity used is the smallest of the predicted capacities for the ranges required by a given task, thereby, accounting for the worst or most stressful task situation.

$$JSI^3_y = \sum_{j=1}^{M} \left[\frac{DAYS_j}{DAYS_T} * \frac{HRS_j}{HRS_T} \right] \sum_{i=1}^{N_j} \left[\frac{F_i}{F_{Tj}} * \frac{WT_i}{CAP_{iy}} \right] \qquad (7)$$

Where:

CAP_{iy} = The smallest of the one or more capacities for the ranges required by task i for individual y.

The fourth index is also similar to the first except the capacity is equal to the average of the six capacities for each individual. This JSI ignores the differences in lifting range.

$$JSI^4_y = \sum_{j=1}^{M} \left[\frac{DAYS_j}{DAYS_T} * \frac{HRS_j}{HRS_T} \right] \sum_{i=1}^{N_j} \left[\frac{F_i}{F_{Tj}} * \frac{WT_i}{CAP_y} \right] \tag{8}$$

Where:

CAP_y = Average of six lifting capacities for individual y.

The Job Stress Indices (JSI's) based on work rate and average maximum weight did not show high correlation with the injury data (See Table 16). JSI^3_y takes into account the worst possible case exhibited by a particular task (since CAP_{iy} is in the denominator). Also, this approach eliminated the need to average JSI's for all possible lifting combinations. The JSI^3_y gives a frequency-time weighted average of the task "worst cases." An example of JSI calculation is given in Appendix I .

c. Grouping of the Data

The data was grouped such that each group contained approximately equal numbers of exposure hours. The subjects were arranged in ascending order of job severity and then divided into equal exposure hour groups. This was thought to be the best grouping procedure because two of the four injury measures are functions of exposure hours. As it turned out, the number of individuals per group was relatively constant using the exposure hour grouping method. The analysis presented here divided the subject set into five and ten groups. A third set of 20 groups was also analyzed, but is not presented here because it displayed a very large variance of group averages and hence showed very little significance.

Another grouping consideration pertained to lost time injuries. The injury data shows (Table 13) two injuries in an excess of ten days lost, each. The injury severity and average days charged were analyzed both with and without the inclusion of those two injuries. Tables 15 and 16 gives the correlation coefficient between the injury measures and the JSI's, work rate, maximum weight, and average capacity for give groups and ten groups, respectively. As is clear from the correlation coefficients in Tables 15 and 16, JSI^3 is more highly correlated with injury frequency and severity than the other JSI's.

d. Models to Predict Job Stress Measures

Best fit equations were developed for the five independent variables (JSI^1, JSI^3, WR, WT, and CAP) and it was found that JSI^3 explained variance better than others. The models developed were of the form:

$$Y'(\text{dependent variable}) = \text{intercept} + \text{constant}\ (\text{function}(JSI^3)).$$

Tables 17 and 18 give the actual observed averages of injury measures and JSI^3 for five groups and ten groups, respectively. The following are the prediction models for various injury measures as a function of the JSI^3.

$$\text{Frequency (number of injuries/1000 man-hrs.)} = 0.42243 + 0.13949*LN(JSI^3) \quad (9)$$

$R^2 = 0.9463$

$$\text{Frequency (number of injuries/1000 man-hrs.)} = -0.10061 + 0.49823*[LN(1 + JSI^3)] \quad (10)$$

$R^2 = 0.9535$

Although model (10) is slightly better, model (9) is recommended because it is easier to use.

Figure 37 is the scatter diagram of frequency and JSI^3 and R^2 for model (9).

TABLE 15: Correlation Coefficients For Five Group Averages (R)

	Frequency	Severity	Severity (Excluding 2)	Days Charged	Days (Excluding 2)	Proportion Injured
JSI[1]	.6488	.7698	.3540	.5836	.0832	.1154
JSI[2]	.3306	.8111	.3196	.8676	.2434	.0000
JSI[3]	.8294	.7604	.7121	.6666	.4847	.4511
JSI[4]	.9164	.7111	.3384	.6236	.0201	.5366
WR	.8932	.1112*	.9314	.1413*	.2253	.8989
AWT	.8237	.0111	.7563	.0173	.1108	.8060
ACAP	.0986	.5223*	.1874*	.5587*	.4016*	.2774

*Negative Correlations

TABLE 16: Correlation Coefficients for Ten Group Averages (R)

	Frequency	Severity	Severity (Excluding 2)	Days Charged	Days (Excluding 2)	Proportion Injured
JSI^1	.6351	.5991	.3332	.3925	.0070	.3091
JSI^2	.1725	.6121	.3149	.6255	.1181	.0008
JSI^3	.7021	.6353	.4671	.5186	.1609	.2271
JSI^4	.6076	.5982	.3163	.2837	.0120	.2543
WR	.7554	.0363	.4169	.0551	.0544	.6863
AWT	.5689	.0000	.3694	.0002*	.0227	.6821
ACAP	.0947	.3845*	.0067*	.4142*	.0998*	.4052

*Negative Correlations

TABLE 17: Observed Averages of Injury Measures (5 Groups)

Group	Average JSI^3	JSI^3 Limits	Number of Subjects	Number of X 1000	Frequency (# of Injuries/ 1000 Man-hours	Severity (All Injuries) (# Work Days Lost/ 1000 Man-hours)	Severity (Minor Injuries) (# Work Days Lost/ 1000 Man-hours)	Days Charged (All Injuries) (# Work Days Lost/ # of Injuries)	Days Charged (Minor Injuries) (# Work Days Lost/# of Injuries)	Proportion Injured (Fraction of People in Group with 1 of More Injuries
1	0.2294	0.0000- 0.4368	42	36.9622	0.13527	0.05411	0.05411	0.40001	0.40001	0.11905
2	0.6433	0.4369- 0.9365	50	38.4950	0.20783	0.70139	0.05195	3.37499	0.28571	0.14000
3	1.1406	0.9366- 1.3412	42	37.8061	0.37031	0.07935	0.07935	0.21428	0.21428	0.28571
4	1.5955	1.34130 1.8718	52	37.7117	0.39775	0.37124	0.39124	0.93335	0.93335	0.22642
5	2.9480	1.8719- 7.6449	48	38.4265	0.46843	5.28281	0.36433	11.27769	0.82353	0.25000

TABLE 18: Observed Averages of Injury Measures (10 Groups)

Group	Average JSI[3]	Number of Subjects	Number of X 1000	Frequency (# of Injuries/ 1000 Man-hours)	Severity (All Injuries) (# Work Days Lost/ 1000 Man-hours)	Severity (Minor Injuries) (# Work Days Lost/ 1000 Man-hours)	Days Charged (All Injuries) (# Work Days Lost/# of Injuries)	Days Charged (Minor Injuries) (# Work Days Lost/# of Injuries)	Proportion Injured (Fraction of People in Group with 1 or More Injuries
1	0.1283	21	18.3569	0.16343	0.05448	0.05448	0.33333	0.33333	0.14286
2	0.3304	21	18.6053	0.10750	0.05375	0.05375	0.50000	0.50000	0.09524
3	0.5556	30	18.6767	0.21417	0.00000	0.00000	0.00000	0.00000	0.10000
4	0.7748	20	19.8183	0.20183	1.36237	0.15137	6.75000	1.00000	0.25000
5	1.0348	22	19.0080	0.26305	0.10521	0.10521	0.40000	0.40000	0.18182
6	1.2570	20	18.7932	0.47877	0.05319	0.05319	0.11111	0.11111	0.40000
7	1.4844	30	18.6661	0.48216	0.58930	0.58930	1.22222	1.22222	0.23333
8	1.7405	23	19.0457	0.31503	0.15752	0.15752	0.50000	0.50000	0.21739
9	2.0564	21	18.9838	0.31606	0.15803	0.15803	0.50000	0.50000	0.23809
10	3.6414	27	19.4428	0.61720	10.28658	0.51433	16.66667	0.90909	0.25926

Current Injury Data

Injuries/1000 hrs. = 0.32243 + 0.13949 (Ln JSI^3)

R^2 = 0.9463

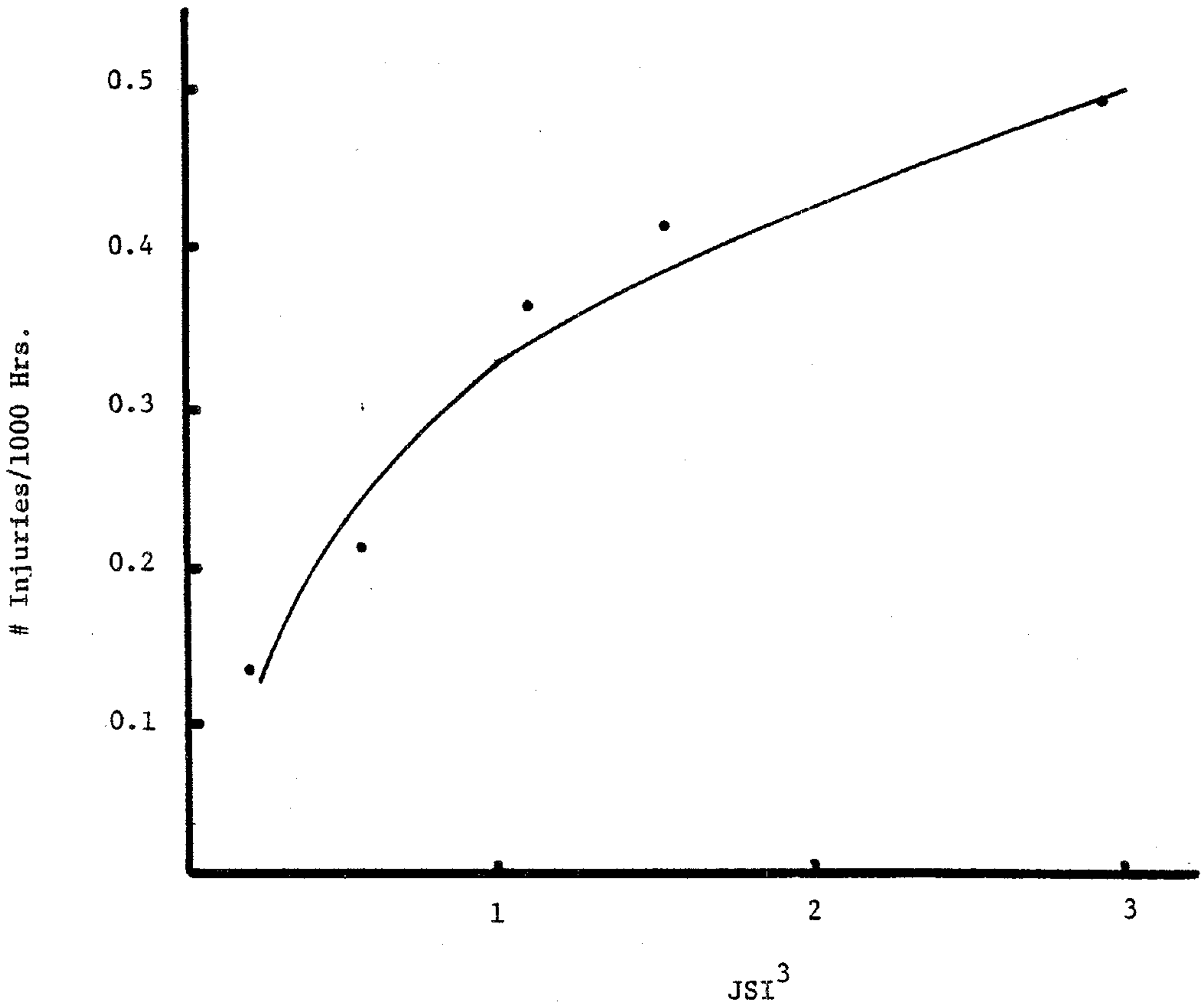

Figure 37: Scatter Diagram of Injury Frequency and JSI^3 (5 groups)

Severity (number of work days lost/1000 man hrs.)

$$= 0.297528 + 0.000838(\text{Exp.})^{(\text{JSI}^3)**2} \quad (11)$$

(All injuries)

$R^2 = 0.9864$

Severity (number of work days lost/1000 man hrs.)

$$= 0.061803 + 0.305981*X \quad (12)$$

(Minor injuries)

where

$X = 0$, if $\text{JSI}^3 \leq 1.3412$

1, otherwise

$R^2 = 0.9957$

Days charged (number of work days lost/number of

$$\text{injuries}) = 1.22285 + 0.00169)*(\text{Exp.})^{(\text{JSI}^3)**2} \quad (13)$$

(All injuries)

$R^2 = 0.9263$

Figure 38 is the scatter diagram and R^2 for the model.

Days charged (number of work days lost/number of

$$\text{injuries}) = 0.3 + 0.57844*X \quad (14)$$

(Minor injuries)

where

$X = 1$, if $\text{JSI}^3 \geq 1.3413$

0, otherwise

$R^2 = 0.9445$

Proportion injured (fraction of people in a group with

$$\text{one or more injuries}) = 0.207026 + 0.59726*\text{LN}(\text{JSI}^3) \quad (15)$$

$R^2 = 0.6501$

Proportion injured (fraction of people in group with one

$$\text{or more injuries}) = 0.129525 + 0.124518*X \quad (16)$$

Current Injury Data

Work Days Lost/1000 Man-hrs. = 0.297528 + 0.000838 *(exp) JSI^3**2

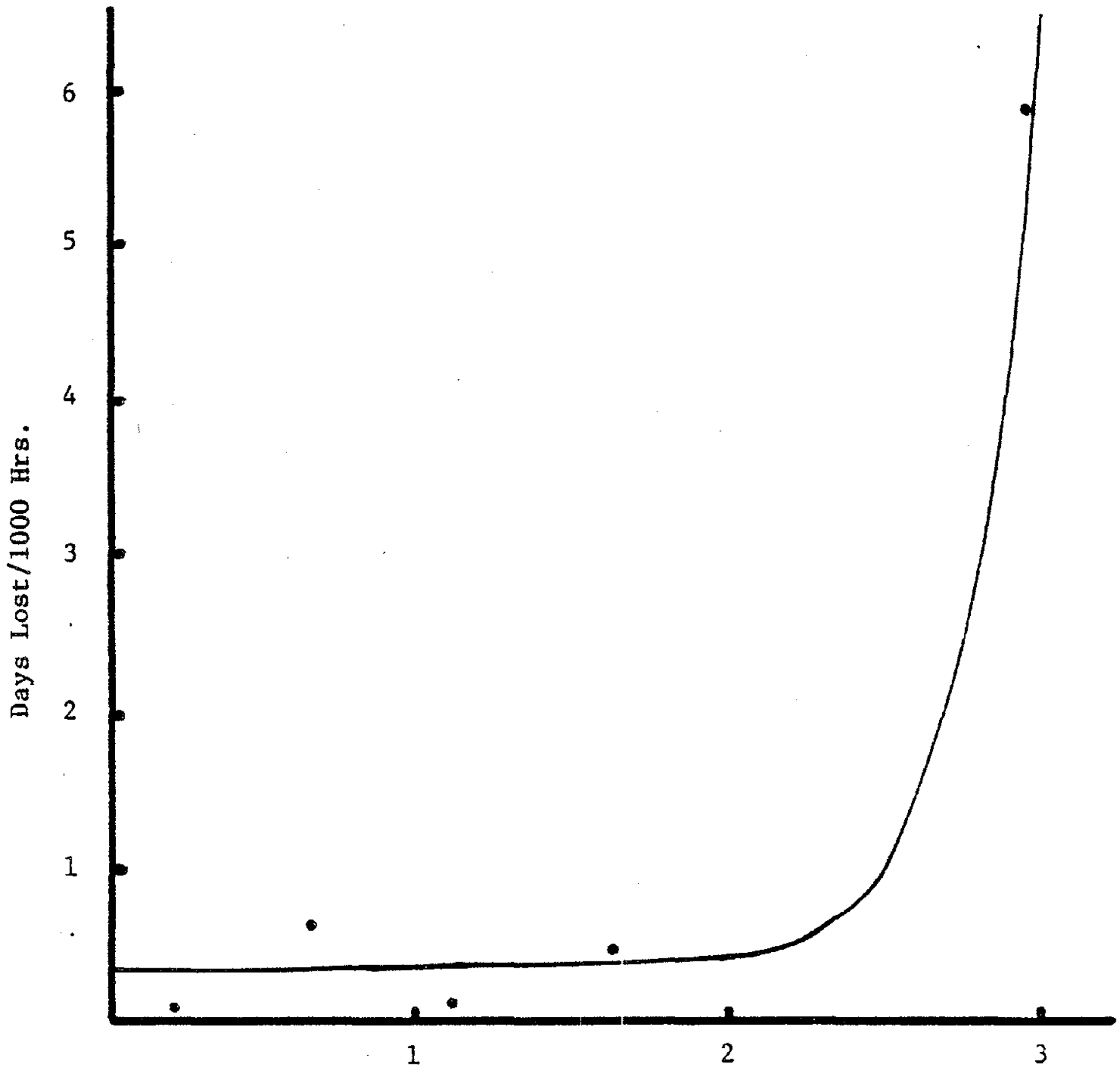

Figure 38: Scatter Diagram of Severity and JSI^3 (5 groups)

where

$X = 1$, if $JSI^3 \geq 0.9366$

0, otherwise

$R^2 = 0.9047$

It is recommended that model (16) be used as it accounts for 90 percent of the variance even though it is discontinuous.

Models 9 thru 16 are based on five groups. Injury frequency shows a natural log relationship between injury frequency and JSI^3 is indicated. This relationship is not evident when ten groups are used. The injury frequency prediction model, using ten groups, as shown below, indicates a linear relationship.

$$\text{Injury frequency} = 0.143512 + 0.132585*JSI^3$$

$R^2 = 0.7021$

Comparison of the two models indicates that the difference in the relationships are due to grouping. Similarly, the prediction model for proportion of workers injured, for ten groups, also indicates a linear relationship.

$$\text{Proportion injured} = 0.1127 + 0.14157*X$$

where

$X = 1$, if $JSI^3 \geq 0.6591$

0, otherwise.

$R^2 = 0.5842$

3. Job Design and Employee Placement Procedures

The results can be used as a tool for job design and employee placement. The following is a step-by-step procedure for job designs:

Step 1. Describe the job as a series of tasks, each having a weight distribution, average frequency, and ranges of lift.

Step 2. Select the maximum acceptable injury frequency (based on company, union, or insurance policy).

Step 3. Select the population for which the job is to be designed (i.e., 95 percent of the population? Males or females? or both?).

Step 4. Using step 2, determine the corresponding JSI from table 19.

Step 5. For each task:

a. Select the smallest of the predicted lifting capacities using Table 8 (i.e., if a task requires three lifting ranges, select the smallest capacity of the three). Use table 14 to determine the ranges.

b. Calculate the maximum design weight of lift for the task as follows:

$$WT = capacity*JSI^3 \qquad (19)$$

c. Multiply by sex factor

$$WT = WT*Sex\ Factor \qquad (20)$$

Sex Factor = 1 for men
= 0.56 for women (calculated from Table 5).

Step 6. If for a given task, the required weight of lift is above the designed weight of lift, the job should be redesigned (change the range of lift, adjust the frequency, etc.). As long as the overall JSI^3 remain unchanged, other factors can be adjusted.

It should be noticed that:

1. The design weight is the maximum weight allowed for the task. It is not the average.

2. The procedure is not applicable if the models given in Table 10 predict negative capacity.

3. If the job is to be designed both for men and women, design limits for women should be used.

The procedure for employee placement is given below:

Step 1. Record the various strength and anthropometric measures needed for predicting the lifting capacity (See Table 10).

Step 2. Determine the JSI[3] for the person.

Step 3. Use Table 19 to determine the predicted injury frequency.

Step 4. Make the decision.

TABLE 19: Injury Frequency and the Corresponding JSI^3

Injury/1000 Man-Hrs. Maximum Acceptable Frequency	Corresonding Value of JSI^3
0.14	0.0000
0.15	0.0489
0.16	0.1244
0.17	0.1998
0.18	0.2752
0.19	0.3506
0.20	0.4261
0.21	0.5015
0.22	0.5709
0.23	0.6523
0.24	0.7277
0.25	0.8032
0.30	1.1803
0.35	1.5574
0.40	1.9345
0.45	2.3116
0.50	2.6888
0.60	3.4430
0.75	4.5743
1.00	6.4599
1.16	7.6449

V. CONCLUSIONS AND DISCUSSION

This section includes conclusions drawn from the analysis of maximum acceptable weight of lift, lifting capacity prediction models, historical injury data, and current injury data.

A. Lifting Capacity

Based on the experimental data, lifting capacity norms (Table 5) were developed for the male and female industrial populations. The difference in the lifting capacity due to sex was highly significant. This leads to the conclusion that sex of the operator must be considered while assigning an employee for a given lifting job or designing lifting jobs.

It is recommended that the lifting capacity data for the ninetieth and fifteenth percentile should be used as lower and upper capacity limits, respectively for job design. A majority of the population should be able to lift loads of ninetieth percentile and below. Above the fifteenth percentile value, relatively few individuals would be able to handle the load and as shown in equation 4 where the severity of injury increases if the weight is more than 75 pounds. Subject selection procedures should be used if the job requires to lift a load manually between these limits. Lifting capacity prediction models should be employed for the purpose of selection.

1. Effect of Task Variables

Several task variables were considered in this study. These were: height of lift, frequency of lift, and size of the box handled. As the vertical height of lift (from the same starting point) increased, the lifting capacity decreased. This was true for both, males and females. The effect is clearly indicated in Figures 4 and 5.

Frequency of lift and box size data indicate a linear relationship with the lifting capacity. As the frequency of lift or box size increased, the lifting capacity decreased linearly. However, in case of males, for the knuckle to reach and the shoulder to reach height levels, the lifting capacity increased with the increase in box size. The reason for this behavior is not understood and no explanation can be given at this time.

Although the frequency box size interaction was not statistically tested, similar effects are expected.

2. Effect of Age

The lifting capacity data indicated that age did not have a significant effect on the lifting capacity of male or female workers. This may be due to on-the-job training and/or experience.

B. Lifting Capacity Prediction Models

Lifting capacity models were developed to predict the lifting capacity of an individual worker (male or female). These models require isometric strength data and anthropometric data of the individual. The final set of models predict the body weight plus maximum acceptable weight for that particular worker.

1. Variables in the Model

The lifting capacity prediction models utilize strength and anthropometric variables as the independent variables. Although the lifting capacity is affected by task variables, only the height of lift has shown significant partial correlation. Frequency of lift and box size were not as strongly correlated with the lifting capacity as the strength and anthropometric variables. However, other task variables need to be included in some future study before a conclusive statement can be made about the effect of task variables on the lifting capacity and their inclusion in the prediction models.

2. Model Statistics

The lifting capacity prediction models, developed in this study, explain 85 to 88 percent of the variance. Although additional variance can be explained by including other operator and task variables, this increase is not significant to justify their inclusion. The average error in the predicted value of lifting capacity varies from approximately 1 to 6 pounds. Table 11 gives the details of model verification.

3. Applicability

The measurement required as input in the lifting capacity prediction models (strength and anthropometric) can be made quickly and accurately. This makes these models suitable for industrial use for the purpose of employee selection and placement.

These models are for six different height levels, which cover the majority of the height levels involved in manual lifting. Any other height level between the floor and reach can be converted into these six height ranges by the procedure described in Table 13.

C. Historical Injury Data

The relationship between back injuries and job demand was established by collecting the injury history information and developing regression equations for back injuries and work days lost. These models use the maximum weight lifted on the job and work rate as independent variables.

1. Work Rate vs. Maximum Weight of Lift

Work rate and maximum weight of lift were used to develop one variable and two variable models to predict the number of back injuries and work days lost. These models lead to an important conclusion that the amount of weight lifted on the job alone is not as important a measure of severity as work rate. Work rate is a more important measure.

A light load at high frequency could be as hazardous, or more, as a heavy load at low frequency. This is also endorsed by the inclusion of dynamic endurance in the lifting capacity prediction models.

2. Relationship Between Work Days Lost and Maximum Weight Lifted on the Job

The work days lost prediction model, based on two variables, is a two stage model. The first stage is up to 74 pounds weight of lift and the second stage is for weights of 75 pounds or greater. If the weight of lift is 75 pounds or greater, there is a sharp increase in the number of work days lost due to lifting back injuries. This leads to the conclusion that a load of 75 pounds is the upper limit if it is to be handled manually. This number closely corresponds to the fifteenth percentile value of the lifting capacity.

D. Current Injury Data

The analysis of current injury data indicates a definite relationship between injury frequency and job severity. This relationship has been specifically described as a function of JSI^3 and indicates that by proper job design JSI^3 can be reduced and hence the injury frequency and severity.

1. JSI^3 Limit

The relationship between JSI^3 and the number of days lost per 1000 exposure hours are plotted in Figure 38. The relationship is exponential. As the JSI^3 value exceeds two, there is a steep increase in the number of days lost. It can be concluded from this data that a JSI^3 value of two may be considered the upper limit for manual lifting activities. Thus, if for an individual the JSI^3 value for a given job exceeds two, either the job should be redesigned or the right person for the job be selected.

2. Relationship Between Injury Frequency and Job Severity

The relationship between JSI^3 and the number of injuries per 1000 exposure hours is plotted in Figure 37. Initially, the number of injuries increases sharply, followed by a gradual decrease in this rate of increase. As the job demands increase, the number of potential injuries for a given work increases.

3. Job Design (Redesign) and/or Employee Selection/ Placement

A procedure for designing jobs and selecting employees for particular jobs based on job demand has been outlined earlier.

If the procedure is utilized in conjunction with the limitations (capacity limits, JSI^3 value, etc.) discussed in previous sections, it can be expected that the frequency and severity of injuries resulting from manual lifting should decrease. The procedure considers the worst case and enables the job demand to be matched with the capacity of an individual.

4. Injury Breakdown

Table 21 gives the breakdown of lifting and non-lifting type injuries and the work days lost due to them. There were a total of 40 non-lifting injuries against 27 lifting injuries, but 211 work days were lost due to lifting injuries while 38 work days were lost due to non-lifting injuries. About five times more work days were lost due to lifting injuries even though they accounted for less than half the total number of injuries. Injuries attributed to lifting activities were generally incurred by fewer people as opposed to those injuries attributed to non-lifting activities; however, they were generally more severe. Therefore, it is reasonable to conclude that lifting injuries, based on the number of work days lost, are more severe.

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Appendix A

Personal Data and Consent Form
Lifting Experiment

Personal Data

1. Name:____

2. Address:______________________________________

3. Phone: Work__________________ Home________________

4. Employer's name:_________________________________

5. Employer's address:_______________________________

6. (a) Does your job involve lifting? Yes No. If yes, do you lift continuously (i.e., with no rest between successive lifts), intermittently (i.e., with enough time in between lifts to rest), or occasionally (i.e., few times per shift)?

____

(b) If the lifting is continuous, for what percentage time? __________. If intermittent, how many times per hour?_____

(c) What height ranges do you normally lift in: knee height, waist height, shoulder height, full arm reach, all heights, or other?______________________________________

(d) In what weight range do you normally lift?______pounds to ______pounds

7. (a) How long have you been employed in this capacity?______ years _________ months

(b) If less than three months, did your previous job require lifting? Yes No

(c) If yes, explain in the same order as for question 6.

____

Physical Data

1. Have you ever sought medical attention for lower back pain?

   Yes No If yes, explain ____________________________

2. Have you suffered extreme lower back pain without consulting medical personnel? Yes No If yes, when ______________

3. Have you suffered extreme shoulder or arm pain? Yes No

   If yes, which arm? __________ shoulder? ________ Did you you receive medical attention? Yes No

4. Have you lost time from work recently due to lower back pain or arm or leg problems? Yes No Which? ______________

5. Do you participate in an exercise program? Yes No

   If yes, on which of the following type of basis ____________

   a. regular (at least three times a week)

   b. intermittent (less than three times a week)

   c. occasional (whenever you feel like it)

6. (a) Do you have a hernia? Yes No

   (b) Have you had any corrective treatment for a hernia?

   Yes No If yes, how many times? __________

7. How much sleep did you have last night? ______ hours. Is this normal, less than normal, more than normal? __________

8. Time since last meal? _______ hours. Quantity eaten? Normal, less than normal, more than normal? ____________________

9. Are you taking any type of medication? Yes No If yes, what is the medication, the nature of your illness? ________

   ____

10. The above are true to the best of my knowledge. I hereby voluntarily consent to participate in the study entitled:

Determination and Modeling of Lifting Capacity. I understand that these studies are part of an Industrial Engineering research project, and have had the purpose and risks of participation explained to me by the investigator responsible for conducting the studies, and I understand these risks. The risks are possible stresses on the musculoskeletal system such as sore muscles, or possible muscle injury due to manually handling weights. However, the probability of such injuries are small when the instructions are carefully followed. I have read the attached instructions and understand that I can adjust the work load to avoid strain or becoming unusually tired, weakened, overheated or out of breath. I also understand that I may discontinue this study at any time that I choose.

SUBJECT SIGNATURE______________________________

Signature of Responsible Investigator____________________

WITNESS______________________________________

DATE____

Appendix B

Lifting Data Collection Form

Knuckle Height__________ Subject#__________

Shoulder Height__________ Block #__________

Reach Height__________

Lifting Experiment

Subject Name__________ __ __________ Code [| | |]

Data:__________ Time:__________

Box Wt [ ] lbs.

Total Wt [ ] lbs.

Treatment #									
Trial #	1	2	3	4	5	6	7	8	9
1. Range of Lift									
2. Frequency of Lift									
3. Box Size									
4. Starting Time									
5. Ending Time									
6. Duration									
7. Storage Container & wts. lb.									
kg.									
8. Max. Acc. Wt. of Lift lb.									

Appendix C

Experimental Design and Layout

```
                 BALANCED INCOMPLETE RANDOMIZED BLOCK DESIGN
                 *******************************************
                       (COCHRON-COX, P390,482,534)

I.  "FACTORS" INVOLVED:
(1) BOX SIZE: 3 LEVELS 12", 18", 24"
(2) FREQUENCY: 4 LEVELS 2L/M, 4L/M, 6L/M, 8L/M
               WHERE L/M = LIFTS/MINUTE
(3) HEIGHT: 6 LEVELS
    FLOOR TO KNUCKLE     (FK)
    FLOOR TO SHOULDER    (FS)
    FLOOR TO REACH       (FR)
    KNUCKLE TO SHOULDER  (KS)
    KNUCKLE TO REACH     (KR)
    SHOULDER TO REACH    (SR)

II. SUBJECT CODE:
    EACH SUBJECT IS ASSIGNED A CODE OF THE FORM IJKLL
    WHERE

    I = SEX CODE = 0, MALES
                 = 1, FEMALES
    J = AGE CODE = 0, 29 YEARS OR LESS
                 = 1, 30 - 39 YEARS
                 = 2, 40 YEARS OR MORE
    K = WEIGHT CODE = 0, BELOW THE MEDIAN
                    = 1, ABOVE THE MEDIAN
    LL = SUBJECT CONTRIBUTION NUMBER
       = TWO DIGIT CODE, I.E., 01,02,.....,12

III. DESIGN
    NUMBER OF TREATMENTS = 73
    NUMBER OF BLOCKS(SUBJECTS) = 73
    NUMBER OF REPLICATIONS/TREATMENT = 9
    NUMBER OF TREATMENTS/BLOCK = 9

    THE EXPERIMENT WILL BE DONE TWICE.
    THE TREATMENT NUMBERS IN EXP.1 ARE IDENTIFIED WITH R AND BLOCKS WITH I
    THE TREATMENT NUMBERS IN EXP.2 ARE IDENTIFIED WITH G AND BLOCKS WITH II.
    R73 SAME AS R32
    G73 SAME AS G38
```

SBJ. CODE IJKLL	SBJ. NO.	BLK. NO.	ORDER OF EXPERIMENTATION (ORDER OF TREATMENT NO. ON P.534, C-C, RANDOMIZED) 1	2	3	4	5	6.	7	8	9
00001	1	I-67	(45) 188FR	(9) 124FR	(63) 246FR	(67) 248FR	(38) 186FS	(56) 244FS	(27) 182FR	(2) 122FS	(20) 128FS
2	2	I-46	(71) 248KR	(59) 244KR	(32) 184FS	(39) 186FR	(50) 242FS	(9) 124FR	(46) 188KS	(21) 128FR	(4) 122KS
3	3	I-20	(58) 244KS	(20) 128FS	(68) 248FS	(32) 184FS	(41) 186KR	(15) 126FR	(54) 242SR	(37) 186FK	(3) 122FR
4	4	II-42	(63) 244FK	(54) 186FS	(35) 124KS	(13) 248KR	(8) 182SR	(71) 124FK	(17) 188KR	(42) 186FR	(28) 242KS
5	5	I-11	(54) 242SR	(4) 122KS	(47) 188KR	(61) 246FK	(67) 248FK	(25) 182FK	(18) 126SR	(40) 186KS	(11) 124KR
6	6	II-21	(68) 122FK	(21) 128KR	(48) 122FR	(10) 126SR	(25) 248KS	(6) 186SR	(36) 122KS	(51) 244FS	(63) 244FK
7	7	I-9	(16) 126KS	(10) 124KS	(13) 126FK	(11) 124KR	(9) 124FR	(15) 126FR	(65) 246KR	(14) 126FS	(12) 124SR
8	8	I-58	(39) 186FR	(73) 184FS	(45) 188FR	(25) 182FK	(14) 126FS	(19) 128FK	(52) 242KS	(8) 124FS	(58) 244KS
9	9	II-2	(34) 126KS	(66) 186FK	(58) 126FS	(2) 246SR	(42) 186FR	(18) 186KR	(50) 246FS	(10) 126SR	(26) 246KS
10	10	I-6	(38) 186FS	(66) 246SR	(6) 122SR	(14) 126FS	(22) 128KS	(54) 242SR	(46) 188KS	(30) 182SR	(62) 246FS
11	11	I-53	(72) 248SR	(28) 182KS	(58) 244KS	(40) 186KS	(9) 124FR	(43) 188FK	(53) 242KR	(6) 122SR	(23) 128KR
12	12	I-65	(73) 184FS	(68) 248FS	(69) 248FR	(72) 248SR	(66) 246SR	(71) 248KR	(65) 246KR	(67) 248FK	(70) 248KS

SBJ. CODE IJKLL	SBJ. NO.	BLK. NO.	ORDER OF EXPERIMENTATION (ORDER OF TREATMENT NO. ON P.534, C-C,RANDOMIZED) 1	2	3	4	5	6	7	8	9
00101	13	II-35	(25) 248KS	(70) 126FK	(46) 126FR	(2) 246SR	(15) 244KR	(24) 122KR	(53) 188FS	(60) 122FS	(35) 124KS
2	14	II-41	(47) 124FR	(43) 184FR	(46) 126FR	(41) 188FR	(44) 182FR	(65) 188FK	(48) 122FR	(45) 128FR	(42) 186FR
3	15	I-21	(36) 184SR	(63) 246FR	(10) 124KS	(48) 188SR	(6) 122SR	(21) 128FR	(68) 248FS	(51) 242FR	(25) 182FK
4	16	I-40	(40) 186KS	(63) 246FR	(5) 122KR	(12) 124SR	(70) 248KS	(41) 186KR	(50) 242FS	(30) 182SR	(19) 128FK
5	17	II-7	(7) 184SR	(15) 244KR	(55) 184FS	(63) 244FK	(31) 184KS	(66) 186FK	(47) 124FR	(39) 244FR	(23) 124KR
6	18	II-56	(72) 122FK	(7) 184SR	(12) 122SR	(59) 124FS	(22) 126KR	(56) 182FS	(25) 248KS	(42) 186FR	(37) 248FR
7	19	I-61	(55) 244FK	(24) 128SR	(3) 122FR	(30) 182SR	(36) 184SR	(73) 184FS	(61) 246FK	(42) 186SR	(9) 124FR
8	20	I-27	(42) 186SR	(1) 122FK	(69) 244FR	(15) 126FR	(21) 128FR	(52) 242KS	(40) 186KS	(27) 182FR	(62) 246FS
9	21	II-43	(62) 246FK	(55) 184FS	(20) 182KR	(34) 126KS	(25) 248KS	(5) 188SR	(16) 242KR	(71) 124FK	(43) 184FR
10	22	II-62	(62) 246FK	(4) 242SR	(23) 124KR	(56) 182FS	(29) 188KS	(35) 124KS	(73) 246FR	(10) 126SR	(41) 188FR
11	23	I-5	(45) 188FR	(29) 182KR	(61) 246FK	(66) 246SR	(5) 122KR	(21) 128FR	(53) 242KR	(37) 186FK	(13) 126FK
12	24	I-8	(56) 244FS	(32) 184FS	(64) 246KS	(66) 246SR	(16) 126KS	(8) 124FS	(48) 188SR	(40) 186KS	(24) 128SR
13	145	I-44	(6) 122SR	(19) 128FK	(71) 248KR	(56) 244FS	(15) 126FR	(33) 184FR	(44) 188FS	(26) 182FS	(61) 246FK

SBJ. CODE IJKLL	SBJ. NO.	BLK. NO.	ORDER OF EXPERIMENTATION (ORDER OF TREATMENT NO. ON P. 534, C-C, RANDOMIZED) 1	2	3	4	5	6	7	8	9
01001	25	II-16	(16) 242KR	(49) 248FS	(30) 186KS	(35) 124KS	(58) 126FS	(67) 184FK	(44) 182FR	(7) 184SR	(21) 182KR
2	26	II-61	(30) 186KS	(61) 248FK	(3) 122FR	(36) 122KS	(73) 246FR	(55) 184FS	(24) 122KR	(9) 128SR	(42) 186FR
3	27	II-20	(54) 186FS	(41) 188FR	(32) 182KS	(20) 182KR	(3) 244SR	(37) 248FR	(68) 182FK	(58) 126FS	(15) 244KR
4	28	II-55	(26) 246KS	(55) 184FS	(41) 188FR	(11) 124SR	(72) 122FK	(38) 246FR	(8) 182SR	(21) 128KR	(60) 122FS
5	29	II-51	(64) 242FK	(45) 128FR	(30) 186KS	(17) 188KR	(34) 126KS	(51) 244FS	(4) 242SR	(15) 244KR	(72) 122FK
6	30	II-54	(27) 244KS	(72) 122FK	(57) 128FS	(44) 182FR	(5) 188SR	(10) 126SR	(54) 186FS	(24) 122KR	(39) 244FR
7	31	II-11	(40) 242FR	(47) 124FR	(67) 184FK	(11) 124SR	(25) 248KS	(54) 186FS	(61) 248FK	(4) 242SR	(18) 186KR
8	32	I-73	(73) 184FS	(51) 242FR	(7) 124FK	(20) 128FS	(40) 186KS	(46) 188KS	(26) 182FS	(13) 126FK	(57) 244FR
9	33	II-30	(59) 124FS	(30) 186KS	(8) 182SR	(53) 188FS	(10) 126SR	(47) 124FR	(33) 128KS	(20) 182KR	(69) 128FK
10	34	I-30	(10) 124KS	(59) 244KR	(33) 184FR	(8) 124FS	(20) 128FS	(30) 182SR	(47) 188KR	(53) 242KR	(69) 248FR
11	35	I-69	(44) 188FS	(23) 128KR	(13) 126FK	(69) 248FR	(64) 246KS	(3) 122FR	(50) 242FS	(38) 186FS	(25) 182FK
12	36	II-66	(41) 188FR	(33) 128KS	(66) 186FK	(17) 188KR	(57) 128FS	(1) 248SR	(41) 188FR	(25) 248KS	(9) 128SR

SBJ. CODE IJKLL	SBJ. NO.	BLK. NO.	ORDER OF EXPERIMENTATION (ORDER OF TREATMENT NO. ON P. 534, C-C, RANDOMIZED) 1	2	3	4	5	6	7	8	9
01101	37	II-63	(73) 246FR	(34) 126KS	(53) 188FS	(1) 248SR	(63) 244FK	(11) 124SR	(32) 182KS	(44) 182FR	(22) 126KR
2	38	II-27	(69) 128FK	(52) 242FS	(1) 248SR	(40) 242FR	(27) 244KS	(15) 244KR	(62) 246FK	(21) 128KR	(42) 186FR
3	39	I-70	(70) 248KS	(48) 188SR	(22) 128KS	(55) 244FK	(13) 126FK	(58) 244KS	(33) 184FR	(27) 182FR	(4) 122KS
4	40	I-39	(6) 122SR	(39) 186FR	(70) 248KS	(49) 242FK	(20) 128FS	(64) 246KS	(11) 124KR	(42) 186SR	(29) 182KR
5	41	I-43	(43) 188FK	(16) 126KS	(62) 246FS	(25) 182FK	(55) 244FK	(5) 122KR	(20) 128FS	(34) 184KS	(71) 248KR
6	42	I-17	(65) 246KR	(20) 128FS	(21) 128FR	(22) 128KS	(17) 126KR	(23) 128KR	(24) 128SR	(19) 128FK	(18) 126SR
7	43	II-29	(48) 122FR	(60) 122FS	(34) 126KS	(9) 128SR	(69) 128FK	(54) 186FS	(29) 188KS	(19) 184KR	(7) 184SR
8	43	II-47	(12) 122SR	(29) 188KS	(58) 126FS	(47) 124FR	(51) 244FS	(38) 246FR	(1) 248SR	(71) 124FK	(24) 122KR
9	45	I-47	(47) 188KR	(71) 248KR	(12) 124SR	(29) 182KR	(1) 122FK	(38) 186FS	(51) 242FR	(24) 128SR	(58) 244KS
10	46	II-59	(38) 246FR	(48) 122FR	(28) 242KS	(15) 244KR	(49) 248FS	(73) 246FR	(5) 188SR	(18) 186KR	(59) 124FS
11	47	I-18	(13) 126FK	(68) 248FS	(56) 244FS	(43) 188FK	(1) 122FK	(39) 186FR	(18) 126SR	(60) 244SR	(30) 182SR
12	48	I-26	(14) 126FS	(24) 128SR	(63) 246FR	(49) 242FK	(26) 182FS	(4) 122KS	(37) 186FK	(69) 248FR	(43) 188FK

SBJ. CODE IJKLL	SBJ. NO.	BLK. NO.	ORDER OF EXPERIMENTATION (ORDER OF TREATMENT NO. ON P.534, C-C,RANDOMIZED)								
			1	2	3	4	5	6	7	8	9
02001	49	II-49	(53) 188FS	(65) 188FK	(51) 244FS	(55) 184FS	(49) 248FS	(52) 242FS	(50) 246FS	(56) 182FS	(54) 186FS
2	50	II-70	(70) 126FK	(48) 122FR	(33) 128KS	(4) 242SR	(58) 126FS	(27) 244KS	(13) 248KR	(22) 126KR	(55) 184FS
3	51	II-25	(31) 184KS	(29) 188KS	(32) 182KS	(27) 244KS	(65) 188FK	(30) 186KS	(25) 248KS	(26) 246KS	(28) 242KS
4	52	II-5	(45) 128FR	(66) 186FK	(29) 188KS	(5) 188SR	(53) 188FS	(13) 248KR	(21) 128KR	(61) 248FK	(37) 248FR
5	53	I-10	(28) 182KS	(37) 186FK	(55) 244FK	(46) 188KS	(19) 128FK	(10) 124KS	(1) 122FK	(67) 248FK	(64) 246KS
6	54	I-24	(50) 242FS	(24) 128SR	(68) 248FS	(11) 124KR	(33) 184FR	(45) 188FR	(28) 182KS	(62) 246FS	(7) 124FK
7	55	I-25	(32) 184FS	(28) 182KS	(27) 182FR	(65) 246KR	(25) 182FK	(29) 182KR	(30) 182SR	(26) 182FS	(31 184FK
8	56	II-23	(49) 248FS	(34) 126KS	(8) 182SR	(12) 122SR	(61) 248FK	(68) 182FK	(23) 124KR	(46) 126FR	(27) 244KS
9	57	II-67	(45) 128FR	(20) 182KR	(27) 244KS	(67) 184FK	(56) 182FS	(63) 244FK	(9) 128SR	(2) 246SR	(38) 246FR
10	58	I-50	(20) 128FS	(1) 122FK	(72) 248SR	(35) 184KR	(61) 246FK	(31) 184FK	(48) 188SR	(14) 126FS	(50) 242FS
11	59	I-54	(27) 182FR	(5) 122KR	(54) 242SR	(10) 122KS	(24) 128SR	(44) 188FS	(39) 186FR	(72) 248SR	(57) 244FR
12	60	II-33	(65) 188FK	(36) 122KS	(35) 124KS	(38) 246FR	(40) 242FR	(37) 248FR	(39) 244FR	(33) 128KS	(34) 126KS

SBJ. CODE IJKLL	SBJ. NO.	BLK. NO.	ORDER OF EXPERIMENTATION (ORDER OF TREATMENT NO. ON P. 534, C-C, RANDOMIZED) 1	2	3	4	5	6	7	8	9
02101	61	I-36	(59)	(26)	(54)	(36)	(16)	(1)	(23)	(45)	(70)
			244KR	182KS	242SR	184SR	126KS	122FK	128KR	188FR	248KS
2	62	I-22	(47)	(64)	(68)	(52)	(9)	(35)	(22)	(5)	(26)
			188KR	246KS	248FS	242KS	124FR	184KR	128KS	122KR	182FS
3	63	II-36	(54)	(59)	(70)	(36)	(26)	(16)	(1)	(23)	(45)
			186FS	124FS	126FK	122KS	246KS	242KR	248SR	124KR	128FR
4	64	II-6	(46)	(14)	(30)	(62)	(66)	(6)	(54)	(38)	(22)
			126FR	246KR	186KS	246FK	186FK	186SR	186FS	246FR	126KR
5	65	I-68	(68)	(44)	(55)	(2)	(17)	(14)	(29)	(59)	(40)
			248FS	188FS	244FK	122FS	126KR	126FS	182KR	244KR	186KS
6	66	I-45	(40)	(22)	(3)	(49)	(31)	(10)	(60)	(45)	(71)
			186KS	128KS	122FR	242FK	184FK	124KS	244SR	188FR	248KR
7	67	II-57	(58)	(62)	(64)	(59)	(65)	(63)	(60)	(57)	(61)
			126FS	246FK	242FK	124FS	188FK	244FK	122FS	128FS	248FK
8	68	II-22	(68)	(35)	(47)	(26)	(22)	(9)	(52)	(5)	(64)
			182FK	124KS	124FR	246KS	126KR	128SR	242FS	188SR	242FK
9	69	I-14	(32)	(60)	(67)	(51)	(23)	(42)	(5)	(33)	(14)
			184FS	244SR	248FK	242FR	128KR	186SR	122KR	184FR	126FS
10	70	I-7	(31)	(39)	(55)	(7)	(23)	(66)	(63)	(47)	(15)
			184FK	186FR	244FK	124FK	128KR	246SR	246FR	188KR	126FR
11	71	I-4	(52)	(60)	(66)	(44)	(36)	(20)	(28)	(12)	(4)
			242KS	244SR	246SR	188FS	184SR	128FS	182KS	124SR	122KS
12	72	II-73	(51)	(73)	(46)	(20)	(40)	(7)	(57)	(13)	(26)
			244FS	246FR	126FR	182KR	242FR	184SR	128FS	248KR	246KS

ORDER OF EXPERIMENTATION (ORDER OF TREATMENT NO. ON P.534, C-C, RANDOMIZED)

SBJ. CODE IJKLL	SBJ. NO.	BLK. NO.	1	2	3	4	5	6	7	8	9
10001	73	I-33	(65) 246KR	(33) 184FR	(40) 186KS	(37) 186FK	(34) 184KS	(36) 184SR	(35) 184KR	(38) 186FS	(39) 186FR
2	74	II-8	(40) 242FR	(8) 182SR	(32) 182KS	(24) 122KR	(56) 182FS	(16) 242KR	(64) 242FK	(48) 122FR	(66) 186FK
3	75	I-19	(53) 242KR	(16) 126KS	(42) 186SR	(68) 248FS	(31) 184FK	(57) 244FR	(19) 128FK	(38) 186FS	(4) 122KS
4	76	I-62	(41) 186KR	(10) 124KS	(35) 184KR	(73) 184FS	(4) 122KS	(29) 182KR	(56) 244FS	(62) 246FS	(23) 128KR
5	77	II-13	(24) 122KR	(67) 184FK	(6) 186SR	(13) 248KR	(59) 124FS	(31) 184KS	(34) 126KS	(52) 242FS	(41) 188FR
6	78	I-35	(24) 128SR	(25) 182FK	(15) 126FR	(46) 188KS	(35) 184KR	(60) 244SR	(70) 248KS	(53) 242KR	(2) 122FS
7	79	I-28	(69) 248FR	(28) 182KS	(16) 126KS	(22) 128KS	(2) 122FS	(41) 186KR	(61) 246FK	(39) 186FR	(51) 242FR
8	80	II-4	(44) 182FR	(66) 186FK	(20) 182KR	(60) 122FS	(12) 122SR	(36) 122KS	(4) 242SR	(28) 242KS	(52) 242FS
9	81	I-31	(69) 248FR	(31) 184FK	(17) 126KR	(11) 124KR	(46) 188KS	(36) 184SR	(58) 244KS	(56) 244FS	(5) 122KR
10	82	I-56	(7) 124FK	(37) 186FK	(72) 248SR	(22) 128KS	(12) 124SR	(42) 186SR	(59) 244KR	(25) 182FK	(56) 244FS
11	83	II-1	(7) 184SR	(8) 182SR	(4) 242SR	(1) 248SR	(3) 244SR	(2) 246SR	(6) 186SR	(65) 188FK	(5) 188SR
12	84	II-69	(25) 248KS	(64) 242FK	(50) 246FS	(69) 128FK	(13) 248KR	(38) 246FR	(44) 182FR	(23) 124KR	(3) 244SR

SBJ. CODE IJKLL	SBJ. NO.	BLK. NO.	ORDER OF EXPERIMENTATION (ORDER OF TREATMENT NO. ON P.534, C-C, RANDOMIZED) 1	2	3	4	5	6	7	8	9
10101	85	II-65	(70) 126FK	(73) 246FR	(68) 182FK	(65) 188FK	(66) 186FK	(72) 122FK	(71) 124FK	(67) 184FK	(64) 128FK
2	86	I-52	(52) 242KS	(46) 188KS	(63) 246FR	(33) 184FR	(29) 182KR	(3) 122FR	(18) 126SR	(72) 248SR	(16) 126KS
3	87	II-48	(71) 124FK	(48) 122FR	(52) 242FS	(57) 128FS	(23) 124KR	(11) 124SR	(2) 246SR	(30) 186KS	(37) 248FR
4	88	II-58	(14) 246KR	(25) 248KS	(58) 126FS	(19) 184KR	(8) 182SR	(73) 246FR	(52) 242FS	(39) 244FR	(45) 128FR
5	89	I-13	(13) 126FK	(52) 242KS	(24) 128SR	(6) 122SR	(34) 184KS	(67) 248FK	(31) 184FK	(41) 186KR	(59) 244KR
6	90	I-71	(14) 126FS	(64) 246KS	(41) 186KR	(27) 182FR	(53) 242KR	(36) 184SR	(7) 124FK	(18) 126SR	(71) 248KR
7	91	I-37	(51) 242FR	(37) 186FK	(70) 248KS	(9) 124FR	(62) 246FS	(31) 184FK	(44) 188FS	(8) 124FS	(18) 126SR
8	92	I-63	(34) 184KS	(11) 124KR	(22) 128KS	(73) 184FS	(44) 188FS	(63) 246FR	(1) 122FK	(32) 184FS	(53) 242KR
9	93	II-64	(31) 184KS	(33) 128KS	(43) 184FR	(12) 122SR	(73) 246FR	(2) 246SR	(64) 242FK	(31) 128KR	(54) 186FS
10	94	I-2	(66) 246SR	(10) 124KS	(50) 242FS	(58) 244KS	(2) 122FS	(18) 126SR	(26) 182FS	(42) 186SR	(34) 184KS
11	95	II-17	(21) 128KR	(22) 126KR	(19) 184KR	(23) 124KR	(65) 188FK	(24) 122KR	(17) 188KR	(18) 186KR	(20) 182KR
12	96	II-52	(16) 242KR	(19) 186KR	(72) 122FK	(46) 126FR	(52) 242FS	(29) 188KS	(63) 244FK	(3) 244SR	(33) 128KS
13	146	II-31	(46) 126FR	(36) 122KS	(58) 126FS	(5) 188SR	(17) 188KR	(69) 128FK	(31) 184KS	(56) 182FS	(11) 124SR

SBJ. CODE IJKLL	SBJ. NO.	BLK. NO.	ORDER OF EXPERIMENTATION (ORDER OF TREATMENT NO. ON P.534, C-C, RANDOMIZED) 1	2	3	4	5	6	7	8	9
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2	98	II-50	(48) 122FR	(61) 248FK	(14) 246KR	(1) 248SR	(20) 182KR	(72) 122FK	(31) 184KS	(35) 124KS	(50) 246FS
3	99	I-32	(12) 124SR	(45) 188FR	(35) 184KR	(57) 244FR	(69) 248FR	(18) 126SR	(32) 184FS	(55) 244FK	(6) 122SR
4	100	II-45	(40) 242FR	(71) 124FK	(45) 128FR	(31) 184KS	(49) 248FS	(60) 122FS	(10) 126SR	(22) 126KR	(3) 244SR
5	101	II-10	(28) 242KS	(55) 184FS	(67) 184FK	(37) 248FR	(1) 248SR	(46) 126FR	(19) 184KR	(64) 242FK	(10) 126SR
6	102	I-29	(29) 182KR	(9) 124FR	(7) 124FK	(19) 128FK	(34) 184KS	(54) 242SR	(48) 188SR	(69) 248FR	(60) 244SR
7	103	I-3	(3) 122FR	(59) 244KR	(19) 128FK	(43) 188FK	(35) 184KR	(11) 124KR	(66) 246SR	(51) 242FR	(27) 182FR
8	104	I-1	(7) 124FK	(2) 122FS	(4) 122KS	(3) 122FR	(5) 122KR	(6) 122SR	(8) 124FS	(1) 122FK	(65) 246KR
9	105	I-41	(47) 188KR	(43) 188FK	(46) 188KS	(44) 188FS	(42) 186SR	(45) 188FR	(48) 188SR	(41) 186KR	(65) 246KR
10	106	I-66	(57) 244FR	(49) 242FK	(25) 182FK	(9) 124FR	(1) 122FK	(33) 184FR	(17) 126KR	(66) 246SR	(41) 186KR
11	107	II-34	(14) 246KR	(3) 244SR	(28) 242KS	(56) 182FS	(70) 126FK	(47) 124FR	(21) 128KR	(57) 128FS	(34) 126KS
12	108	II-72	(47) 124FR	(2) 246SR	(49) 248FS	(32) 182KS	(62) 246FK	(19) 184KR	(36) 122KS	(72) 122FK	(13) 248KR

SBJ. CODE IJKLL	SBJ. NO.	BLK. NO.	ORDER OF EXPERIMENTATION (ORDER OF TREATMENT NO. ON P.534, C-C.RANDOMIZED) 1	2	3	4	5	6	7	8	9
11101	109	II-46	(39) 244FR	(21) 128KR	(4) 242SR	(71) 124FK	(59) 124FS	(50) 246FS	(32) 182KS	(9) 128SR	(46) 126FR
2	110	I-23	(34) 184KS	(61) 246FK	(46) 188KS	(8) 124FS	(49) 242FK	(27) 182FR	(23) 128KR	(12) 124SR	(68) 248FS
3	111	II-26	(26) 246KS	(69) 128FK	(49) 248FS	(37) 248FR	(43) 184FR	(24) 122KR	(14) 246KR	(4) 242SR	(63) 244FK
4	112	II-40	(12) 122SR	(40) 242FR	(41) 188FR	(63) 244FK	(70) 126FK	(30) 186KS	(50) 246FS	(5) 188SR	(19) 184KR
5	113	I-48	(71) 248KR	(57) 244FR	(30) 182SR	(48) 188SR	(11) 124KR	(23) 128KR	(37) 186FK	(52) 242KS	(2) 122FS
6	114	I-60	(27) 182FR	(16) 126KS	(60) 244SR	(17) 126KR	(6) 122SR	(50) 242FS	(47) 188KR	(37) 186FK	(73) 184FS
7	115	I-72	(47) 188KR	(13) 126FK	(72) 248SR	(36) 184SR	(32) 184FS	(2) 122FS	(49) 242FK	(19) 128FK	(62) 246FS
8	116	II-28	(2) 246SR	(41) 188FR	(28) 242KS	(39) 244FR	(69) 128FK	(22) 126KR	(16) 242KR	(61) 248FK	(51) 244FS
9	117	II-39	(64) 242FK	(29) 188KS	(20) 182KR	(42) 186FR	(11) 124SR	(39) 244FR	(70) 126FK	(49) 248FS	(6) 186SR
10	118	II-68	(29) 188KS	(59) 124FS	(68) 182FK	(2) 246SR	(44) 182FR	(14) 246KR	(40) 242FR	(55) 184FS	(17) 188KR
11	119	II-18	(43) 184FR	(39) 244FR	(1) 248SR	(60) 122FS	(56) 182FS	(13) 248KR	(68) 182FK	(18) 186KR	(30) 186KS
12	120	II-38	(70) 126FK	(17) 188KR	(61) 248FK	(32) 182KS	(38) 246FR	(43) 184FR	(52) 242FS	(7) 184SR	(10) 126SR

SBJ. CODE IJKLL	SBJ. NO.	BLK. NO.	ORDER OF EXPERIMENTATION (ORDER OF TREATMENT NO. ON P. 534, C-C, RANDOMIZED) 1	2	3	4	5	6	7	8	9
12001	121	II-14	(33) 128KS	(67) 184FK	(5) 188SR	(23) 124KR	(32) 182KS	(14) 246KR	(42) 186FR	(51) 244FS	(60) 122FS
2	122	I-59	(38) 186FS	(15) 126FR	(18) 126SR	(48) 188SR	(5) 122KR	(59) 244KR	(38) 186FS	(28) 182KS	(73) 184FS
3	123	II-71	(36) 122KS	(27) 244KS	(18) 186KR	(41) 188FR	(71) 124FK	(64) 242FK	(7) 184SR	(14) 246KR	(53) 188FS
4	124	II-3	(59) 124FS	(11) 124SR	(43) 184FR	(51) 244FS	(3) 244SR	(19) 184KR	(35) 124KS	(27) 244KS	(66) 186FK
5	125	I-55	(11) 124KR	(60) 244SR	(41) 186KR	(26) 182FS	(38) 186FS	(72) 244SR	(55) 244FK	(21) 128FR	(8) 124FS
6	126	I-57	(58) 244KS	(57) 244FR	(59) 244KR	(62) 246FS	(61) 246FK	(63) 246FR	(60) 244SR	(64) 246KS	(65) 246KR
7	127	I-16	(35) 184KR	(21) 128FR	(16) 126KS	(49) 242FK	(44) 188FS	(67) 248FK	(58) 244KS	(20) 182SR	(7) 124FK
8	128	II-19	(38) 246FR	(16) 242KR	(42) 186FR	(57) 128FS	(4) 242SR	(31) 184KS	(68) 182FK	(19) 184KR	(53) 188FS
9	129	I-34	(56) 244FS	(14) 126FS	(28) 182KS	(3) 122FR	(57) 244FR	(34) 184KS	(47) 188KR	(70) 248KS	(21) 128FR
10	130	II-15	(57) 128FS	(43) 184FR	(67) 184FK	(50) 246FS	(29) 188KS	(22) 126KR	(9) 182SR	(36) 122KS	(15) 244KR
11	131	II-44	(61) 248FK	(56) 182FS	(33) 128KS	(15) 244KR	(71) 124FK	(26) 246KS	(19) 184KR	(6) 186SR	(44) 182FR
12	132	II-32	(57) 128FS	(69) 128FK	(55) 184FS	(12) 122SR	(32) 182KS	(35) 124KS	(18) 186KR	(6) 186SR	(45) 128FR

SBJ. CODE IJKLL	SBJ. NO.	BLK. NO.	ORDER OF EXPERIMENTATION (ORDER OF TREATMENT NO. ON P.534, C-C,RANDOMIZED) 1	2	3	4	5	6	7	8	9
12101	133	I-38	(43) 188FK	(10) 124KS	(32) 184FS	(38) 186FS	(52) 242KS	(17) 126KR	(61) 246FK	(70) 248KS	(7) 124FK
2	134	II-24	(62) 246FK	(28) 242KS	(68) 182FK	(7) 184SR	(33) 128KS	(50) 246FS	(45) 128FR	(24) 122KR	(11) 124SR
3	135	II-12	(26) 246KS	(3) 244SR	(53) 188FS	(67) 184FK	(39) 244FR	(12) 122SR	(48) 122FR	(62) 246FK	(17) 188KR
4	136	I-51	(45) 242FR	(15) 126FR	(51) 242FR	(34) 184KS	(72) 248SR	(4) 122KS	(30) 182SR	(17) 126KR	(64) 246KS
5	137	II-37	(51) 244FS	(70) 126FK	(44) 182FR	(18) 186KR	(62) 246FK	(9) 128SR	(37) 248FR	(8) 182SR	(31) 184KS
6	138	II-53	(9) 128SR	(28) 242KS	(53) 188FS	(58) 126FS	(43) 184FR	(72) 122FK	(23) 124KR	(40) 242FR	(6) 186SR
7	139	I-42	(17) 126KR	(13) 126FK	(63) 246FR	(29) 182KS	(42) 186SR	(54) 242SR	(71) 248KR	(8) 124FS	(35) 184KR
8	140	II-60	(47) 124FR	(6) 186SR	(60) 122FS	(50) 246FS	(37) 248FR	(17) 188KR	(73) 246FR	(16) 242KR	(27) 244KS
9	141	I-49	(49) 242FK	(50) 242FS	(54) 242SR	(65) 246KR	(56) 244FS	(52) 242KS	(55) 244FK	(51) 242FR	(53) 242KR
10	142	I-64	(64) 246KS	(31) 184FK	(12) 124SR	(43) 188FK	(73) 184FS	(2) 122FS	(33) 184FR	(21) 128FR	(54) 242SR
11	143	I-15	(29) 182KR	(57) 244FR	(36) 184SR	(15) 126FR	(50) 242FS	(67) 248FK	(8) 124FS	(42) 188FK	(22) 128KS
12	144	II-9	(14) 246KR	(16) 244KR	(10) 126SR	(13) 248KR	(15) 244KR	(9) 128SR	(11) 124SR	(12) 122SR	(65) 188FK

Appendix D

Lifting Phase Instructions for Subjects

The objectives of this study are twofold:

1. To secure data on the weight-lifting ability of individuals in a representative work situation.
2. To measure individuals size and strength and relate the lifting ability to these strength and size measures. It is hoped that from this it would be possible to predict the lifting ability from a few measures of strength and size.

THIS IS NOT A TEST TO DETERMINE YOU MAXIMUM WEIGHT LIFTING CAPACITY. I repeat, THIS IS NOT A TEST TO DETERMINE YOU MAXIMUM WEIGHT LIFTING CAPACITY. Rather, it is a study to find reasonable quantities, I repeat, reasonable quantities, that individuals can can lift repetitively throughout the workday.

We want you to imagine that you are on piece work, getting paid for the amount of work that you do, but working a normal eight-hour shift that allows you to go home without feeling "bushed." In other words, we want you to work as hard as you can without straining yourself or without becoming unusually tired, weakened, overheated, or out of breath.

ONLY YOU WILL ADJUST THE WORKLOAD. If you feel that you can work harder without getting overheated, add more weight to the tote box. If you feel you are working too hard and could not keep up the rate for a long period, you should remove some weight from the box. Remember only you will adjust this workload.

DO NOT BE AFRAID TO MAKE ADJUSTMENTS. You have to make enough adjustments so that you get a good feeling for what is too heavy and what is too light. You can never make too many adjustments, but you can make too few.

You will be working today at nine different lifting combinations which involve different heights and frequencies of lift. You will work at each of these combinations for approximately 20 minutes. A signal light and a buzzer on the lifting machine will help you in maintaining the proper pace or speed. When the signal comes on - start your lift. Then return to your normal standing posture and wait for the next signal to start the next lift.

REMEMBER. . . .

THIS IS NOT A CONTEST.

EVERYONE IS NOT EXPECTED TO DO THE SAME AMOUNT OF WORK.

WE WANT YOUR JUDGMENT ON HOW HARD YOU CAN WORK WITHOUT BECOMING UNUSUALLY TIRED.

Remember to adjust the weight, when necessary, so that the tote box represents the maximum weight that you would be willing to lift, at this pace and height, over an eight hour workday.

Appendix E

Experiment Evaluation

Here are a few final questions about the work you were asked to do for this study. Please give your honest opinions, since your answers will help us in future work. Please circle the response for each question that best describes your feelings.

1. In this study, in terms of physical labor I worked:
   a. Much harder than I usually do on my job
   b. Somewhat harder than I usually do
   c. About the same as I usually do
   d. Not quite as hard as I usually do
   e. Not nearly as hard as I usually do

2. The work situation in this study was:
   a. Much more demanding than my regular work situation
   b. Somewhat more demanding than my regular work situation
   c. About the same as my regular work situation
   d. Somewhat less demanding than my regular work situation
   e. Much less demanding than my regular work situation

3. After doing the physical work in this study, I felt:
   a. Much more tired than I usually do at work
   b. Somewhat more tired than I usually do at work
   c. About as tired as I usually do at work
   d. Somewhat less tired than I usually do at work
   e. Much less tired than I usually do at work

4. I think the information from this project:
   a. Will probably be worthwhile
   b. Will probably not be worthwhile

   Please give your reasons:___________________________________

   ____

5. At some future time I would:
   a. Like to be in a study like this again
   b. Not want to participate again
   c. Do not care either way

   Please add any comments you may have about this project:

   ____

   ____

Appendix F

A Preliminary Manual For Selected Anthropometric, Strength, and Endurance Measurements

by

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January 1977

Anthropometric, Strength and Endurance Measurements

General:

Each subject, through written and oral instructions, is briefed concerning the procedure and significance of the various measurements. (See Attachment I for written instructions.)

The various anthropometric, strength, and endurance measurements are taken in accordance with standard procedures. The measurements are:

a) Static Arm Strength

b) Static Shoulder Strength

c) Static Back Strength (2 measurement procedures)

d) Static Leg Strength

e) Static Composite Strength

f) Static Endurance

g) Dynamic Endurance

h) Height

i) Weight

j) Other basic anthropometric measurements and age.

Each measurement procedure is described and shown in the next section.

Accurate strength measurements are dependent on the subject's ability to maintain a steady, even exertion. Any jerks, twists, or other disruptive movements result in the particular reading being cancelled and the measurement repeated.

Each strength measurement is repeated a minimum of three times. The readings recorded are to be consistent within a range of 10%. The individual strength measurements are repeated until three readings within the specified range are obtained. The minimum time interval, after the absolute minimum of one minute, is determined by the subject.

Each individual strength measurement effort is sustained, at the peak value, for a minimum of five seconds.

Anthropometric Measurement Equipment (Figure F-1):

Anthropometric calipers, manufactured by Seibert, were utilized.

Strength Measurement Equipment:

The equipment consists of a load cell and associated electronic circuitry manufactured by Schaevitz (Figure F-2) and hardware manufactured by Texas Tech University laboratories (Figure F-3 and Table F-1.

Endurance Measurement Equipment:

The equipment consisted of a standard stopwatch, a recording of an electronic metronome, and barbell type weights.

Postures:

The procedures used to obtain the various measurements are standard. However, for clarification, each posture and procedure is described and pictorially displayed.

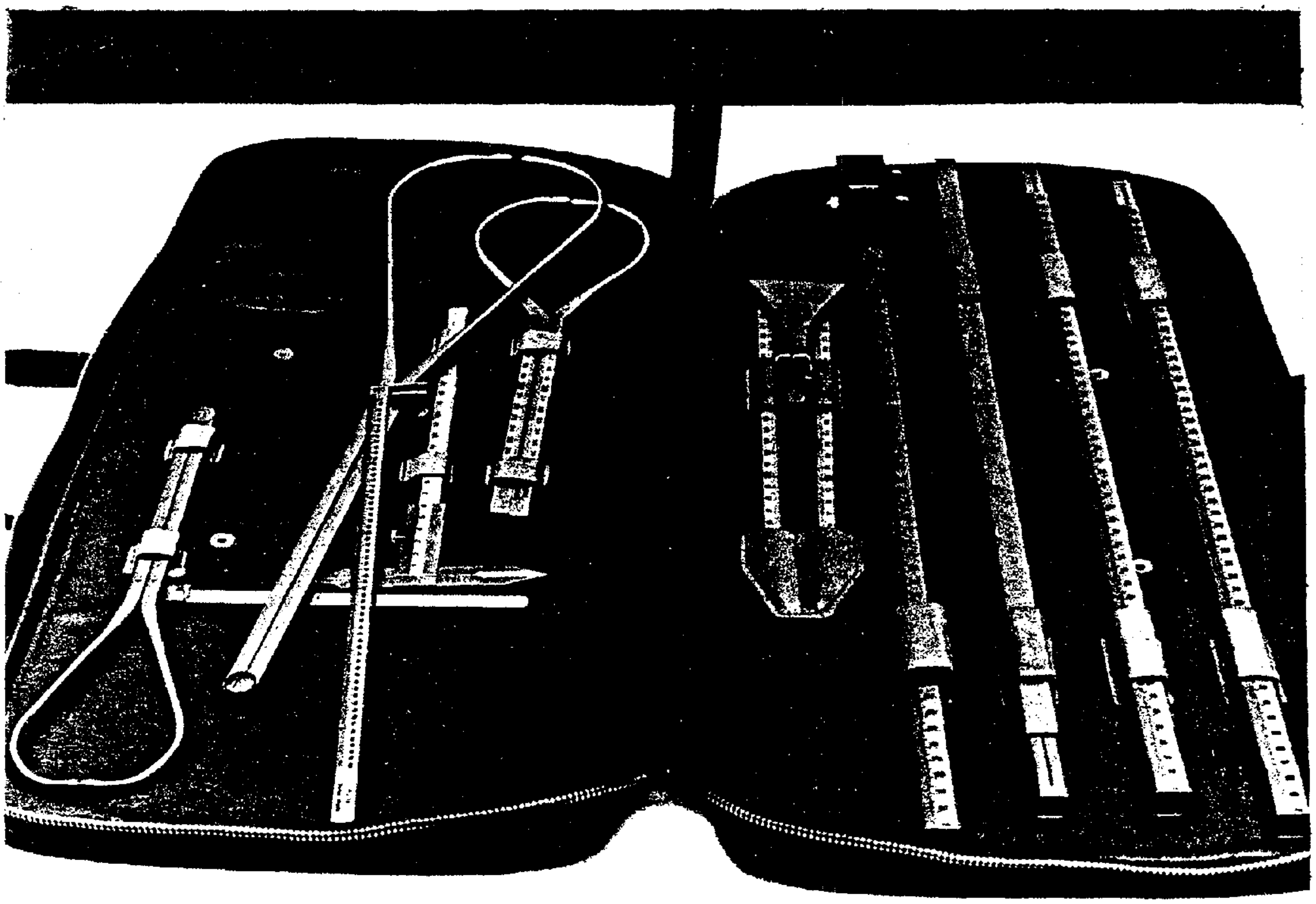


Figure F-1. Anthropometric Measurement Equipment.

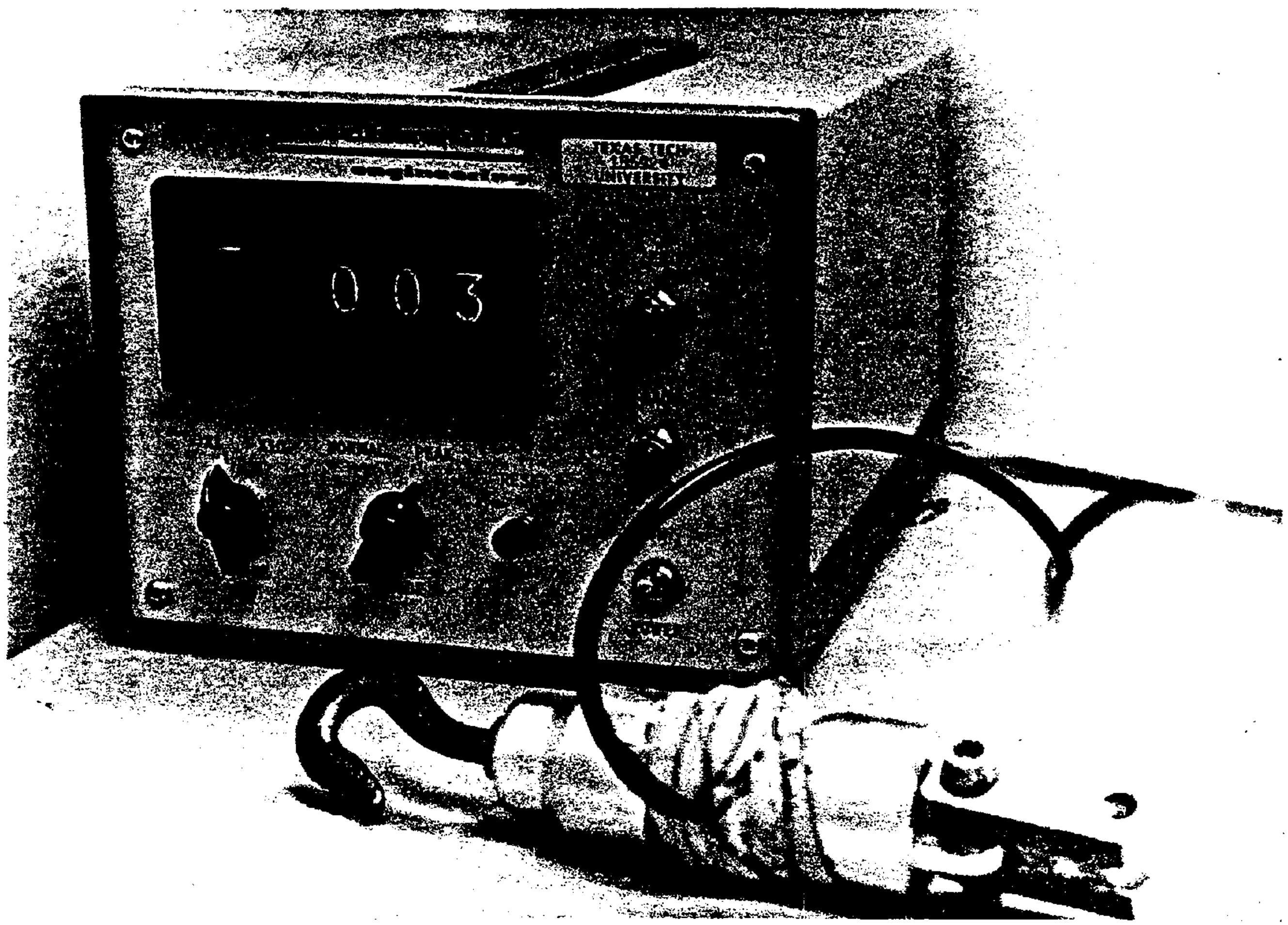


Figure F-2. Strength Measurement Equipment. Load Cell and Associated Electronic Circuitry.

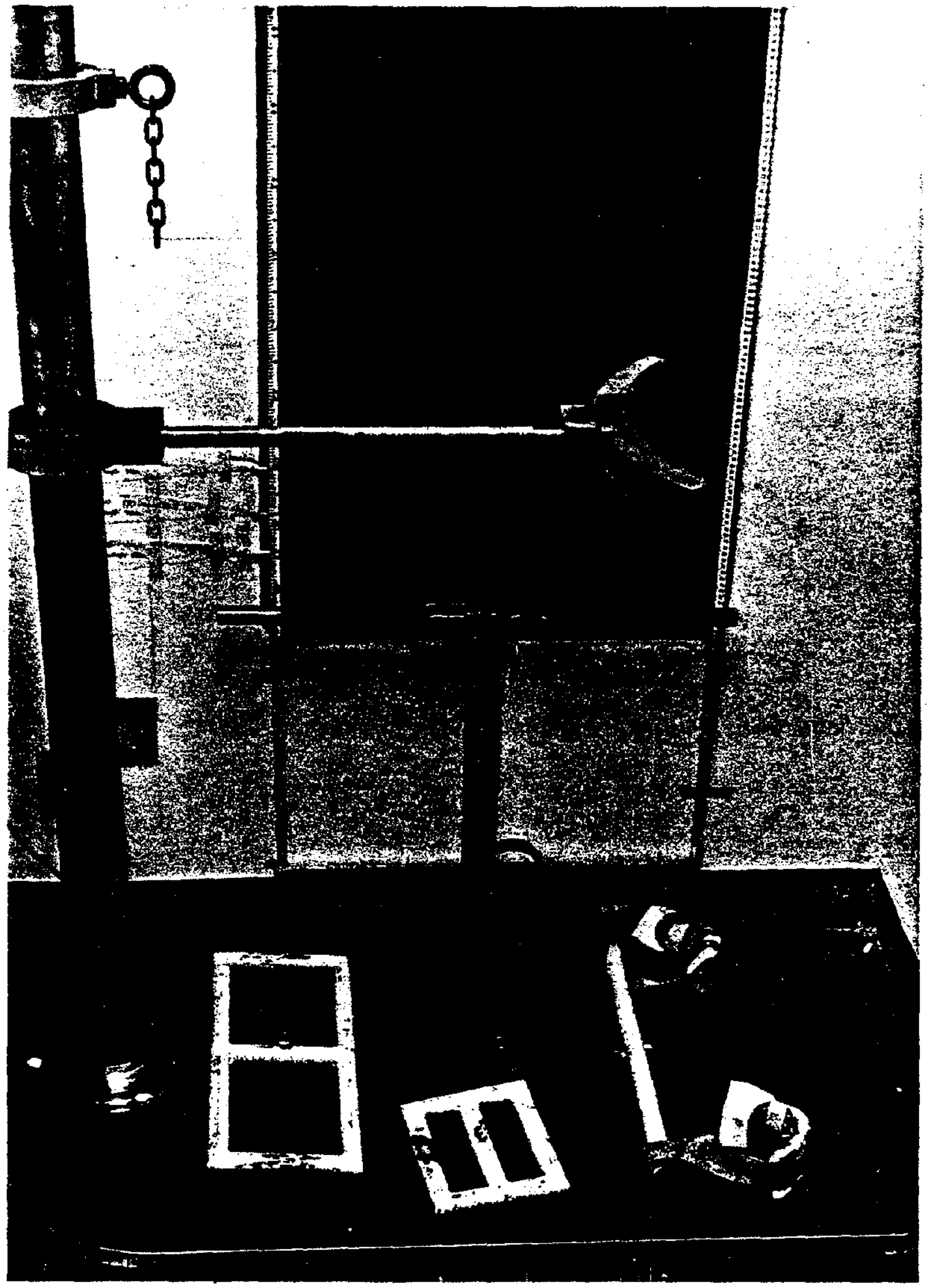


Figure F-3. Strength Measurement Equipment.
Associated Hardware.

TABLE F-1: Strength Measurement Equipment
Associated Hardware Descriptions

Term	Static Strength Measurement	Outside Dimension Inches (cm)	GCS* Inches (cm)	Bar Tube Diameter Inches (cm)	Weight Pounds (kg)	Load Cell/Chain Connection	Comments
Long Handle	Arm Back, Test 1	8 3/8 x 19 1/2 (21.3 x 49.5)	18 1/2 (47)	1 3/16 (3)	3 1/8 (1.42)	On 1 3/16" (cm) diameter tube. At junction of outside dimension bisectors.	Construction: Welded
Short Handle	Composite	7 1/4 x 8 1/2 (18.4 x 21.6)	6 1/8 (15.5)	1 3/16 (3)	2 (.91)	On 1 3/16 (cm) diameter tube. At junction of outside dimension bisectors.	Construction: Welded
Bar with Two Straps	Shoulder	21 (53.3)	18 1/4 (46.4)	OD: 1 3/16 (3) ID: 1 1/16 (2.7)	1 3/4 (.79)	Junction of grip center separation and tube diameter bisectors.	Strap: Cotton, 1 1/2" (58.4) circumference. Supplement with covered foam padding, 3 1/4" wide, 1/2" thick. (1.3 cm)
Padded Board	Back, Test 2	4 1/6 x 26 3/8 (10.3 x 67)	24 1/4** (61.6)	N/A	3 3/8 (1.53)	Connects to adjustable strap at point in midpoint plane of strap connection separation.	Adjustable strap permits standardization of subject posture. Used 7" (17.8 cm) of chain (.24 lb or 0.4 kg).
Padded Brace	Back, Test 2	Total length-26 1/2" Width 2 (5) Inside radius 12 (30.5)	N/A	N/A		N/A	Brace width-16 1/4" Tube length-21" Brace depth at tube connection-3 1/4" Curvature depth-2 7/8"

TABLE F-1: Strength Measurement Equipment
Associated Hardware Descriptions
(Continued)

Term	Static Strength Measurement	Outside Dimension Inches (cm)	GCS* Inches (cm)	Bar Tube Diameter Inches (cm)	Weight Pounds (kg)	Load Cell/Chain Connection	Comments
Bar	Leg	30 (76.2)	N/A	OD: 1 (2.5) ID: 7/8 (22)	2 7/8 (1.3)	Midpoint of bar	NONE
Chain	Arm Back, Test 1 Composite Shoulder Leg	48 (122)	N/A	N/A	1.6/m (.74/m)	Varies; chain kept vertical	
Load Cell	All				1 1/2 (.68)	Kept vertical with exception of back, Test 1 (horizontal)	

* Grip Center Separation

** Strap Connection Separation

Weight (Figure F-4):

The subject is weighed on a standard medical scale with weights recorded to the nearest half pound.

The subjects are lightly clothed (slacks and blouse or shirt). Other items, such as shoes, sweaters, coats, and hats, are removed.

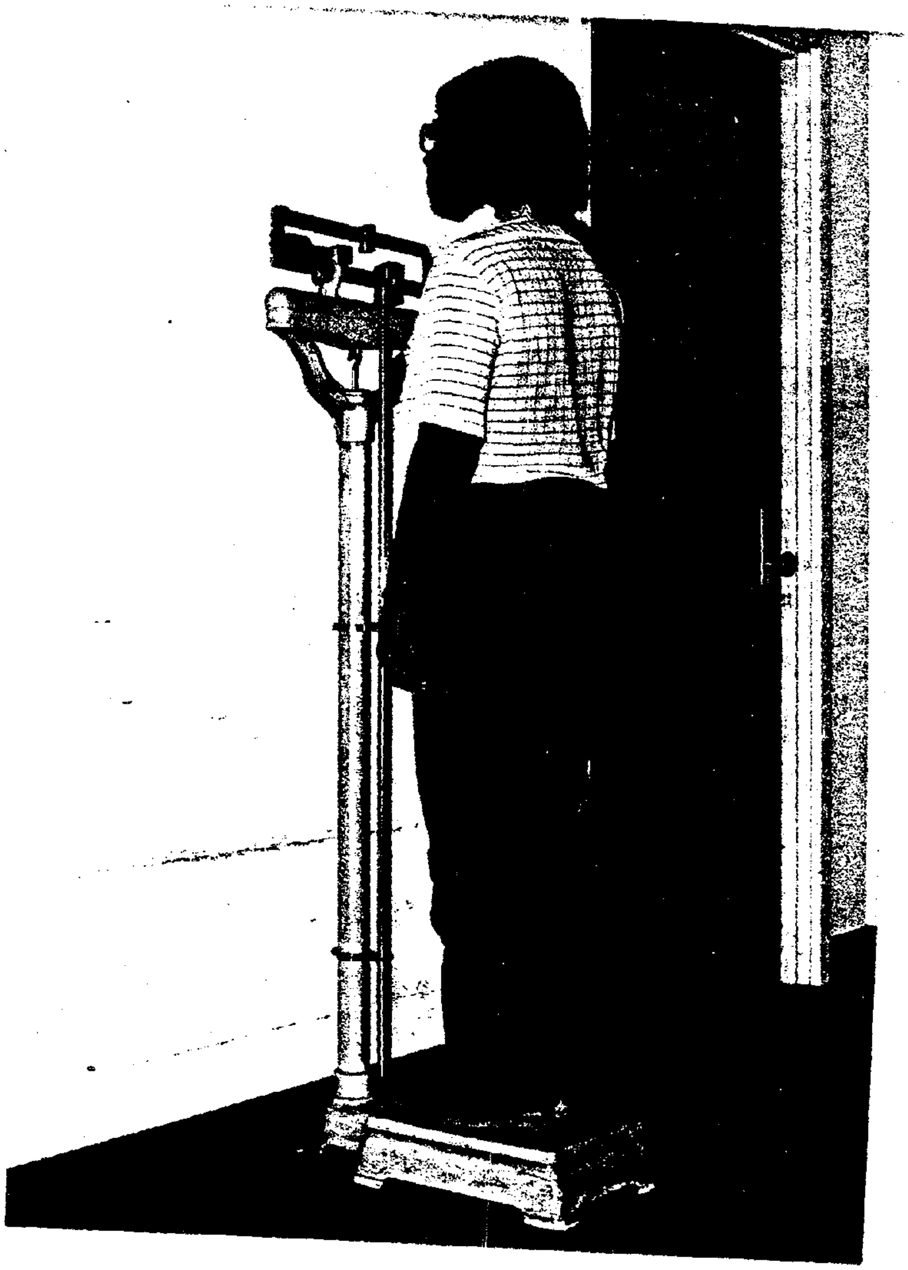


Figure F-4. Subject Weight Measurement.

Height Measurement (Figure F-5):

The subject stands erect against a vertical wall, feet separated at shoulder width, heels, buttocks, and scapulae against the wall, upper extremities adjacent and parallel to lateral surfaces of the torso, and eyes looking straight ahead. The vertical distance is measured, with an anthropometer, firmly contacting the scalp, from the floor to the superior surface of the subject's skull.

Figure F- 5. Subject Height Measurement.

Acromion Height Measurement (Figure F-6):

The measurement is performed on the right side of the subject's body. The subject stands erect against a vertical wall, feet separated at shoulder width, heels, buttocks, and scapulae against the wall, upper extremities adjacent and parallel to the lateral surfaces of the torso, and eyes looking straight ahead. The vertical distance measured, with an anthropometer, is from the floor to the superior lateral border palpable on the margin of the acromion process of the right scapula.

Figure F-6. Subject Acromion Height Measurement.

Knuckle Height Measurement (Figure F-7):

The measurement is performed on the right side of the subject's body. The subject stands erect against a vertical wall, feet separated at shoulder width, heels, buttocks, and scapulae against the wall, upper extremities adjacent and parallel to the lateral surfaces of the torso, and eyes looking straight ahead. The vertical distance is measured, with an anthropometer, from the floor to the third distal metacarpal joint of the right hand.

Figure F-7. Subject Knuckle Height Measurement.

Standing Iliac Crest Height Measurement (Figure F-8):

The measurement is performed on the right side of the subject's body. The subject stands erect against a vertical wall, feet separated to shoulder width, with the heels, buttocks, and scapulae against the wall, upper extremities adjacent and parallel to the lateral surfaces of the torso, and eyes looking straight ahead. The vertical distance is measured, with an anthropometer, from the floor to the anterior superior surface of the iliac spine of the right ilium.

Figure F-8. Subject Standing Iliac Crest Height Measurement.

Knee Height Measurement (Figure F-9):

The measurement is performed on the subject's right leg. The subject stands erect against a vertical wall, with the feet separated at shoulder width, the heels, buttocks, and scapulae against the wall, upper extremities adjacent and parallel to the laterial surfaces of the torso, and eyes looking straight ahead. The vertical distance is measured, with an anthropometer, from the floor to the superior surface of the medial condyle of the right tibia. Experimenter identification of this anthropometric landmark is accomplished as shown in Figure F-10.

Figure F-9. Subject Knee Height Measurement.

Figure F-10. Superior Surface of the Medial Condyle Location Technique.

Forearm Grip Distance Measurement (Figure F-11):

The measurement is performed on the subject's right forearm. The subject stands erect, the right arm is vertical, at the side of the torso and the right forearm is flexed 90° relative to the upper arm. A rod (5/16" in diameter) is held, by the right hand, in a vertical position. The distance (1.1 cm.) measured with an anthropometer is from posterior surface of the olecranon to the vertical axis of the rod.

Figure F-11. Subject Forearm-Grip Distance Measurement.

Chest Depth Measurement (Figure F-12):

The subject stands erect in a comfortable stance. The respiration is to be smooth and normal. The chest depth is measured with a caliper. One end of the instrument is pressed lightly against the sternum at the level of the fourth sterno-costal joint. The other end of the caliper is placed on the back, between the scapulae, also at the level of the fourth sterno-costal joint, such that the caliper tips are in a horizontal plane. Because of the periodic variations in the dimensions of the thoracic cage, wait for a few seconds until the reading is constant. Or, determine visually the median reading and record it.

Figure F-12. Subject Chest Depth Measurement.

Chest Width Measurement (Figure F-13):

The subject stands erect in a comfortable stance. The respiration is to be smooth and normal. The subject's arms are abducted. The tips of the caliper are pressed lightly against the laterial surfaces of the torso at the level of the fourth sterno-costal joint. The subject then adducts the arms and stands erect. Because of the periodic variations in the dimensions of the thoracic cage, wait for a few seconds until the reading is constant. Or, determine visually the median reading and record it.

Figure F-13. Subject Chest Width Measurement.

Abdominal Depth Measurement (Figure F-14):

The subject is required to stand erect in a comfortable stance. One end of the caliper is pressed lightly against the abdomen, one inch below the navel, while the other end of the caliper is placed on the lower back, such that the caliper tips are in the medial plane and in a horizontal plane.

Figure F-14. Subject Abdominal Depth Measurement.

Static Shoulder Strength Measurement (Figure F-15):

The subject stands erect and supports, with both arms, a bar with two straps. The straps are positioned over the distal end of the humerus by inserting the arms outside-in. The arms are flexed to a posture such that the arms are perpendicular to the subject's torso, i.e., at the shoulder level, and the forearms are vertical, i.e., parallel to the torso. The subject's feet are to remain flat, the legs straight, and the back erect. A load cell and a vertical, link chain connect the bar to the platform on which the subject is standing. The exerted force is to be upward, vertical and generated by only the shoulder muscles.

Figure F-15. Subject Posture for Shoulder Strength Measurement.

Static Arm Strength Measurement (Figure F-16):

The measurement requires that the long handle be adjusted such that the forearms are flexed 90°, i.e., perpendicular to the subject's torso, and the arms are vertical, i.e., parallel and adjacent to the torso. The subject stands erect, with legs and back straight and with the feet flat. A load cell and a chain connect the handle to the platform on which the subject is standing. The exerted force is to be upward, vertical and generated by only the arm muscles. The subject is instructed to avoid any shoulder movement.

Figure F-16. Subject Posture for Arm Strength Measurement.

Static Composite Strength Measurement (Figure F-17):

The short handle is adjusted to the height of 15 inches above the platform (the height is measured from the platform to the lower horizontal plane of the handle). The subject is to take a semi-squat position, such that the handle is between the legs. The subject's elbows are extended. Contact between the upper and lower extremities is not permitted. The heads of the first metatarsals are to be placed opposite one another and intersect the vertical plane of the chain and the load cell. The feet are to remain flat on the platform. The subject is to exert an upward, vertical force by extending the knees and simultaneously extending the torso.

Figure F-17. Subject Posture for Composite Strength Measurement.

Static Endurance Measurement (Figure F-18):

The subject is seated on a flat-top stool with scapulae and buttocks against a vertical wall. The forearms are flexed 90°, i.e., perpendicular to the torso.

The subject is to hold, with both arms, a total weight equal to 25% of the subject's average static arm strength. The subject is instructed to hold the weight as long as possible.

Throughout the test, the upper arms are kept vertical and adjacent to, but not contacting the torso. The forearm is horizontal, i.e., perpendicular to the torso. Prior to the measurement the subject assumes the measurement posture. The weight is then handed to the subject. The task duration time is recorded as the static endurance time.

Figure F-18. Subject Posture for Static Endurance Measurement.

Static Back Strength Measurement #1 (Figure F-19):

The long handle is located at 75% of the knee height (tibiale height) and approximately 15 inches in front of the medial malleolus. (The height measurement is from the platform to the lower horizontal plane of the handle.)

The subject's feet are separated at shoulder width. Both feet are kept at an equal distance from the chain anchor point. The subject flexes the torso in order to grip the handle.

The upward, vertical force is exerted by torso extension. The elbows and knees are fully extended and the eyes are looking straight ahead.

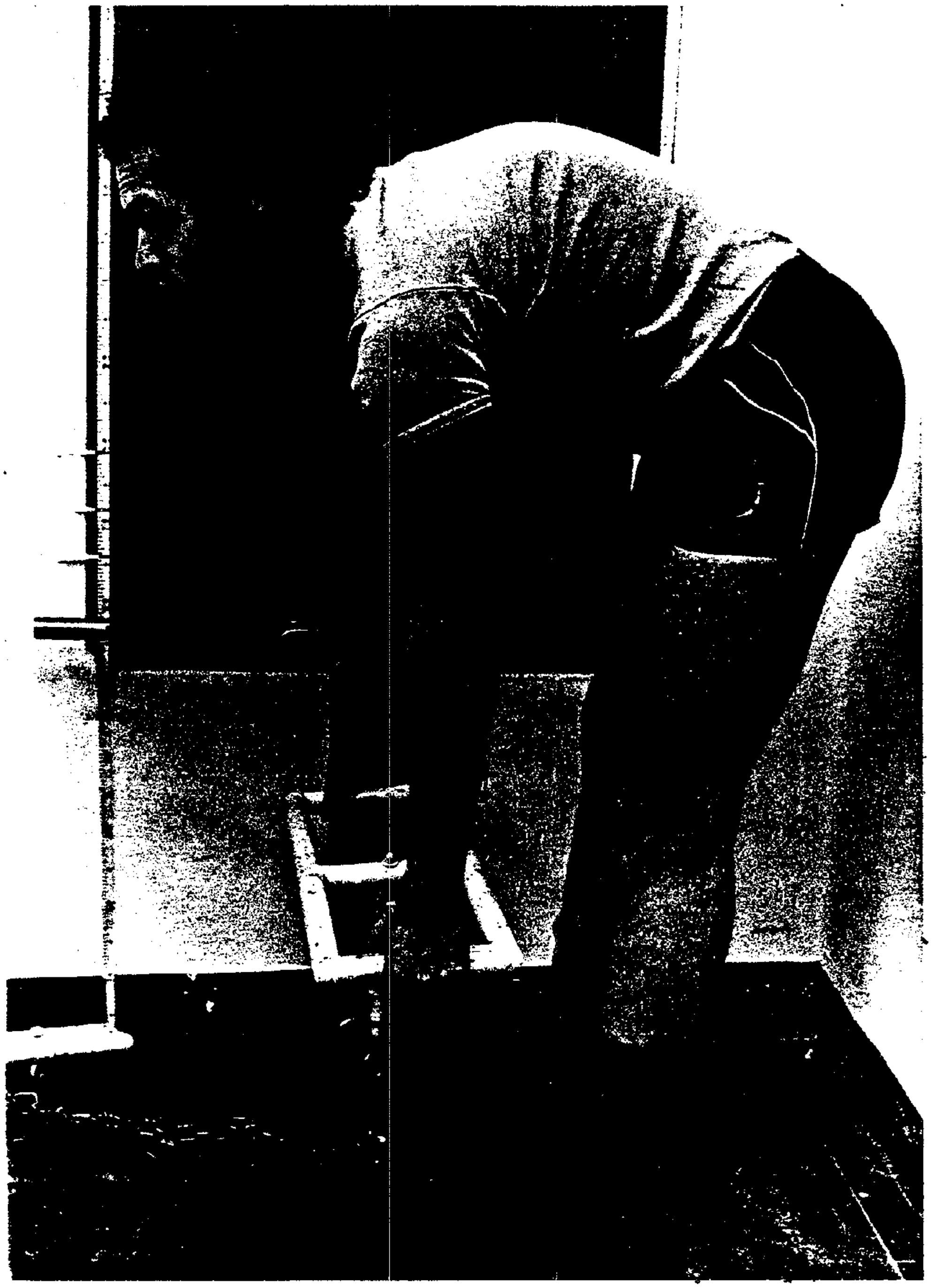


Figure F-19. Subject Posture for Back Strength Measurement #1.

Static Back Strength Measurement #2 (Figure F-20):

The subject stands erect and rests the anterior surfaces of the pelvis and the abdominal muscles against a padded brace. The brace is adjusted to a height such that the subject can comfortably apply a horizontal pelvic/abdominal pressure. A padded board is placed on the subject's back at the level of the posterior surface of the crest of the spine on the scapulae. The load cell is hooked to a strap which is connected to the padded board. A link chain connects the load cell to a vertical brace. The chain and load cell are to be kept perpendicular to the torso.

The measurement requires the subject to exert a horizontal, rearward force against the padded board, by extending the torso. The knees are fully extended, the upper extremities are parallel to the lateral surfaces of the torso and the feet are kept flat.

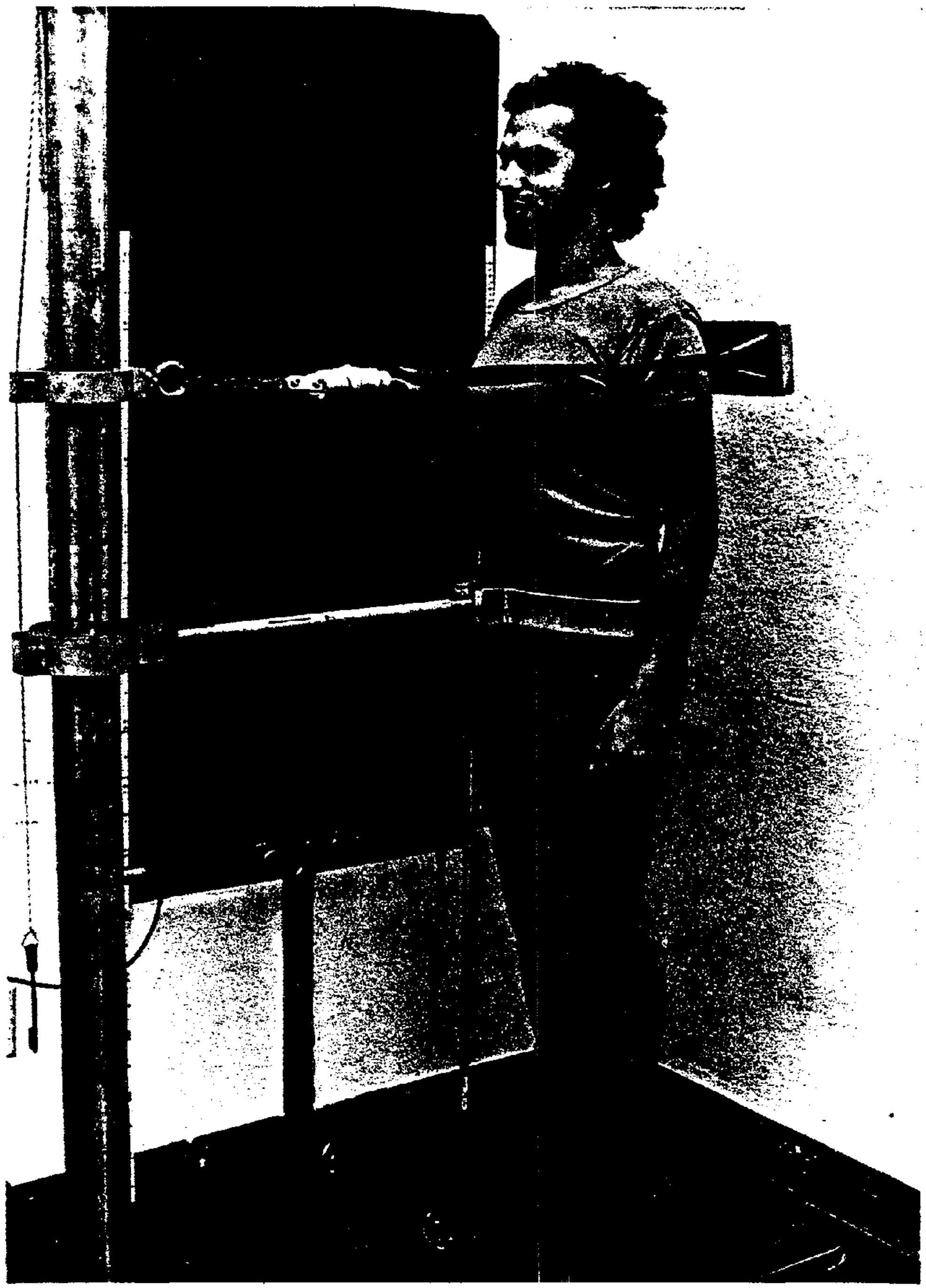


Figure F-20. Subject Posture for Back Strength Measurement #2.

Static Leg Strength Measurement (Figure F-21):

The height of the bar is based on the subject's stature:

a) For subject heights equal to or below 169.5 cm, the bar is placed at a height of 66 cm.

b) For subject heights between 169.5 cm and 179 cm, the bar is placed at a height of 72 cm.

c) For subject heights equal to or greater than 179 cm, the bar is placed at a height of 79 cm.

The horizontal bar is gripped with the palm of the hands (finger grasping is not permitted) such that the dorsal surfaces of the hands are facing outward (visible to the experimenter). The subject exerts an upward, vertical force on the bar, by extending the knees, while keeping the scapulae, the buttocks, and the heels against a common vertical plane, such as a wall. The feet are to be kept flat.

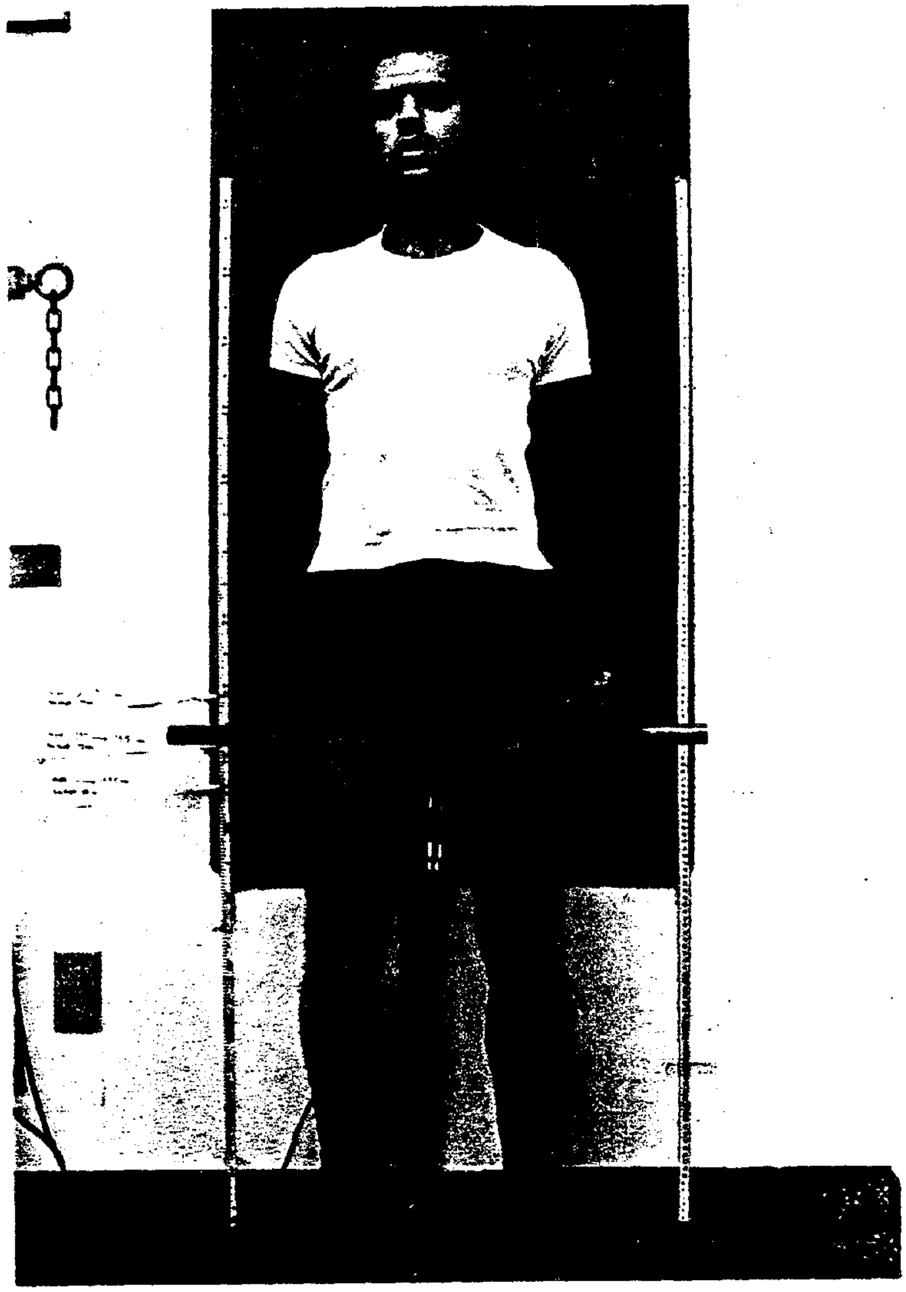


Figure F-21. Subject Posture for Static Leg Strength Measurement.

Dynamic Endurance Measurement (Figures F-22 & F-23):

The subject stands erect, against a wall, while holding, with both hands, bar/weights at the waist level (Figure F-22). (Heels, buttocks and scapulae maintain contact with the wall.) The total bar/weight is 25% of the subject's average static arm strength.

Prior to the measurement the subject is instructed to maintain the established task pace of 50 movements per minute for as long as possible. The pace is established by the percussion of an electronic metronome recorded on a cassette tape.

The subject assumes the measurement posture and is handed the weights. The subject rhythmically lifts and lowers, by elbow flexion and extension, the weights from a horizontal plane (established by 90° flexion of the elbow from the anatomical position) to the chest and vice versa (Figure F-23). The only movement permitted is that of the elbow joint. The task duration time is recorded as the dynamic endurance time.

Figure F-22. Subject Initial Posture for Dynamic Endurance Measurement.

Figure F-23. Subject Sequential Posture for Dynamic Endurance Measurement.

Attachment F-I

Measurement Instructions for Subjects

The experiment that you are going to participate in as a subject has as its objective the determination of the capacity of an individual to lift weights. There are two parts to this experiment. First, the measurement of your body size and strength and second, the actual lifting of the industrial type tote box containing lead weights.

During the first part of the study certain dimensions of your body will be measured. The experimenter will need to locate particular bony land marks on your body by pressing the fingers (experimenter's) against the skin. Measurements such as arm length, shoulder height, chest depth and so on will be made. During this phase you should be wearing light clothing so the joints and bony land marks can be accurately located.

The strength measurements deal with your maximum capability to apply force under a given condition. It is your maximum strength that is needed. Let me repeat that: it is your maximum strength that is needed. In order to obtain the maximum strength you will need to exert the force smoothly over three or four seconds. Hold it for five seconds and then release. Again, in order to obtain the maximum strength you will need to build up the force smoothly over three or four seconds. Hold that position for five seconds and then release. While building up the force do not pull suddenly or jerk or shake.

Appendix G

Measurement Instructions for Subjects

The purpose of the experiment that you are going to participate in as a subject has as its objective the determination of capacity of an individual to lift weights. There are two parts to this experiment. First the measurement of your body size and strength which will be performed in a few minutes and secondly the actual lifting of the industrial type tote box full of weights.

During the first part of the study certain dimensions of your body will be measured. The experimenter will need to locate certain bony land marks on your body by pressing his fingers against the skin. Measurements such as arm length, standing knee heights, so forth will be made. During this phase you should be wearing light clothing so the joints and bony landmarks can be accurately located.

The strength measurements which will be made deal with your maximum capability to apply force under a given condition. Remember it is your maximum strength that is needed. Remember it is your maximum strength that is needed. In order to obtain the maximum strength you need to build up the force smoothly over three or four seconds. Hold it for two seconds or so and then release. In order to obtain the maximum strength you need to build up the force smoothly over three or four seconds. Hold it for five seconds or so and then release. Do not pull suddenly or jerk or shake while pulling. Let me repeat that again, while pulling do not pull suddenly or jerk or shake.

If you have any doubts about what is expected of you, do not hesitate to consult the experimenter who will be on duty in the room with you at all times. The success of the experiment depends on your understanding of the verbal and written instructions and performing accordingly. Thank you for your participation.

Appendix H

Subject Measurement Data Collection Form

Lifting Experiment

Subject Name ______________ ___ ______________ Code

Sex ___M ___F

1.	Date ______________		Time ________ AM PM		
2.	Temperature	______ °F ______ °C	Humidity ______ %		
3.	Shoulder Strength	____ lb ____ kg	____ lb ____ kg	____ lb ____ kg	
4.	Arm Strength	____ lb ____ kg	____ lb ____ kg	____ lb ____ kg	
5.	Composite Strength	____ lb ____ kg	____ lb ____ kg	____ lb ____ kg	
6.	Static Endurance (25%)	____ min			
7.	Age		____ yrs		
8.	Weight			____ lb ____ kg	
9.	Height	____ cm	Bar Ht Class ____		
10.	Shoulder Height	____ cm			
11.	Knuckle Height		____ cm		
12.	Standing Iliac Crest Height			____ cm	
13.	Knee Height	____ cm			
14.	Fore arm-grip distance		____ cm		
15.	Static Back Strength Test #1	____ lb ____ kg	____ lb ____ kg	____ lb ____ kg	
16.	Test #2	____ lb ____ kg	____ lb ____ kg	____ lb ____ kg	
17.	Leg Strength	____ lb ____ kg	____ lb ____ kg	____ lb ____ kg	

Subject Code

18. Chest Depth ______ cm

19. Chest Width ______ cm

20. Abdominal Depth ______ cm

21. RPI = $H/\sqrt[3]{W}$

22. Dynamic Endurance (25%) ______ min

Appendix I

Psychological Test Battery

Lifting Experiment

OPINION QUESTIONNAIRE I

There are a number of areas of life listed below. Please ask yourself how satisfied you are with each area, then circle one response on the left in each case.

If you feel Very Dissatisfied, circle VDS

If you feel Dissatisfied, circle DS

If you cannot decide one way or the other, circle N

If you feel Satisfied, circle S

If you feel Very Satisfied, circle VS

Very Dissatisfied	Somewhat Dissatisfied	Neutral	Somewhat Satisfied	Very Satisfied	
VDS	SD	N	S	VS	1. My health
VDS	SD	N	S	VS	2. My family's health
VDS	SD	N	S	VS	3. My financial situation
VDS	SD	N	S	VS	4. My marriage
VDS	SD	N	S	VS	5. My children
VDS	SD	N	S	VS	6. My job
VDS	SD	N	S	VS	7. My social life
VDS	SD	N	S	VS	8. The world situation

Very Dissatisfied	Somewhat Dissatisfied	Neutral	Somewhat Satisfied	Very Satisfied		
VDS	SD	N	S	VS	9.	My community
VDS	SD	N	S	VS	10.	In general, the way I am spending my life these days

The next items refer to your present job. Please circle one answer, just as you have done above, to tell how satisfied you are with these aspects of your job.

VDS	SD	N	S	VS	11.	Being able to keep busy all the time
VDS	SD	N	S	VS	12.	The chance to work alone on the job
VDS	SD	N	S	VS	13.	The chance to do different things from time to time
VDS	SD	N	S	VS	14.	The chance to be "somebody" in the community
VDS	SD	N	S	VS	15.	The way my boss handles his men
VDS	SD	N	S	VS	16.	The competence of my supervisor in making decisions
VDS	SD	N	S	VS	17.	Being able to do things that don't go against my conscience
VDS	SD	N	S	VS	18.	The way my job provides for steady employment
VDS	SD	N	S	VS	19.	The chance to do things for other people
VDS	SD	N	S	VS	20.	The chance to tell people what to do
VDS	SD	N	S	VS	21.	The chance to do something that makes use of my abilities
VDS	SD	N	S	VS	22.	The way company policies are put into practice
VDS	SD	N	S	VS	23.	My pay and the amount of work I do
VDS	SD	N	S	VS	24.	The chance for advancement on this job
VDS	SD	N	S	VS	25.	The freedom to use my own judgment
VDS	SD	N	S	VS	26.	The chance to try my own methods of doing the job

Very Dissatisfied	Somewhat Dissatisfied	Neutral	Somewhat Satisfied	Very Satisfied	
VDS	SD	N	S	VS	27. The working conditions
VDS	SD	N	S	VS	28. The way my co-workers get along with each other
VDS	SD	N	S	VS	29. The praise I get for doing a good job
VDS	SD	N	S	VS	30. The feeling of accomplishment I get from the job

OPINION QUESTIONNAIRE II

Listed below are pairs of statements. Please read one pair at a time, then decide which statement of the pair you agree with the most. If you strongly prefer the statement labeled A, circle the capital A. If you only slightly prefer A, circle the lower case a. Similarly, if you strongly prefer B, circle capital B. If you only slightly prefer B, circle the lower case b.

Here is an example.

A a B b 1. A. Around here, we get some of the best weather in the country.

B. The weather around here is miserable.

Circling A would mean you very much like your weather, and B would be the opposite. If you didn't have strong feelings either way, but thought your weather was a little better than average, you would circle a. If a little worse than average, b.

Now, please proceed to circle one letter for each of the following pairs of statements.

A a B b 1. A. Becoming a success is a matter of hard work, luck has little or nothing to do with it.

B. Getting a good job depends mainly on being in the right place at the right time.

A a B b 2. A. The best games are games of chance.

B. The best games are those involving only skill.

A a B b 3. A. In my work, I demand too much of myself.

B. I do only what I have to do to get by at work.

A a B b 4. A. Most people don't realize the extent to which their lives are controlled by accidental happenings.

B. There really is no such thing as "luck."

A a B b 5. A. I would only bet on a sure thing.

B. I like to take a big chance now and then.

A a B b 6. A. I usually do more than I had planned to do.

B. I usually get much less done than I had planned.

A a B b 7. A. I enjoy working more than most people.

B. Working is something I would rather not do.

A a B b 8. A. Many times I feel that I have little influence over the things that happen to me.

B. It is impossible for me to believe that chance or luck plays an important role in my life.

A a B b 9. A. I like taking on added responsibilities.

B. I wish I had fewer responsibilities than I do now.

A a B b 10. A. I hardly ever finish things I've started.

B. I almost always finish what I start.

A a B b 11. A. Other people think I work too hard.

B. Other people think I take life pretty easy.

A a B b 12. A. Life would be dull if people didn't take risks.

B. The best life would be free of all risks.

A a B b 13. A. I seem to work for long periods oftime without getting tired.

B. I find it's important to take frequent rest breaks while working.

A a B b 14. A. It would be an ideal life if people didn't have to work.

B. A life without work would be very unpleasant.

A a B b 15. A. I stick to difficult jobs longer than I should.

B. When something is difficult, I give up quickly.

OPINION QUESTIONNAIRE III

The purpose of the next section is to measure the meanings of various concepts to you by having you judge them against a series of descriptive scales. Please make your judgments on the basis of what these concepts mean to you. You will find a series of concepts to be judged, and under each, a set of scales. You are to rate the concept on each of these scales in order.

Here is how you are to use these scales:

If you feel that the concept which the scale refers to is very closely related to one end of the scale, you should place your check mark as follows:

FAIR : X : ___ : ___ : ___ : ___ : ___ : ___ : UNFAIR

OR

FAIR : ___ : ___ : ___ : ___ : ___ : ___ : X : UNFAIR

If you feel that the concept is quite closely related to one or the other end of the scale (but not extremely), you should place your check mark as follows:

STRONG : ___ : X : ___ : ___ : ___ : ___ : ___ : WEAK

OR

STRONG : ___ : ___ : ___ : ___ : ___ : X : ___ : WEAK

If the concept seems only slightly related to one side as opposed to the other side (but is not really neutral), then you should check as follows:

ACTIVE : ___ : ___ : X : ___ : ___ : ___ : ___ : PASSIVE

OR

ACTIVE : ___ : ___ : ___ : ___ : X : ___ : ___ : PASSIVE

The direction toward which you check, of course, depends on which of the two ends of the scale seem most characteristic of the thing you're judging.

If you consider the concept to be neutral on the scale, both sides of the scale equally unassociated with the concept, or if the scale is completely irrelevant, unrelated to the concept, then you should place your check mark in the middle space.

SAFE : ___ : ___ : ___ : X : ___ : ___ : ___ : DANGEROUS

IMPORTANT: (1) Place your check marks in the middle of spaces, not on the boundaries:

:____: X :____:____:____:____:X____:

THIS NOT THIS

(2) Be sure you check every scale for every concept-- DO NOT OMIT ANY.

(3) Please do not put more than one check mark on a single scale.

Physical pain is:

NICE	:	:	:	:	:	:	:	AWFUL
ACTIVE	:	:	:	:	:	:	:	PASSIVE
PAST	:	:	:	:	:	:	:	SLOW
RUGGED	:	:	:	:	:	:	:	DELICATE
HEALTHY	:	:	:	:	:	:	:	SICK
GOOD	:	:	:	:	:	:	:	BAD
LARGE	:	:	:	:	:	:	:	SMALL
STRONG	:	:	:	:	:	:	:	WEAK
YOUNG	:	:	:	:	:	:	:	OLD
SHARP	:	:	:	:	:	:	:	DULL
BRAVE	:	:	:	:	:	:	:	COWARDLY

My job is:

GOOD :____:____:____:____:____:____:____: BAD

HEALTHY :____:____:____:____:____:____:____: SICK

RUGGED :____:____:____:____:____:____:____: DELICATE

FAST :____:____:____:____:____:____:____: SLOW

ACTIVE :____:____:____:____:____:____:____: PASSIVE

NICE :____:____:____:____:____:____:____: AWFUL

BRAVE :____:____:____:____:____:____:____: COWARDLY

STRONG :____:____:____:____:____:____:____: WEAK

SHARP :____:____:____:____:____:____:____: DULL

YOUNG :____:____:____:____:____:____:____: OLD

LARGE :____:____:____:____:____:____:____: SMALL

My life in general is:

SHARP :____:____:____:____:____:____:____: DULL

BRAVE :____:____:____:____:____:____:____: COWARDLY

NICE :____:____:____:____:____:____:____: AWFUL

ACTIVE :____:____:____:____:____:____:____: PASSIVE

FAST :____:____:____:____:____:____:____: SLOW

RUGGED :____:____:____:____:____:____:____: DELICATE

HEALTHY :____:____:____:____:____:____:____: SICK

GOOD :____:____:____:____:____:____:____: BAD

LARGE :____:____:____:____:____:____:____: SMALL

STRONG :____:____:____:____:____:____:____: WEAK

YOUNG :____:____:____:____:____:____:____: OLD

Work is:

BRAVE :____:____:____:____:____:____:____: COWARDLY

NICE :____:____:____:____:____:____:____: AWFUL

ACTIVE :____:____:____:____:____:____:____: PASSIVE

FAST :____:____:____:____:____:____:____: SLOW

RUGGED :____:____:____:____:____:____:____: DELICATE

HEALTHY :____:____:____:____:____:____:____: SICK

GOOD :____:____:____:____:____:____:____: BAD

LARGE :____:____:____:____:____:____:____: SMALL

STRONG :____:____:____:____:____:____:____: WEAK

YOUNG :____:____:____:____:____:____:____: OLD

SHARP :____:____:____:____:____:____:____: DULL

Appendix J

Initial Contact Letter and Enclosure

Sept. 28, 1976

Mr. Bill Smith
XYZ Company
1200 N. Main
Arlington, TX 76010

Dear Mr. Smith:

The problem of occupational injury due to lifting is a serious problem in industrial settings where the manual handling of materials is required. In light of rapidly increasing injury related costs, any attempt to reduce the frequency and severity of such injuries seems justified. An experimental research project, currently underway at the University of Texas at Arlington, is attempting to provide a tool which could be used to aid the industrial sector in the proper selection and placement of individuals in materials handling. The results of the research will enable personnel departments to predict the likelihood of injury for a prospective employee if placed in a specific lifting job.

This letter is a request for your aid in providing the human subjects and certain other information upon which to base the research. Enclosed is a description of the research project and the specific research needs for which help is being requested.

The participating companies will be given complete access to all research findings. The use of the expected results would certainly lead to cost savings both from the potential reduction of injury costs and from the increased effectiveness of the placement activity. In addition, currently available criteria for the design of materials handling jobs will be given to the participating companies. Your favorable consideration in this matter will be greatly appreciated. All questions are welcome.

Sincerely,

D.H. Liles

Reply to: D.H. Liles
Department of Industrial Engineering
University of Texas at Arlington
Arlington, TX 76019
817/273-3092

Enclosure: Lifting Research - D.H. Liles

1. Research Description

The experiment will consist of certain physical strength measurements to be taken from each of a large number of human subjects provided by industry. Each set of individual measurements will be used as inputs for a previously defined and verified mathematical model which predicts the maximum allowable weight of lift for a given individual working in a specific job. The maximum allowable weight of lift for each individual will then be compared to the actual weight of lift required by that individual's job. The entire set of such comparisons or ratios will then be statistically correlated to the incidence of subsequent injury. The result will be a function describing the likelihood of lifting injury given the ratio of actual job requirements to predicted individual capacity.

2. Experimental Subjects

The experimental subjects must satisfy certain specifications. Each subject:

- must be involved in lifting activity
- must have been engaged in the activity for at least six months
- must be between 20 and 50 years of age
- may be either male or female
- must have no previous lifting related injury
- must be a volunteer

3. Testing

Each subject must complete a questionnaire and must undergo a series of strength measurements. The testing procedure will take place within each participating facility and will require approximately thirty minutes per subject. The testing should be done in a private area of the plant to reduce the effects of external influences such as passers by. Testing will commence in September 1976.

4. Injury Data

The prior injury history of each subject is to be determined either from medical records or by the use of the questionnaires. In addition, the occurrence of subsequent injury during the duration of the research must be reported and recorded. This information is required for use in the determination of the probability function.

5. Job Requirements

The job lifting requirements for each subject or group of subjects are needed. This information is to be obtained either from the formal job description or by experimental observation done by the experimenters.

Appendix K

Job Description Procedure

I. Job Description: MASTER

A. Assign to each job, within a company, a unique two digit identification number. Place the appropriate company code and the job identification number in a box A.

B. Record the job title on line B. If the everyday title is different from the official title, specify both.

C. Record the average length of the work week (Box C: number of days).

D. Record the average length of the workday or shift (Box D: number of hours).

E. Record the number of shifts per day on which the job is performed (Box E).

F. After all sub-tasks are defined, record the number of lifting and non-lifting sub-tasks defined (Boxes F and G).

G. Write a general description of the job in question. Refer to all sub-tasks by number as assigned in the sub-task description (i.e., L-1, NL-2). Refer to position using the layout on the sub-task form(s).

H. Use the "comments" section to describe any unusual aspects of the job such as adverse environmental conditions.

II. Job Description: Lifting Sub-Task

A. Record the job code in Box A.

B. Assign and record an identification number for the sub-task (Box B).

C. Estimate and record the proportion of the work day that the task is performed (Box C). If the sub-task in question is performed simultaneously with other sub-tasks, record the proportion as a percent of the number of hours that the tasks are performed (i.e. 2 sub-tasks performed alternately all day each consuming 50% of 8 hours). If the sub-task is performed by itself, record as 100% of the number of hours the sub-tasks 1, 2, & 3 are performed simultaneously for 3 hours per day and sub-task 4 is performed alone for 5 hours. Indicate which sub-tasks are performed simultaneously, if any.

D. Record the number of days per week that the sub-task is performed (Box D).

E. Record the lifting range in the FROM-TO boxes. In the FROM box record the distance from the worker's <u>hand level at lift initiation</u> to the surface upon which the feet are resting. In the TO box record the distance from the worker's <u>hand level at lift termination</u> to the surface upon which the feet are resting. If worker normally assumes a posture other than standing (i.e. sitting), the measurement should be made to that support surface. Make special note of any posture other than standing on feet. Record any variation in initiation or termination points as a comment.

F. Record the load dimension (Box F). The dimension required is the physical front to back size of the load as measured along a line perpendicular to the lateral plane of the body. Measure this distance in inches.

G. Record the lifting frequency (Box G). Record this frequency in lifts per minute. The frequency recorded should apply only to the sub-task being described and the appropriate time period. (i.e. Suppose item A is lifted 300 times during a five hours period. The frequency recorded should be: 300 ÷ (5 X 60) = 1 lift/minute for 5 hours.)

H. Record the weight of lift (Box H).

NOTE: A lifting sub-task may contain considerable variation in terms of E, F, & H. If the variation in dimension, point of lift initiation or termination, or weight is approximately uniform over a given range of variation, indicate the average in the appropriate box and note the range of variation as a comment. Non-uniform variation should be handled using multiple sub-task descriptions.

III. Job Description: Non-Lifting Sub-Task

Complete Boxes A, B, C, and D in the same manner prescribed for lifting sub-tasks. Provide a general written description of the non-lifting sub-task.

Appendix L

Master Job Description Form

Job Description: MASTER

A. Code A. ________

B. Job Title ________________________

C. Length of Work Week C. ________

D. Length of Workday (Shift) D. ________

E. Number of Shifts E. ____

F. Number of Lifting Sub-Tasks Defined F. ____

G. Number of Non-Lifting Sub-Tasks Defined G. ____

Written Description (General)

Comments

Appendix M

Sub-Task Description Forms

Job Description: LIFTING SUB-TASK

A. Code — A. ______

B. Sub-Task — # ____ out of ____

C. % of Hrs. — C. ______

D. Days/Week — D. _____

E. Range — From _____ in. to _____ in.

F. Dimension — F. _____ in.

G. Frequency — G. ___ lifts per _____

H. Weight — H. ____ lbs.

Comments and Layout

Job Description: NON-LIFTING SUB-TASK

A. Code A. _____-_____

B. Sub-Task # _____ out of _____

C. % of Hrs. C. _______________

D. Day/Week D. _____

E. Written Description

B. Sub-Task # _____ out of _____

C. % of Hrs. C. _______________

D. Days/Week D. _____

E. Written Description

Appendix N

Job Injury History Procedure, Forms and Data Summary

I. Injury History

For each defined job, provide a three year job injury history. These histories should be taken from OSHA or other appropriate records and should include:

1. The reported date of injury.
2. The name of the injured employee.
3. The loss attributed to the injury (workdays lost, termination from company or job, or fatality),
4. The nature of the injury (Provide a clear description of the injury including the part of the body injured, the type of injury, permanent or temporary impairment, and medical attention required.),
5. The description of the incident (This should be a clear and complete description of how, when, and where the injury occurred.).

NOTE:
All injuries that have occurred on the particular job should be recorded, even if a particular injury is not a direct result of lifting. If the job has changed sometime during the three year period, the injury history should include only those injuries pertaining to the current job.

II. Injury History Summary

A. Each injury history should be summarized.

B. Fill in the appropriate job code, job title, and time period.

C. Estimate the total number of worker hours worked during the time period for the job being summarized. This estimate should be as accurate as possible.

D. Record the date of injury, loss, type and cause of injury for each injury that occurred, using type and cause codes.

Injury History Collection Form

Pg. ___ of ___ JOB INJURY HISTORY Company Code ____________

Date of Injury	Employee's Name	ID	Loss WD's, T, LD,F	Nature of Injury	Description of Incident	Job #

Injury History: SUMMARY

A. Code A. ______

B. Job Title ______

C. Time Period Summarized C. ______

D. Total Number of Worker-Hours Worked D. ______

#	Work Days Lost	Light Duty Days	Termi-nation	L/NL, Type	Comments

Injury History Data

Symbols:

1. CJ = company/job code
2. HR = exposure hours
3. WT = maximum weight lifted (lbs)
4. FR = frequency of lift (lifts/min)
5. WR = work rate (inch-pounds/min)
6. LI = number of lifting injuries
7. LL = number of days lost due to lifting injuries
8. NI = number of non-lifting injuries
9. NL = number of days lost due to non-lifting injuries
10. TI = total number of injuries
11. TL = total number of days lost
12. T1, T2, T3, T4, T5 = number of injuries of type 1, 2, 3, 4, 5
13. L1, L2, L3, L4, L5 = number of days lost due to injuries of type 1, 2, 3, 4, 5

Appendix O

Explanations of Project and Instructions
for Subject Measurement

The purpose of the project: Formulation of Job Design Methods for Lifting Activities, is to provide the management of your company with the capability of designing lifting jobs so that you and others are subjected to a smaller chance of injury than may now be the case. In addition to the physical measurements taken today, certain measurements have already been taken which describe your job. The injury history of your job has also been determined.

You are asked, today, to do two things. First of all, you are asked to fill out a questionnaire which asks several things about you and your job. Secondly, you are asked to allow the experimenter to take several of your physical measurements. There are two types of measurements to be taken. These are explained below.

The first series of measurements is to determine certain of your body dimensions. The experimenter will need to locate certain bony landmarks on your body. He will locate these landmarks by pressing his finger on your skin. He will make measurements of your height, weight, knuckle height, shoulder height, chest depth, abdominal depth, knee height, and forearm grip distance.

The second series of measurements consists of certain strength measurements which will measure your maximum capability to exert force. These measurements are the composite, arm, back, dynamic endurance, and shoulder strength measurements. For these measurements, it is your maximum safe strength that is needed. Remember, it is your maximum safe strength that is needed. In order to obtain your maximum safe strength you should build up the force smoothly over three or four seconds; hold it for five seconds; and then release slowly. Remember, in order to obtain your maximum safe strength, you should build up the force smoothly over three or four seconds; hold it for five seconds; and then release slowly. Do not pull suddenly, jerk, or shake during the measurement. Remember, do not pull suddenly, jerk, or shake during the measurement. As was just stated, it is your maximum safe strength that is needed. Do not exert yourself beyond your safe limit.

You will be given special instructions for each measurement when it is made. You will also be shown a photograph of each measurement to be made.

The strength measurements require physical exertion and therefore, there is a chance of injury such as sore muscles. The risk of injury is very small if all instructions are carefully followed. If you do have an injury, it will be handled just as if you had been injured on your regular job.

If you have any doubts about what is expected of you at any time during the experiment, please stop and ask the experimenter. The success of this experiment depends upon your understanding of the instructions and upon your correct performance. Thank you for your participation.

Appendix P

Pre-test Questionnaire and Consent Form

Subject Questinnaire

Subject Code:

Job Code:

1. Name: ______________________________
2. Address: ______________________________
3. Phone: ______________
4. Employer: ______________________________
5. Division/Department: ______________________
6. Employer's Address: ______________________
7. Job description:
   A. Name of job? ______________________
   B. How many times per hour do you lift? ______________
   C. What objects do you normally lift? ______________
   D. What are the sizes of these objects? ______________
   E. What are the weights of these objects? ____________
   F. Where do you lift From? ______________________
   G. Where do you lift To? ______________________
8. Length of employment:
   A. How long have you been doing this job? ____________
   B. If less than three months, did your previous job require lifting? ______________________
   C. If yes, reanswer question 7 for your previous job. ________

   ____

   ____

9. Physical Data:

A. Have you ever sought medical attention for lower back pain? Yes, No. If yes, explain.______________________________

____

B. Have you suffered extreme lower back pain without consulting medical personnel? Yes, No. If yes, when?______________

____

C. Are you now or have you ever been treated for high blood pressure? Yes, No. If yes, explain. __________________

____

D. Have you suffered extreme shoulder or arm pain? Yes, No. If yes, which arm?____________ shoulder?__________________ Did you receive medical attention? Yes, No.

E. Have you lost time from work recently due to lower back pain or arm or leg problem? Yes, No. Which?________________

F. Do you participate in an exercise program? Yes, No. If yes, on which of the following type of basis?_____________

1. Regular (at least three times a week)
2. Intermitten (less than three times a week)
3. Occasionally (whenever you feel like it)

G. Do you have a hernia? Yes, No.

H. Have you had any corrective treatment for a hernia? Yes, No. If yes, how many times? When?______________________

I. How much sleep did you have last night? _______ hours. Is this normal, less than normal, more than normal?__________

J. Time since last meal? ______ hours. Is this normal, less than normal, more than normal?____________________________

K. Are you now taking any type of medication? Yes, No. If yes, what is the medication, the nature of your illness?______

____

L. Have you ever had a heart attack: Yes, No. Have you or do you now have heart disease or a heart condition? Yes, No.

Informed Consent

I hereby voluntarily consent to participate in the study entitled: Formulation of Job Design Methods for Lifting Activities. I understand that these studies are part of an Industrial Engineering research project. I have had the purpose and risks of participation explained to me by the investigator responsible for conducting the studies and I understand these risks. The risks are possible stresses on the musculoskeletal system such as sore muscles or possible muscle injury due to muscle exertion. However, the probability of such injuries is small when the instructions are carefully followed. I understand that if I do have an injury, it will be handled just as if I were injured at my regular job. I have answered the questions on the attached subject questionnaire to the best of my knowledge. I also understand that I may discontinue this study at any time that I choose and that I give up no legal rights by signing this document. I understand that my identity will he held confidential.

Subject Signature____

Signature of responsible investigator____________________

Witness____

Date____

Appendix Q

Subject Measurement Data Collection Form

Data Sheet: Date:____________ Time:__________

Subject Name:____

Job Code ________________ 1.

Sex M. F. Subject Code ____________ 2.

Age (yrs.) ______ 3.

Weight ______lbs. Weight Code ______ 4.

Height (cm.) ______ 5.

Shoulder Height (cm.) ______ 6.

Knuckle Height (cm.) ______ 7.

Knee Height (cm.) ______ 8.

Abdominal Depth (cm.) ______ 9.

Chest Depth (cm.) ______ 10.

RPI ______ 11.

Forearm Grip Distance (cm.) ______ 12.

Shoulder Strength (lb.) ______ 13.

Arm Strength (lb.) ______ 14.

Composite Strength (lb.) ______ 15.

Back Strength #2 (lb.) ______ 16.

Dynamic Endurance (min.) ______ 17.

Appendix R

Post Measurement Injury Data Collection Instructions and Forms

Instructions for Completion of Injury Data Report #1 and #2

(Please Read)

1. Please leave right hand column blank.

2. Please answer all questions on the front side of each individual's report with reference to the date of measurement, the effective date of the report and the job in which the individual is or was working. These three pieces of information are given on each report form. Please use the comments section to give additional details such as suspected fraudulent injury claim or injury resulting in death or permanent disability.

3. Injury Block (reverse side of Report form).

   A. Please report <u>every</u> injury, appearing in your records, sustained by the individuals in question. No injury is too minor to report.

   B. Please report all injuries in chronological order starting with the first injury occurring after the date of measurement.

   C. Please report the number of workdays lost and the number of light duty days worked as a result of each injury. This information is the same as is recorded on your OSHA report. If the individual has not returned to work or to full duty, please put "NOT RETURNED" in the appropriate space.

   D. Please describe the nature of the injury. This description should be sufficient to determine the type of injury (strain, cut, etc.) and the part of the body affected (leg, lower back, eye, etc.)

   E. Please describe the incident causing injury (if known). This description should be sufficient to determine whether or not injury was caused by the lifting or handling of materials.

   F. Please record the total number of hours worked by the individual (excluding light duty) between the date of last injury (or date of measurement) and the date of this injury. <u>Please make this and all total hours worked estimates as accurately as possible</u>.

4. If needed, please use additional injury blocks included in the packet. Be sure to record the name of the individual on the additional injury blocks.

5. Please return reports in the enclosed envelope as soon as conveniently possible. If there are any questions please call Don Liles at 817/273-3092.

Injury Data Report #1

Company: ______________________________ ______

Job: ______________________________ ______

Subject: ______________________________ ______

Date of Measurement: ______________________ ______

Effective Date of this Report: ________________ ______

1. Is this individual still working on the <u>same job</u> as shown above? Yes No ______

   If No, was the transfer or termination a result of an on the job injury: Yes No ______

   Date of transfer or termination (if any): ______________ ______

2. How many total hours has this individual worked <u>on the above job</u> (excluding light duty) between the date of measurement and the effective date of this report (or date of transfer or termination)? The dates are shown above. ______Hours ______

3. Did this individual have a record of injury <u>on the above job</u> prior to the date of measurement? Yes No ______

   If Yes, please record the total number of hours worked by this individual (excluding light duty) between the date of most recent injury (prior to date of measurement) and the date of measurement. ______Hours ______

   If No, please record the total number of hours worked by this individual between the date of employment on this job and the date of measurement. ______Hours ______

4. Has this individual been injured one or more times <u>on the above job</u> since the date of measurement? Yes No ______

If Yes, please complete an injury block (reverse side) for each injury. (See instructions.)

5. Comments: (Refer to injury by number)

Injury Data Report #2

Company: ______________________________ ______

Job: ______________________________ ______

Subject: ______________________________ ______

Date of Last Report: ______________________ ______

Effective Date of this Report: ________________ ______

1. Is this individual still working on the same job as shown above? Yes No ______

   If No, was the transfer or termination a result of an on the job injury? Yes No ______

   Date of transfer or termination (if any): ______________ ______

2. How many total hours has this individual worked on the above job (excluding light duty) between the date of last report and the effective date of this report (or date of transfer or termination)? The dates are shown above. ______ Hours ______

3. Has this individual been injured one or more times on the above job since the date of last report? Yes No ______

   If Yes, please complete an injury block (reverse side) for each injury. (see instructions)

4. Comments: (Refer to injury by number)

Date of First injury: ________________________ ______

Number of regular work-days lost as a result of
this injury: ________ Days ______

Number of light duty days worked as a result of
this injury: ________ Days ______

Nature of this injury: ________________________ ______

____

Description of incident causing injury: ____________ ______

____

____

Total number of hours worked by this individual between the date of measurement and the date of this injury, excluding light duty: ________ Hours ______

Date of Second injury: ________________________ ______

Number of regular work-days lost as a result of
this injury: ________ Days ______

Number of light duty days worked as a result of
this injury: ________ Days ______

Nature of this injury: ________________________ ______

____

Description of incident causing injury: ____________ ______

____

____

Total number of hours worked by this individual between the date of the first injury and the date of this injury, excluding light duty: ________ Hours ______

Reverse Side of Reports #1 and #2

Additional Injury Blocks

Subject Name: ________________________________

Date of ______ injury: ________________________________ ________

Number of regular work-days lost as a result of
this injury: ____________ Days ________

Number of light duty days worked as a result of
this injury: ____________ Days ________

Nature of this injury: ________________________________ ________

____

Description of incident causing injury: ________________ ________

____

____

Total number of hours worked by this individual between
the date of the ______ injury and the date of this injury,
excluding light duty: ____________ Days ________

Subject Name: ________________________________

Date of ______ injury: ________________________________ ________

Number of regular work-days lost as a result of
this injury: ____________ Days ________

Number of light duty days worked as a result of
this injury: ____________ Days ________

Nature of this injury: ________________________________ ________

____

Description of incident causing injury: ________________ ________

____

____

Total number of hours worked by this individual between
the date of the ______ injury and the date of this injury,
excluding light duty: ____________ Days ________

Post Measurement Injury Data

Symbols:

1. CC-JC = company code - subject code
2. MEAS DT = measurement date (1 July 77 = 1)
3. REPORT DT = date of last injury report (1 July 77 = 1)
4. #HRS WKD = number of hours worked during study period
5. TERM DT = date of employee termination (if any)
6. PRIOR INJ = whether or not subject had one or more injury on this job prior to measurement
7. PRIOR HRS = number of hours that the subject worked between the date of last injury (if prior injury) or date of employment (if no prior injury) and the date of measurement.
8. INJ# = injury number
9. DT = date of injury (1 July 77 = 1)
10. TYPE = type of injury "X-Y"

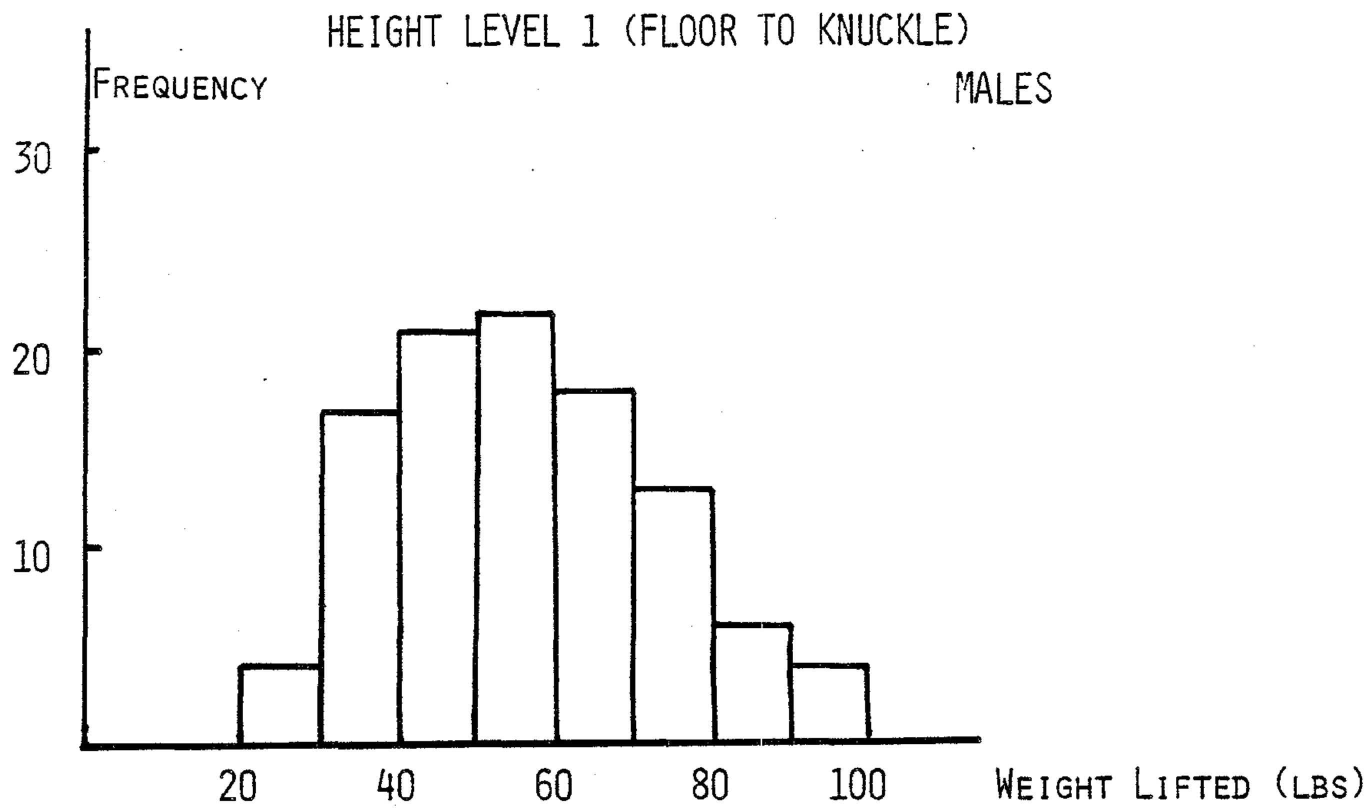
    X = 1 if lifting injury

    = 0 if non-lifting injury

    Y = 1,2,3,4,5 as described in Chapter 3
11. DAYS LOST = number of days lost due to injury
12. HRS = number of hours worked between last injury (or measurement date) and this injury

Appendix S

Lifting Capacity Histograms



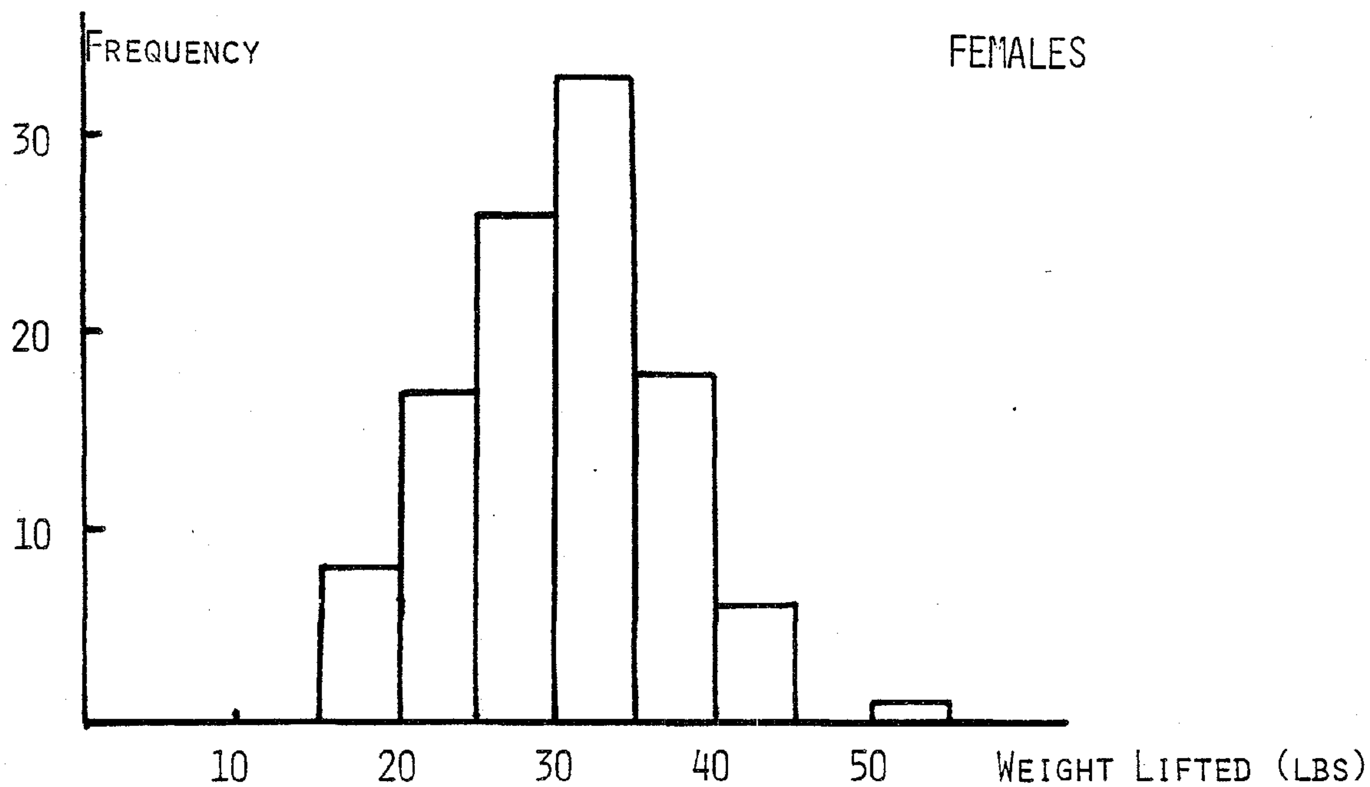
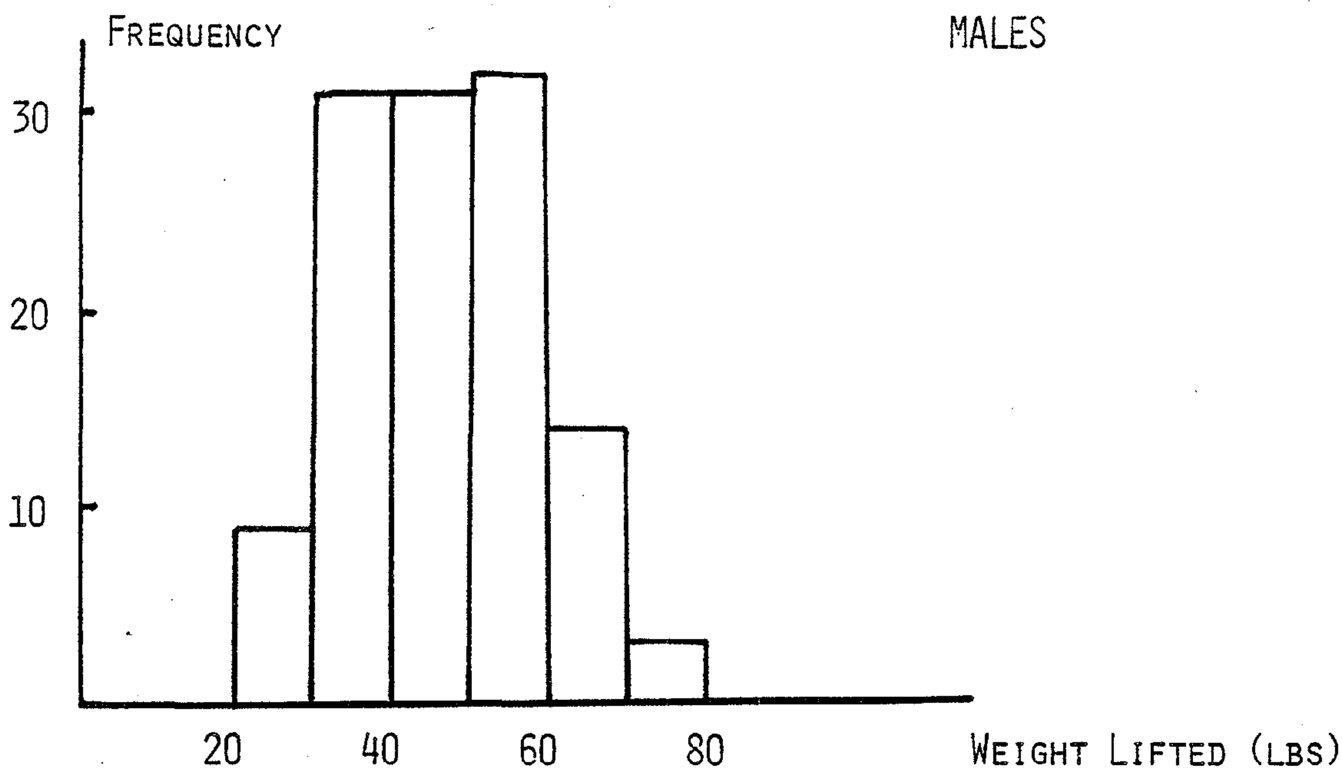


Figure S-1. Lifting Capacity Histograms for Floor to Knuckle Height

HEIGHT LEVEL 2 (FLOOR TO SHOULDER)



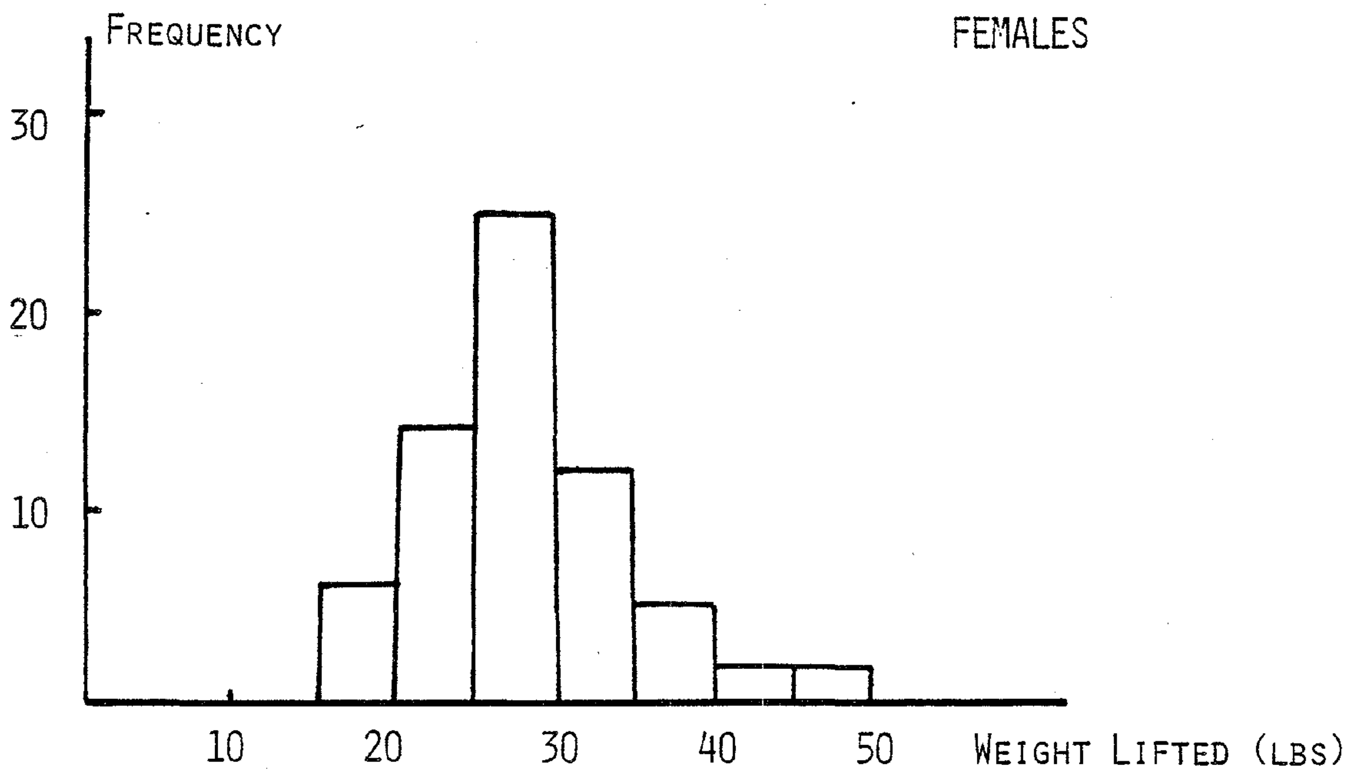
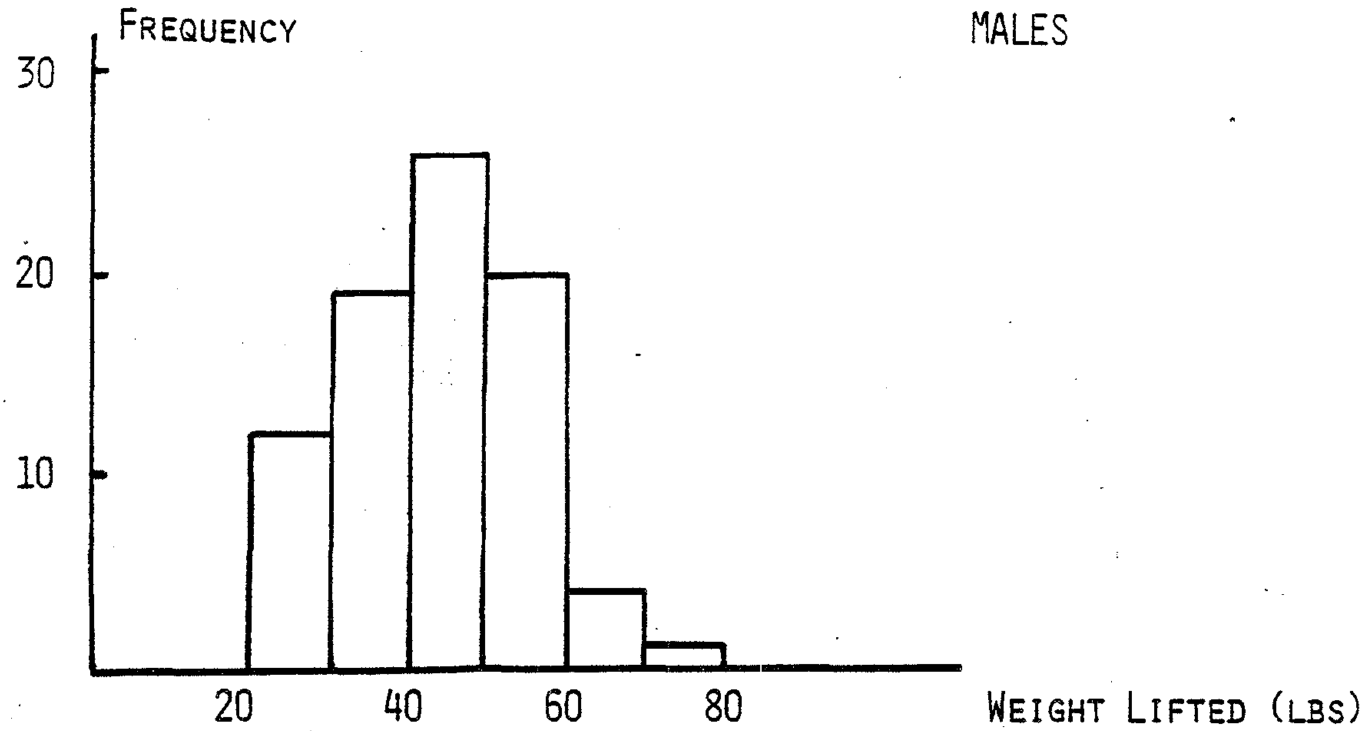


Figure S-2. Lifting Capacity Histograms for Floor to Shoulder Height

HEIGHT LEVEL 3 (FLOOR TO REACH)



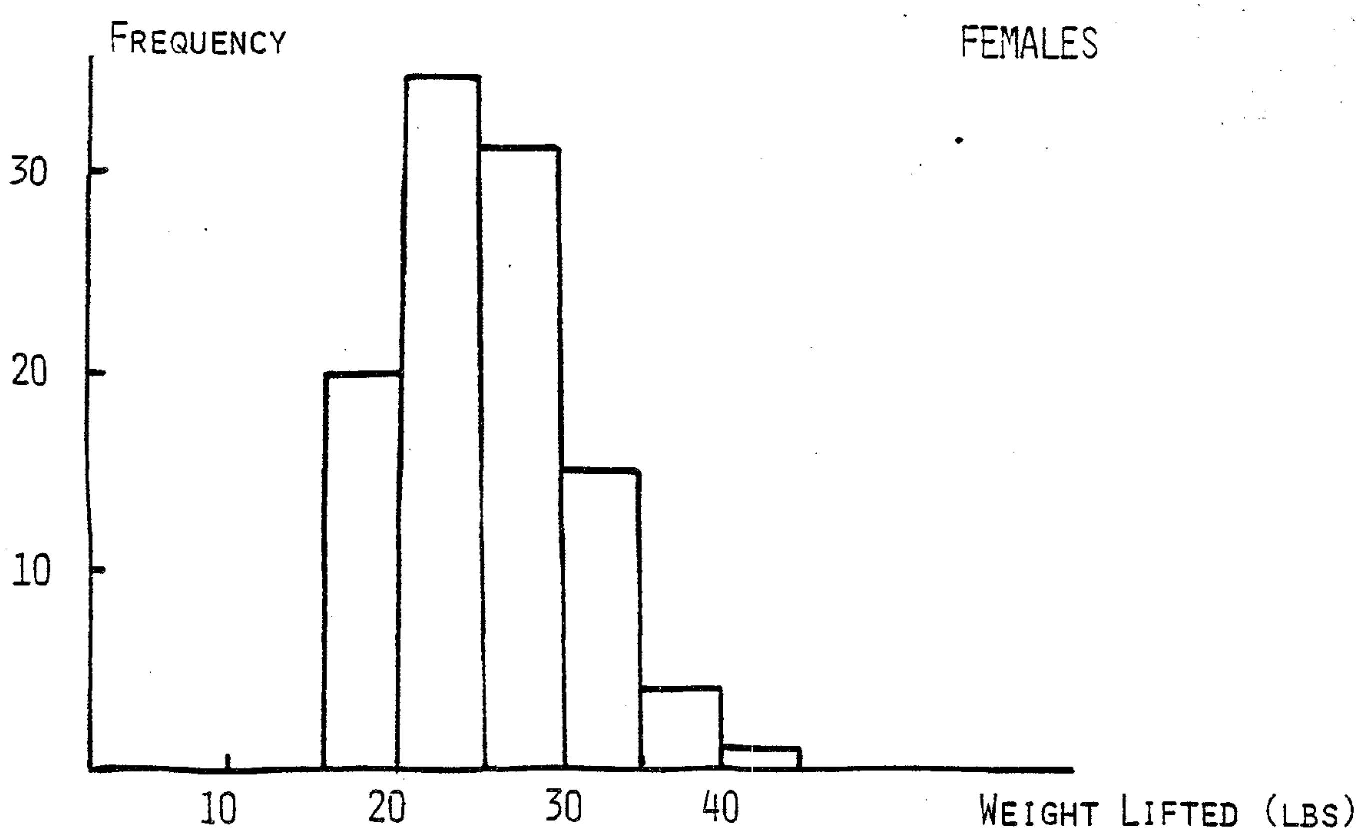
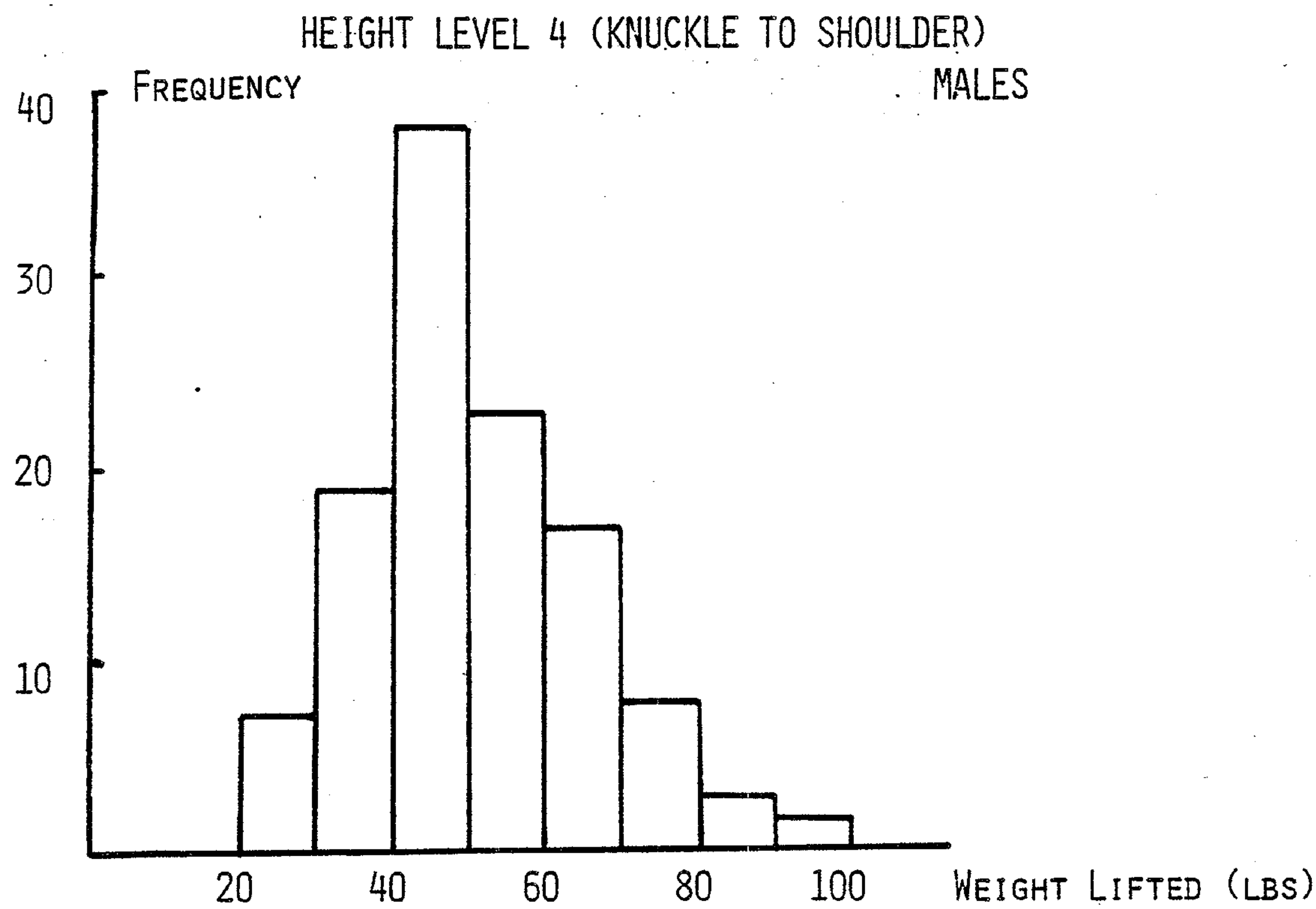


Figure S-3. Lifting Capacity Histograms for Floor to Reach Height



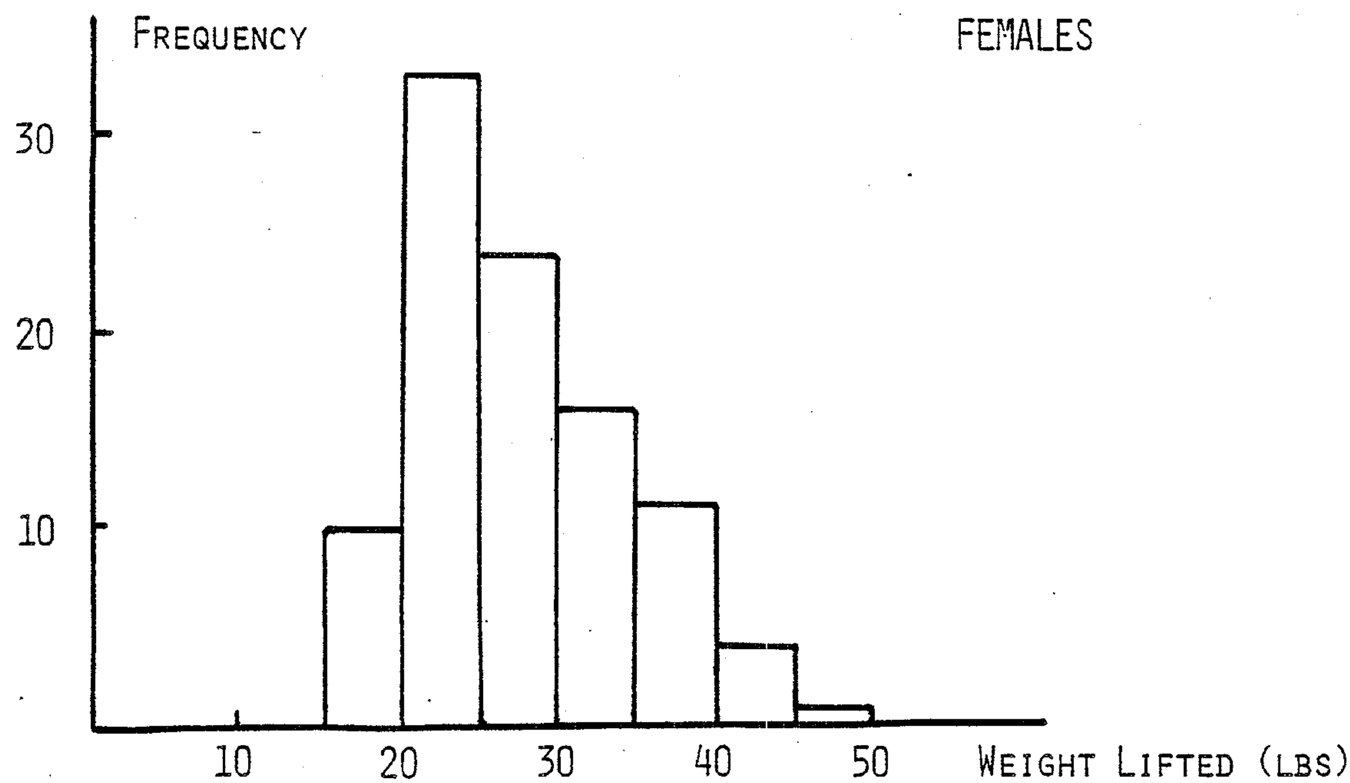


Figure S-4. Lifting Capacity Histograms for Knuckle to Shoulder Height

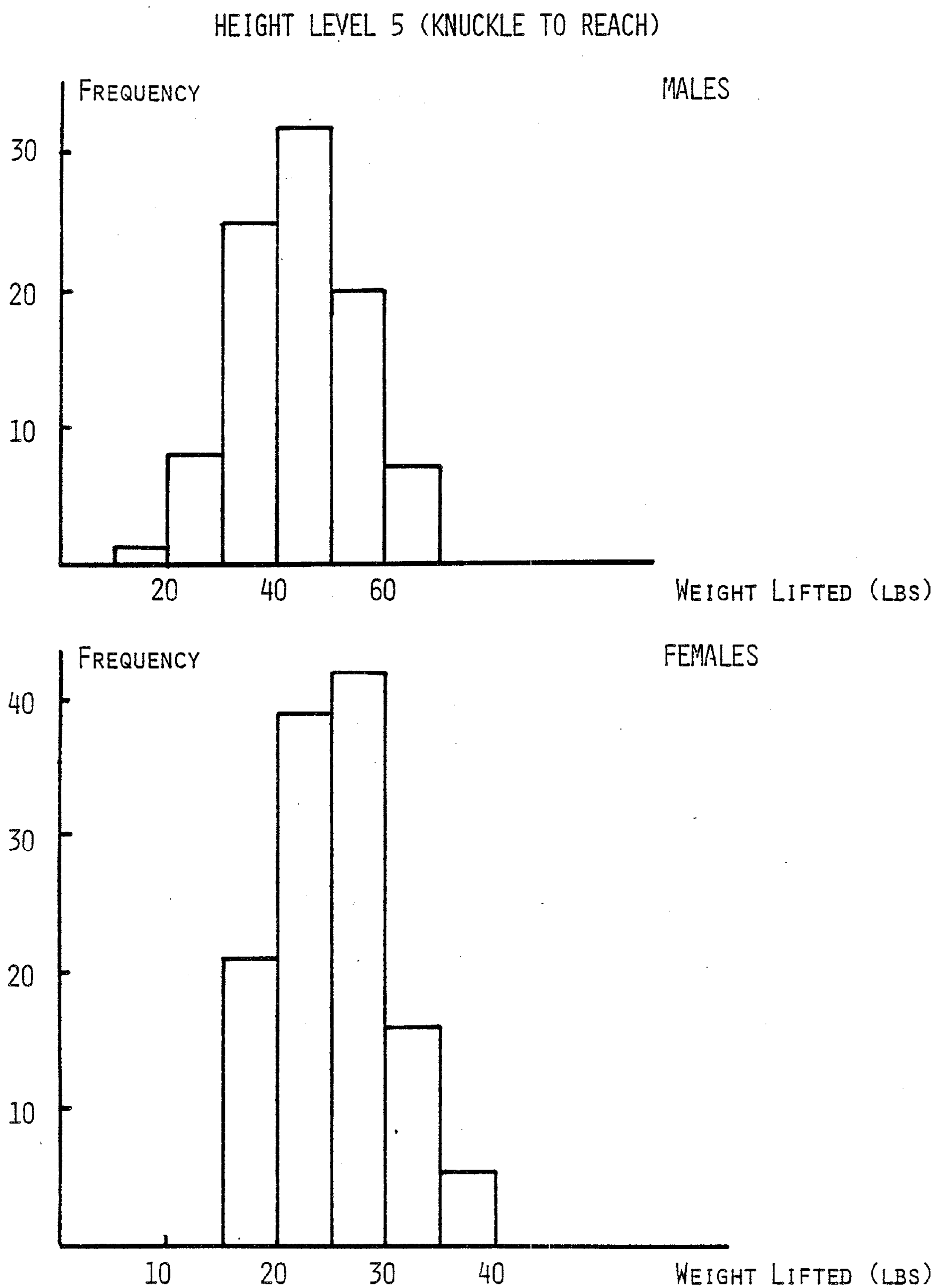


Figure S-5. Lifting Capacity Histograms for Knuckle to Reach Height

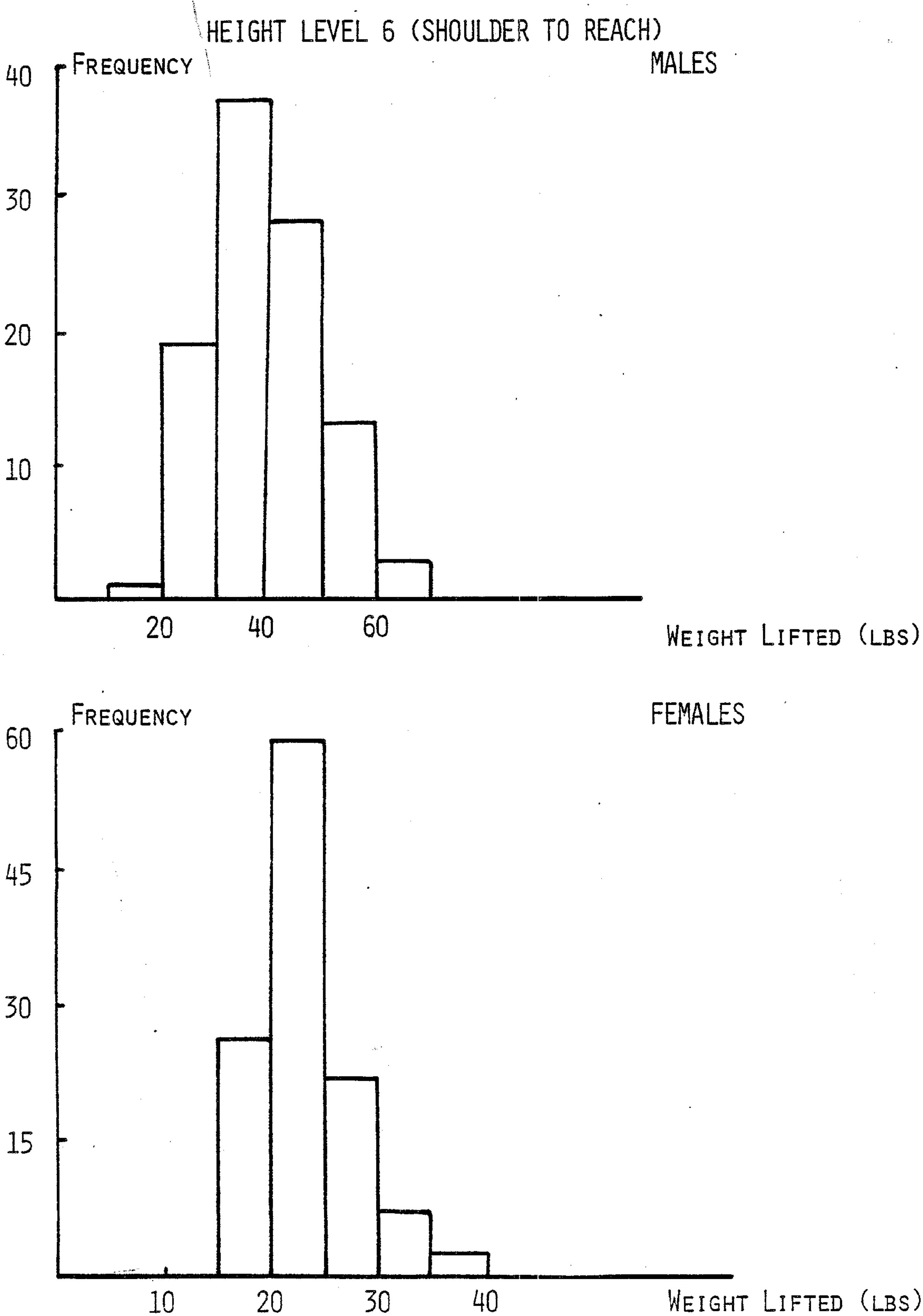
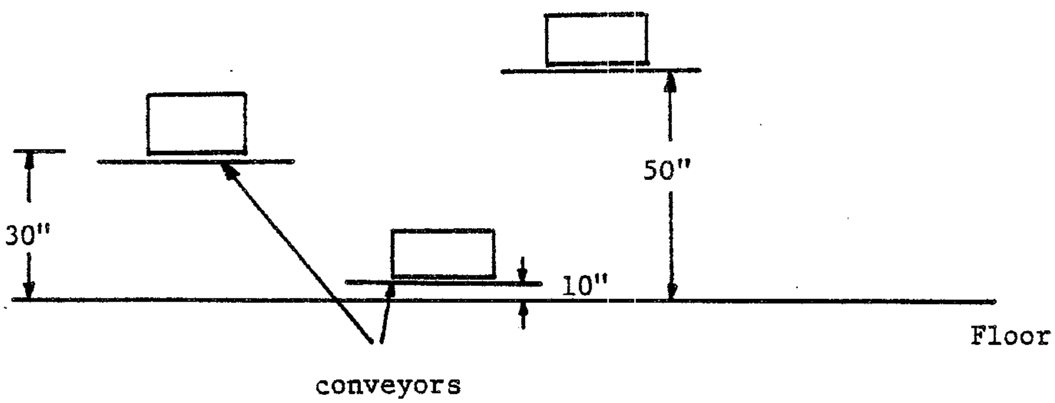


Figure S-6. Lifting Capacity Histograms for Shoulder to Reach Height

Appendix T

Job Stress Index Example Calculation

The following is an example of JSI calculation for a hypothetical job.



Subject has a knuckle height of 30 in. Boxes weigh from 20-45 lbs. and are lifted from the center conveyor to the upper conveyor as required. There is only one group. The frequency of lift from floor to 30 in. conveyor (Task 1) is 1.5 lifts/min. and the frequency of lift from floor to 50 in. conveyor (Task 2) is 1 lift/min. Subject works 8 hours a day and 5 days a week.

$$JSI = \frac{5}{5} * \frac{8}{8} \quad \frac{1.5}{2.5} * \frac{45}{CAP_1} + \frac{1.0}{2.5} * \frac{45}{CAP_2}$$

where CAP_1 = Predicted lifting capacity from the floor to knuckle height

CAP_2 = Predicted lifting capacity from the floor to shoulder height

Both, JSI^1 and JSI^3, would give the same numerical value for the above job. However, if the job is stacking, say from 30 in. height to 70 in. height, this would require lifting in the three height ranges:

Floor to knuckle

Floor to shoulder

Floor to reach.