DEVELOPMENT OF AN
EMPLOYEE STRENGTH ASSESSMENT PROGRAM
FOR UNITED AIRLINES

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FOREWORD

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

Employee strength assessments have been implemented as part of medical examinations in a number of industries as experimental medical procedures with varying success. In evaluating any medical assessment the following criteria are of paramount importance:

1. Is the test safe to administer?
2. Is it reliable and reproducible?
3. Is it practical to administer?
4. Is it predictive of capability and/or risk?
5. Is it specific to the requirements of the job?

It is hoped that the reader will keep these criteria in mind in evaluating the study reported herein and with future studies designed to refine and validate the approach and procedures.

I. INTRODUCTION

A. The Medical Problem

Overexertion injuries occur when people attempt physical exertions beyond the limits of their capabilities. The frequent occurrence of work-related over-exertion injuries during manual material handling tasks is well documented. National Safety Council statistics show that the lifting, pushing, pulling and carrying of objects are the leading cause of work-related injuries in the United States (NSC, 1973). Manual material handling activities have been found to be closely correlated with musculo-skeletal medical incidents, particularly those involving the low back, in recent epidemiological research (Rowe, 1969; Magora, 1970; Chaffin, et al., 1977; Wickstrom, 1978; Snook, 1978). Concern with these injuries appears to be warranted. The annual cost of work-related back injuries alone has been conservatively estimated to be 3.5 billion dollars (NSC, 1977; Konz, 1973).

The amount of off-the-job time associated with manual materials handling injuries is also substantial. Of 194 diagnostic groups discogenic back problems rank as the 11th reason for days spent in the hospital in the total U.S.A., and rank as the number one reason in thirteen western states. Nachemson (1971) estimates that 70 to 80 percent of the world's population suffers from disabling low-back pain at some time in their lives. Furthermore, a majority of these episodes occur during the working ages (20-55 years), with the first episodes most often reported between the ages of 20 and 40 (Nachemson, 1971; Hult, 1954). It also appears that the incidence rate over the last 30 years may be increasing compared to the rates of other compensable injuries.

Exact estimates of the severity of the overexertion injury problem are difficult to acquire. Worker compensation data, for example, reveal that a substantial number of claims are made for overexertion injuries. This type of "claim" accounts for about 19% of total cases, 16% of total compensation payments, and 21% of total medical payments. These claims are generally for strains and sprains of the back, wrist, elbows, shoulders, knees, and ankles. Most of these overexertion injuries are believed to occur while the worker is engaged in manual materials handling activities.

It has been estimated (Little, 1972) that 79% of material handling injuries occur to the lower back. The low-back injury is not usually permanently disabling. Four out of five workers suffering from this type of injury will return to the job within 3 weeks. It is, however, chronic--and occurs with sufficient frequency to affect more than half of the working population at some period during the working career.

Estimates of lost working days due to low-back pain are, 30 million days per year in Great Britain, two million days per year in Sweden, and one-half million days in the State of Washington each year (Hult, 1954; Troup and Chapman, 1969). Rowe (1971) reported that it is second only to upper respiratory problems as a basis for lost time in one large industry. It is also well recognized that the length of incapacitation is much greater (3 to 4 times according to Magora and Taustein, 1969) for the person engaged in heavy labor. Whether this is due only to the reluctance of the physician to allow the person to return to heavy labor after a low-back episode, or whether the type of injuries are more "disabling", has not been determined.

The recurrent nature of low back pain is important. It chronically appears most often every three months to three years according to both Hult (1954) and Rowe (1971). Nachemson (1971) believes that the frequency of repeated episodes peaks in the 40's. The fact that most low-back patients do not demonstrate consistent symptoms with time suggests that diagnosis greatly depends on following the progression of symptoms over time, with five years often being required to establish a good diagnostic classification (Badger, et al., 1972). When such care is taken, it is believed that 70 to 80% of all cases will be diagnosed as discogenic (Rowe, 1971).

It must, therefore, be concluded that low-back pain is a major source of incapacitation, suffering, and cost to the world today. It tends to strike younger people, is recurrent in nature, though between episodes the person may be pain-free. When one combines these low-back pain statistics with the incidence of other sprains, strains, contusions, abrasions, and herniations associated with manual materials handling in general, it is no wonder that manual materials handling activities are ranked as the most hazardous acts in industry (NIOSH, 1981).

B. The Need for Employee Selection Procedures

There are many different methods by which a concerned physician may evaluate a person's capability to handle heavy loads safely in a future job. Some of these methods have merit, while others are of questionable value. Present selection procedures vary widely. A large number of smaller manufacturing, distribution and service industries have neither medical nor nursing staffs, and no formal selection system exists. The principal method has been self-selection by the worker based on their initial tolerance for the demands of the job.

In larger industries, new employees are often asked to complete a questionnaire on health and medical history; and are submitted to routine tests of visual, auditory and pulmonary function, of blood pressure, mobility, etc., often with the addition of a chest X-ray. A physician will only see those whose replies and test results reveal abnormality or doubt on the part of the test administrator. In a few large industries, every recruit is examined by a physician but this usually depends on the existence of recognized physical or environmental hazards.

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

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

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

The fact that some people injure themselves performing work while others do not is clearly recognized. A prominent factor in the etiology of injury is the wide variation inherent in all human capabilities. Human strength (generated by the musculo-skeletal system) for example, is a capability with high between-person variability. It is not uncommon to expect 20 to 1 differences between different individuals in an industrial population (Chaffin et al., 1977). Such differences in strength between selected groups have been recognized for some time. A non-sophisticated approach was taken during the first half of the 20th century, when legislation was first introduced to limit the loads that women and children could handle. As late as 1962 the International Labor Organization suggested limits as shown in Table 1.1. The tenure of these legislative attempts was short when it was recognized that many stronger women were being unjustly discriminated against in their search for employment due to such guidelines. More precisely stated, while men are stronger than women <u>on the average</u>, some individual women are stronger than some individual men. The large variability in human strength leads to a significant overlap in the distributions of male and female strengths as depicted in Figure 1.1.

TABLE 1.1

Suggested Limits for Occasional Weight Lifting (kilograms) (ILO, 1962)

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

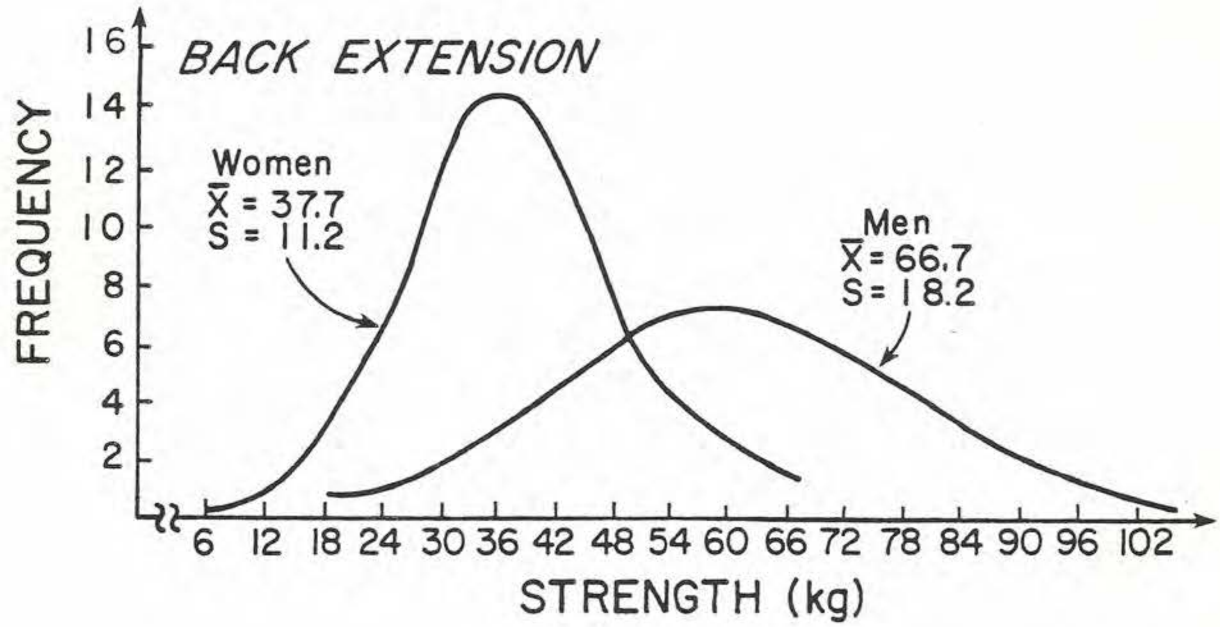


FIGURE 1.1

Overlap of Maximum Strength Distributions for Males and Females
(Kaman and Goldfuss, 1978)

An obvious problem arises with high injury costs and high variability in workers capacity to endure physical stresses in the workplace. One approach would be the re-design of all jobs to be within the capabilities of all workers. This is the view of those in automated production systems design and robotics. While this approach is certainly encouraged, on a practical level, the cost is generally prohibitive especially in terms of the displaced workforce. In most situations, where engineering re-design must follow the slow course of facility replacement, a realistic, interim program must be established for selecting qualified workers for strenuous jobs. Isometric strength testing of prospective employees is one realistic solution.

C. Previous Approaches to Selection

Many techniques have been and are being used in an attempt to control the costs of injuries from manual materials handling. It is beyond the intent of this document to cite all previously suggested selection criteria, but the following is a list of approaches that have received general recognition (NIOSH, 1981).

1. Gender
2. Age
3. Body Weight
4. Stature, Posture, Mobility
5. Clinical Examination
6. Medical History
7. X-Ray

The first two factors, gender and age, have a recognized but complex effect on a person's strength. As discussed previously, while women are weaker on the average than men, gender alone is not a sufficient criteria for job selection. Further, diminished physical capabilities and strength are known to occur during aging. Therefore age could be viewed as a potential risk factor, but not a selection criterion. Here again, the variability between individuals of similar age far exceeds the normal attrition associated with aging.

Body weight, stature and posture have shown evidence as factors in risk of injury. Like age and gender, their relationship to medical incidents is clear for population averages but not any particular individual. Further these effects are probably secondary to strength and endurance of the individual per se.

Medical techniques, such as clinical examination, medical history and low-back X-ray have been used to predict risk of injury. A great deal of controversy exists in the literature relating to these techniques. Low-back X-rays are the least defensible for providing valid predictive information relating to future medical incidents (Montgomery, 1976; AOMA, 1979). The negative side of X-ray is the inherent radiation health hazard to the exposed worker which tends to offset any arguments in support of the technique.

In summary, while several of the listed criteria are believed to be predictive of future medical incidents in some manner, no single one or combination has been shown to be a reliable predictor. These conclusions were substantiated during a study of over 500 employees (Chaffin, et al., 1977) which led the authors to recommend "that neither simple physical attributes of an individual, a clinical impression based on more traditional information of personal risk, nor past physical activity experience are adequate to reasonably explain the types of later medical problems that develop when a reasonably healthy person performs materials handling activities."

Employee selection tests of various types have faded in and out of acceptance in the past few decades. Manipulative tests, such as peg or disk flipping (i.e. grasping, lifting, inverting and lowering a peg or disk from one hole to another) were at one time widely administered. The tests were designed to provide information regarding a prospective employee's future success on manual assembly jobs. Under Equal Employment Opportunity Commission (EEOC) scrutiny, many of these early test procedures were struck down since they did not reflect actual job requirements. EEOC guidelines specify that "careful job analyses" be the basis for determining the critical work behaviors used as criteria for measuring employee performance (Miner and Miner, 1978). Thus, prior to consideration and installation of any pre-employment testing procedure, the reflection of actual job requirements in employee test procedures must be demonstrated.

D. Isometric Strength Assessment as a Practical Alternative

The usefulness of any test of human performance is inherently limited by the reliability, repeatability, and relevance (or job relatedness) of the measurement technique.

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

Static strength is defined as:

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

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

Isometric strength testing procedures have been developed at the University of Michigan, Center for Ergonomics over the past 12 years. The approach is simple: select employees for jobs on the basis of measured employee abilities and actual, objectively-documented job requirements. The program is based upon a series of research projects which were most recently summarized by Stobbe (1982):

> Employee-job matching is a two-phase process. The first phase requires the completion of a comprehensive biomechanical job evaluation to determine the job's requirement for physical strength. The second phase consists of testing a prospective worker's strength to determine whether a given person has the necesary strength to perform a given job.
>
> This approach was suggested by the results of two prospective studies completed at the Center for Ergonomics in 1973 and 1977. In the first study, the relationship between the incidence of low-back injuries and job strength rating (JSR) was examined. JSR is a ratio of required job strength and average employee static job position strength. It was found that jobs that required employees to lift more than the average employee strength (JSR > 1.0) had low-back injury rates three to four times greater than jobs with a JSR < 1.0) (Chaffin and Park, 1973; Chaffin, 1974)
>
> In the second study, a greater variety of industries and a wider geographical distribution were used. In addition, this study concentrated on new employees who had experienced neither on-the-job injuries nor on-the-job strength training. This study looked again at the relationship between low-back injury incidence and the JSR. It also considered the relationship between low-back-injury incidence and the employee strength rating (ESR), which is a ratio between job strength demand and individual employee isometric strength. In this study, the same trend in results was obtained: jobs that had a JSR > 1.0 experienced a low-back and musculoskeletal injury rate that was three times the rate for jobs with a JSR < 1.0 (Chaffin, Herrin, Keyserling, and Foulke, 1977).
>
> The fundamental conclusion of these two studies was that weaker persons (i.e., those unable to demonstrate the required isometric strength) were three times as likely to experience a musculoskeletal or low-back injury as their stronger work associates. This conclusion was tested in a follow-up third study of new employees. In this prospective study, a strength evaluation of each new employee was obtained prior to their actual start on the job.
>
> Their strength was then compared with the measured job requirements and the person was assigned to a qualified (demonstrated required strength) or non-qualified (could not demonstrate required strength) group. The accident and injury records of the groups were then monitored for a six month period to determine whether an employment screen based upon employee

strength could be effective in reducing accidents and injuries. The results of the follow-up study confirmed earlier results: non-qualified persons had a medical incident rate nine times the qualified group rate (Keyserling, 1979).

The evidence from these studies seems to provide a firm basis for the utilization of isometric strength testing as a selection guide in placement of workers on strenuous jobs. The results also appear to be much more consistent and reliable than the other alternatives discussed earlier. Although strength selection appears to show great potential as a effective method for controlling medical incidents relating to strenuous job requirements, the long range goal of gradual facility re-design for reduced job physical stresses should be concurrently pursued.

In support of this methodology, the National Institute for Occupational Safety and Health recently published a "Work Practices Guide for Manual Lifting" (NIOSH, 1981) which summarized over 300 research articles and concluded that selection tests such as isometric strength testing are warranted for all jobs which exceed "action limit" criteria.

E. Adverse Impact Related To Strength Testing

Any personnel selection practice with "adverse impact" must meet certain requirements of the equal employment opportunity guidelines. Selection of employees using strength ability as the criterion is no exception. Adverse impact might be defined as the hiring of unequal proportions of individuals from groups protected under EEO guidelines as a result of an employer utilizing employee selection procedures. Generally speaking, adverse impact is considered a negative effect by the EEOC and must be carefully rationalized. Most importantly, the selection procedure must be based upon critical work elements or behaviors which have been established through "careful job analyses" (Miner and Miner, 1978). Also, the critical work elements leading to the adverse impact effect must be shown to be essential for performance of the type of work involved. This concept is sometimes referred to as the bonafide occupational qualification (BFOQ) concept in job analysis. A burden of proof rests with the employer to show that critical, stressful job requirements are necessary and reasonably unavoidable to successfully perform the work. An easily-modified, stressful work method may not be considered a BFOQ of a job. An important aspect of a professional, engineering job analysis is the provision of practical recommendations to reduce job stresses on a cost-effective basis. Only those stressful job components remaining after a comprehensive re-engineering review process, can realistically be used as a basis for employee selection procedures.

The fact that females are weaker than males, on a population basis, has been well documented. Some data indicates that the American female worker is roughly 70% as strong as her male counterpart (Snook and Irvine, 1967). Other data indicate that females are about 60% as strong as males, on the average (Troup and Chapman, 1968; Brown, 1973; Chaffin, 1974). The exact percentage varies, of course, depending on which muscle group is being measured. The main point to be recognized is that since women in general are somewhat weaker than men, then fewer women will "qualify" on strength tests administered to women and men selected randomly. This adverse impact effect is to be expected in any strength testing program involving males and females.

For this effect to be acceptable under the law, several important criteria must be met as follows:

1. Testing procedures must validly reflect job requirements which have been documented using "careful job analyses."

2. Job requirements should be closely scrutinized to determine if stressful components are bona-fide occupational requirements.

3. Expected beneficial outcomes, such as reduced injury incidence and severity rates, must be scientifically established that outweigh the negative effects of adverse impact.

The following chapters address the specific techniques utilized for analyzing job strength requirements, determination of job-related employee test procedures and administration of isometric strength tests. These procedures reflect the most current, state-of-the-art engineering based procedures which have been documented and accepted in the professional literature.

II. METHODOLOGY

A. Biomechanical Modeling - The Common Link

The objective of an effective strength testing program is to reduce the incidence and severity of overexertion injuries. Accomplishment of this objective involves analyses of two interacting components, the worker and the workplace. The techniques utilized to document and analyze physical work requirements and the physical abilities of the worker should share a common scientific basis. Biomechanical strength modeling provides one common basis. Such models compare the physical stresses generated in the body (due to job defined variables) with the resultant force (or volitional strength) capabilities of industrial work populations. This translation of job stresses into human ability terms is the common link necessary for an effective system for engineering job redesign and personnel selection.

One biomechanical strength model available today was developed at the The University of Michigan's Center for Ergonomics. This model is fully documented elsewhere (Chaffin, 1969; Schanne, 1972; Garg, 1973; Garg and Chaffin, 1975). The following brief description of the model describes the more functional aspects.

The biomechanical strength model considers the body to be a system of rigid links and joints as depicted in Figure 2.1. Essentially, the model operates by first computing required torques at each joint center for a given task. The body angles used to describe the posture of a person are depicted in Figure 2.2. These required torques are a function of:

1) the external forces acting on the body, (e.g. the weight of the object)

2) the position of the hands with respect to the feet, and

3) the body posture maintained while performing the task.

Data describing external forces, hand locations, and body postures are measured during a biomechanical job analysis and serve as input to the model.

Figure 2.1: Linkage Representation Used in the Biomechanical Model
(Garg and Chaffin, 1975)

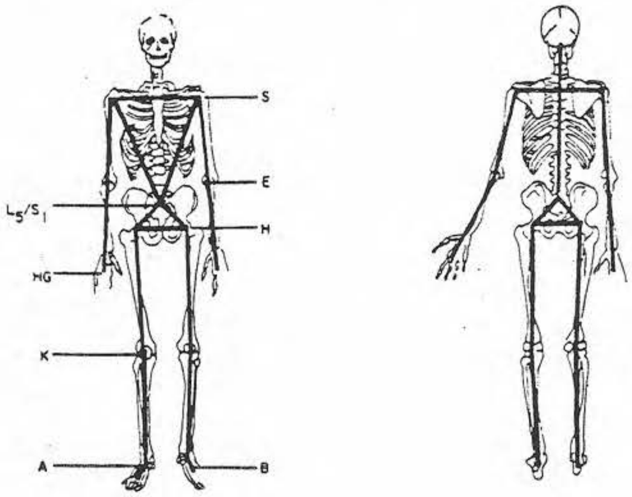
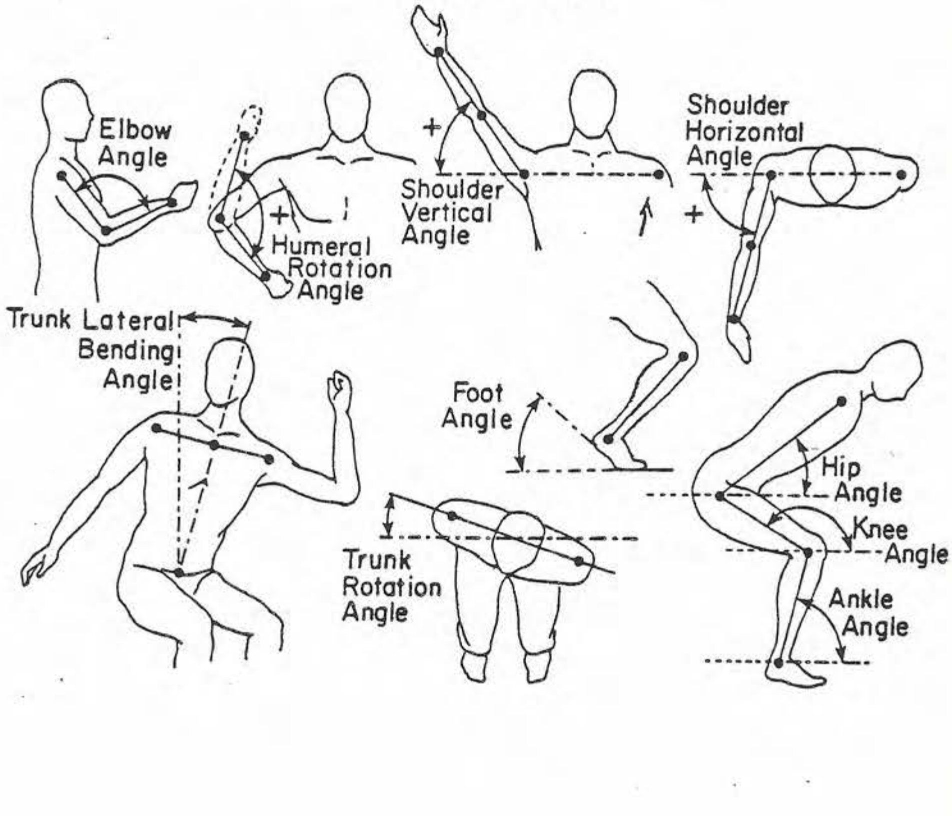


Figure 2.2: Body Angles Used to Depict Posture
(Garg and Chaffin, 1975)



Once the model has computed the required torques at each joint center, the next step is to compare these values to volitional torques (i.e, muscular strengths) which can be produced at each joint. Volitional torque data have been compiled from laboratory experiments and field strength testing of over 3000 workers throughout the United States. For a specified population and body posture, the model computes a volitional torque capability distribution for each joint as shown earlier in Figure 1.1. The required torque at the joint (computed above) is then compared to this distribution in order to statistically estimate the fraction of the population capable of producing the torque. This estimation procedure is repeated at each joint center. The joint with the smallest population fraction is defined to be the limiting muscle strength and determines the percentage of the population that can successfully perform the task. These volitional torque distributions can be stratified for male and female populations as well as older versus younger workforces.

In summary, a biomechanical strength analysis produces three key pieces of information.

1. It rank orders the gross strength requirements of the various tasks involved in a job.
2. It identifies the muscle group which limits performance on each task (see Table 2.1).
3. It predicts the percentage of the male and female working populations that could be expected to perform each job activity.

TABLE 2.1

List of Abbreviations Used for Limiting Muscle Groups

Each of the following muscle groups occur on both the left and right side of the body. A "L" or "R" is used as a suffix to indicate specifically which side is limited:

ELB FLEX - Elbow flexion - an effort to decrease the included angle between the upper and lower arm.

ELB EXTN - Elbow extension - an effort to increase the included angle between the upper and lower arm.

HUM MED - Medial humeral rotation, an effort to bring the lower arm toward the center line of the body by rotating the upper arm (humerus).

HUM LAT - Lateral humeral rotation, an effort to move the lower arm away from the centerline of the body by rotating the humerus.

SHLD ABD - Shoulder abduction, an effort to increase the included angle between the upper arm and torso.

SHLD ADD - Shoulder adduction, an effort to decrease the included angle between the upper arm and torso.

SHLD BACK - Shoulder back, an effort to pull the upper arm behind the torso.

SHLD FRWD - Shoulder forward, an effort to move the upper arm forward.

HIP FLEX - Hip flexion, an effort to decrease the included angle between the upper leg and the pelvis link.

HIP EXTN - Hip extension, an effort to increase the included angle between the upper leg and the pelvis link.

KNEE EXTN - Knee extension, an effort to increase the included angle between the upper and lower leg.

KNEE FLEX - Knee flexion, an effort to decrease the included angle between the upper and lower leg.

ANKL FLEX - Ankle flexion, an effort to decrease the included angle between the lower leg and the foot.

ANKL EXTN - Ankle extension, an effort to increase the included angle between the lower leg and the foot.

Each of the following muscle groups occurs in the torso. No suffix is used to indicate left for right side:

TRNK EXTN - Trunk extension, an effort to increase the included angle between the pelvis link and the upper torso.

TRNK FLXN - Trunk flexion, an effort to decrease the included angle between the pelvis link and the upper torso.

TRNK LEFT - Trunk left, an effort to bend the upper torso to the left.

TRNK RIGHT - Trunk right, an effort to bend the upper torso to the right.

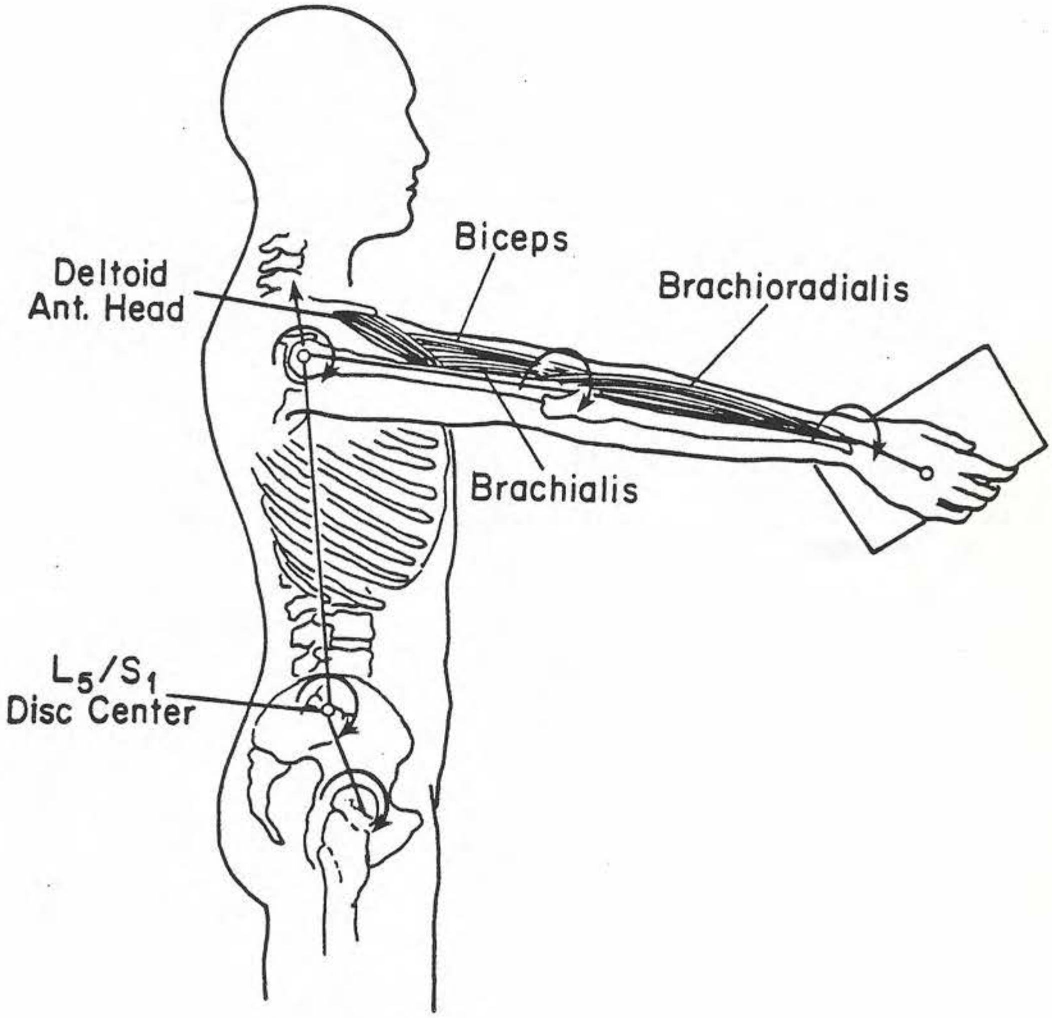
TRNK ROTL - Trunk rotation left, an effort to rotate the trunk counterclockwise (if viewed from above).

TRNK ROTR - Trunk rotation right, an effort to rotate the trunk clockwise, (if viewed from above).

B. Prediction of Low Back Compressive Forces

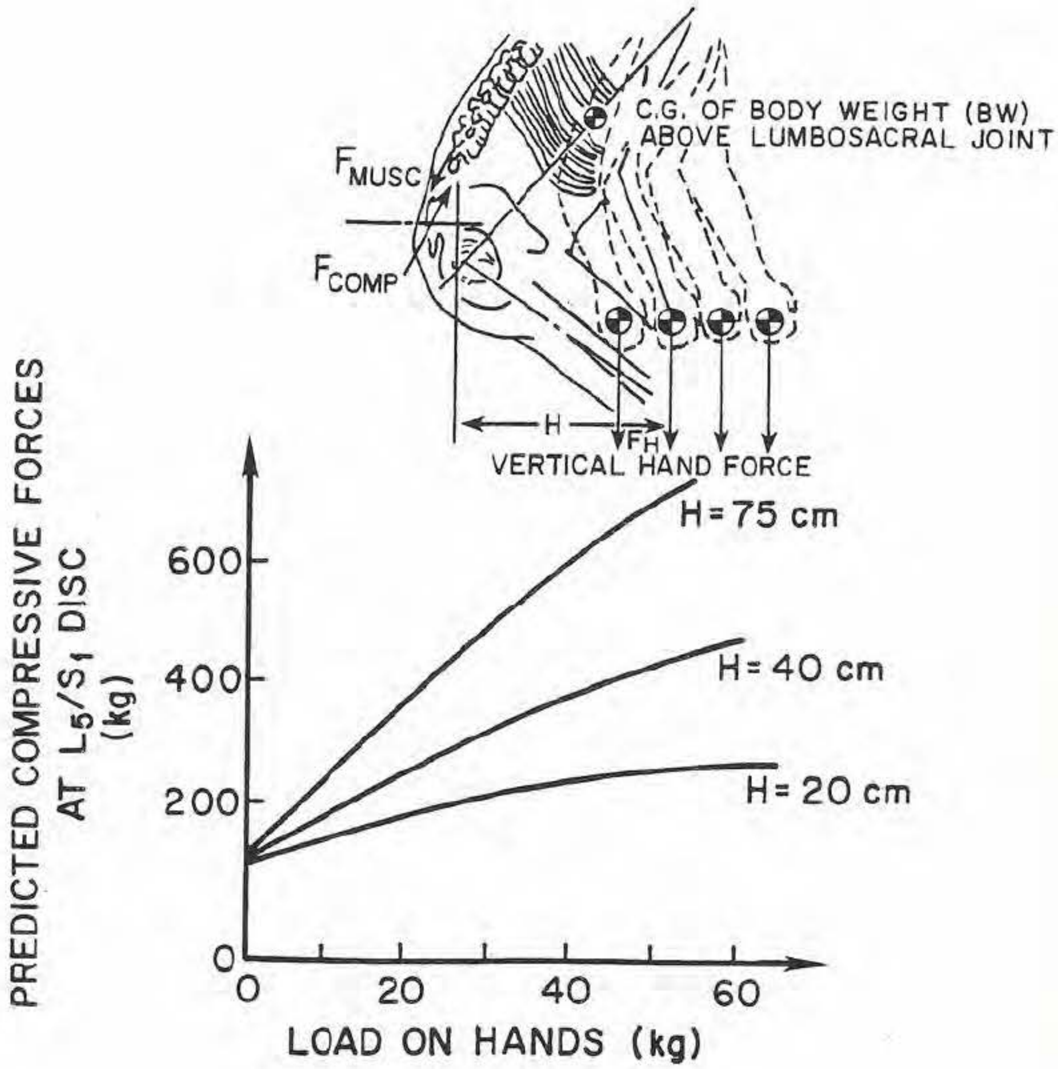
One joint which receives considerable attention (due to its epidemiological injury experience) is the L_5/S_1 disc. Indeed, the human spine can be thought of as a set of small links (vertebrae) separated by flexible articulating structures called discs. Because this structure is mechanically unstable, the weight of the body results in a torque which tends to rotate the torso forward. To prevent this flexion, back muscles (erector spinae) which span the vertebrae, contract to produce a rearward torque, thus stabilizing the structure. This stabilization process is depicted in Figure 2.3 for the lumbosacral (L_5/S_1) spinal joint. It is evident from the figure that the effective moment arm of the erector spinae muscles is quite short (approximately two inches). This means that these muscles must produce very high contractile forces to overcome the torque caused by the weight of the upper body and external forces.

Figure 2.3: Illustration of Leverage on Shoulder, Elbow and Lumbosacral Joint (Chaffin, 1975)



Fortunately for humans, back muscles tend to be very strong. This allows us to lift reasonably heavy loads and to maintain an erect posture for extended periods of time. Unfortunately, however, the close proximity of these muscles to the spine results in high compression forces which act on the spinal discs. If this compression force is sufficient, it can cause small fractures to develop in the cartilage endplates of the discs which often starts a degenerative process. Disc degeneration is believed to be a major factor in the onset of serious low back problems which later become associated with exceptionally high worker's compensation and medical costs. Figure 2.4 illustrates the trade-offs between L_5/S_1 disc compression and load in the hands at various locations in front of the body.

Figure 2.4: Illustration of L_5/S_1 Compressive Forces Generated



The L_5/S_1 disc is of particular concern because of its location in the base of the spinal column. Cadaver studies have shown that compressive forces of 1100 pounds can cause cartilage endplate microfractures in a young, healthy individual. Older people may suffer endplate fractures from exposure to compression forces as low as 600 pounds. This level is exceeded in many industrial manual handling activities. The recently published guideline, Work Practices Guide for Manual Lifting from the National Institute for Occupational Safety and Health (NIOSH, 1981), offers specific guidelines relating to back compression forces generated while performing lifting elements. The guide states that "jobs which place more than 650 kilograms (1430 pounds) compressive forces on the low back are hazardous to all but the healthiest of workers. In terms of a specification for design, a much lower limit of 350 kilograms (770 pounds) or lower should be viewed as an upper limit."

A fourth output of the biomechanical strength model (described in the previous section) is a prediction of compressive forces occurring at the L_5/S_1 disc. This information is very useful for identifying specific tasks where the combination of body posture and weight handled produce sufficient compressive forces to possibly injure the lower back. For more information on low back biomechanics refer to Chaffin (1975).

At the present time, the biomechanical model is a reasonably accurate predictor of the percentage of male and female populations capable of performing a given task and L_5/S_1 disc compression. At times, however, the prediction capability may be slightly in error for one or more of the following reasons:

1. The legs and torso are allowed to assume only gross body postures. Therefore, the arms may not be in an optimal position to perform the task. This may result in underprediction of the population capabilities. An iterative posture optimization routine has been introduced to minimize this error.
2. Strength data (voluntary muscle torques) are limited in certain body postures, particularly when the task requires the worker to raise his/her hands very high above the head. Whenever this occurs, the model does not predict the population strength capabilities well. The output, in this case, is denoted as "post" meaning that a posture which would span this large of a range could not be found for the average person.

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

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

In spite of the above limitations, the model is believed to be a good predictor of the relative stressfulness of given tasks for a large number of common industrial activities. The validity of the strength predictions as compared to measured muscle forces are discussed in the next section.

C. The Validity of Biomechanical Modeling as a Predictor of Human Muscular Strength

The predictive accuracy of the biomechanical strength model at the Center for Ergonomics continues to improve as additional strength data become available for extreme postures. Validation studies examine the simple relationship between predicted and measured hand forces as follows:

$$Fp = B\ Fm$$

where: Fp = Model predicted hand force

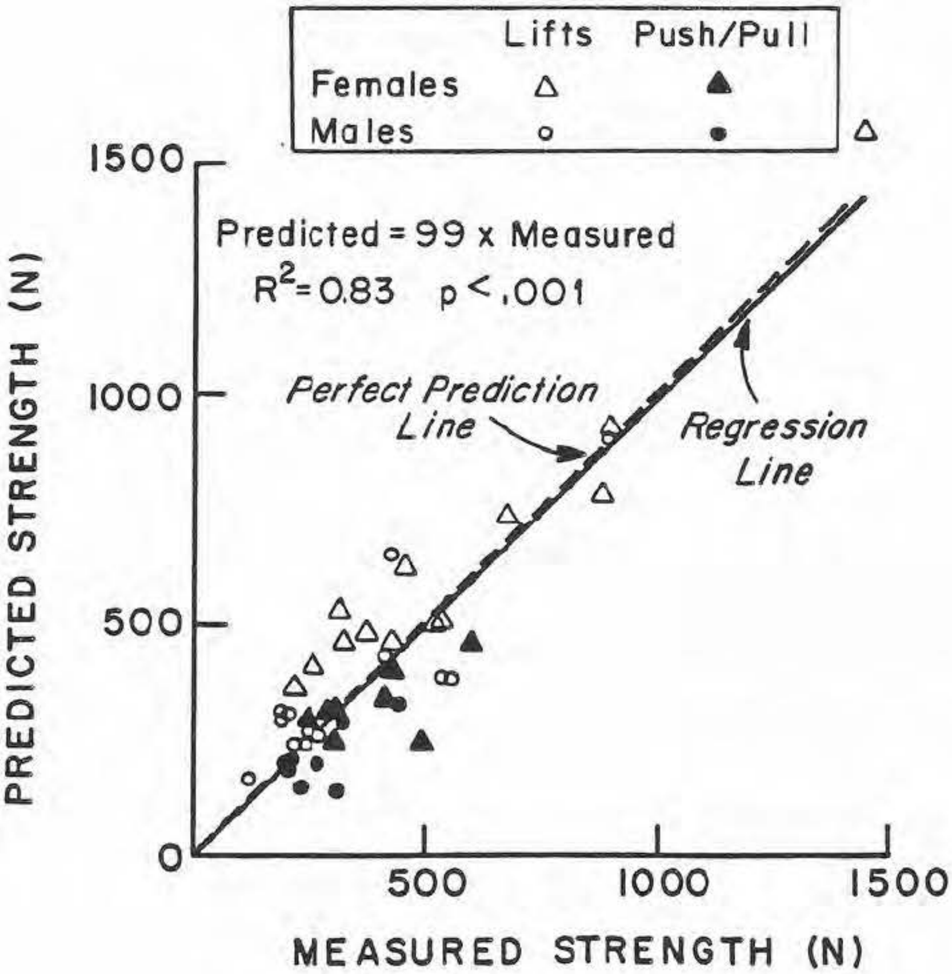
Fm = Measured hand forces

B = Slope of least-squared error regression line.

Where B = 1 would indicate unbiased prediction. Early validation studies (Garg and Chaffin, 1975) yielded B in the range of .82-.87 with a coefficient of determination (R^2) of approximately .75 and an error coefficient of variation of approximately 15% which agreed with earlier research efforts (Chaffin and Baker, 1970; Schanne, 1972). These early validation studies were based on comparison of predicted strength with existing military strength data from the literature. The early studies resulted in the recognition that to improve the predictive accuracy of the model a larger data base of industrial worker strengths was needed.

Based upon a study of 1577 industrial workers involving eight different U. S. companies, the predictive accuracy of the model was much improved (Frievalds, 1980). The slope of the regression between predicted and measured mean strengths was nearly perfect (B = .99) with an R^2 of .83 with a high significance level ($p < .001$). As illustrated in Figure 2.5, the model tends to overpredict slightly on lifts and underpredict on pushes and pulls. Further improvements in model accuracy could be made from additional strength data for extreme postures and consideration of task specific variables, such as more exact posture description and shoe/floor interactions.

Figure 2.5: Predicted versus Measured Strength (Frieivalds, 1982)



Strength data continues to be collected and the problems of more dynamic exertions are being investigated in ongoing research at the Center for Ergonomics. The current biomechanical strength model is believed to be the most technologically advanced, valid predictor of whole body strength exertion available today.

D. Documentation of Job Strength Requirements

To apply the biomechanical model to industrial manual materials handling activities requires a detailed documentation of each task. A complete set of instructions for conducting a biomechanical job analysis is included in Appendix A.

The job analyses should be conducted by a trained analyst, observing an experienced worker who is using a reasonable, preferred method. Very basically, the procedure involves two components:

1. Observing the job and determining which task elements involve forceful strength exertion.
2. Measuring and documenting all information relating to the identified exertions as follows:
   A. Force exerted (in pounds)
   B. Hand location (with respect to the feet) for each hand
   C. Gross body posture (e.g. stand, stoop, squat, lean)
   D. Exertion type (e.g. lift, push, pull)

Output of the model includes:

1. A restatement of input information
2. Percent of males and females capable of exerting sufficient isometric strength to successfully perform any job element.
3. The muscle group which is most limiting to the person performing the exertion.

4. Resultant back compression forces at the L_5/S_1 disc for average males and females.

A complete listing of biomechanical model output for all jobs studied at United Airlines can be found in Appendix E.

E. Isometric Strength Assessment

The measurement equipment needed to assess isometric strength is relatively simple. Appendix C describes the equipment used in this study which complies with the criteria set forth in the American Industrial Hygiene Association guidelines (Chaffin, 1975). Appendix B describes the procedures used to assess isometric strength including setup, instructions, and appropriate coding forms. Appendix D lists the strength test results for the incumbent study reported in Chapter 3.

The AIHA guide provides parameters for several key factors affecting the outcome of a strength test. The first of these is the duration of the exertion. The time period must be long enough for the subject to achieve a steady state exertion , but not so long that the person will fatigue and/or relax before the test is complete. The recommended exertion duration is four to six seconds.

The second major factor is the strength-measuring device. The guide recommends that the device be capable of averaging the force exerted over a three-second period, which is a sub-interval of the four to six second testing time. This averaging is done to account for the physiological tremor and motion dynamics that normally accompany a maximal voluntary exertion.

The third major factor is the provision of rest periods which are sufficient to avoid either local muscle or whole body fatigue. In a prolonged testing session, either is possible. The Guide recommends that a two-minute rest be allowed between tests. The experience of Schanne (1972) suggests that during prolonged testing, fatigue may still occur. In addition to the required rest time, the subjects should be monitored both verbally, and through their performance for indications of fatigue.

The last factor discussed in the Guide is that of subject instructions. The Guide provides considerable detail as to the content and ordering of instructions. The intent of instructions is to prevent motivationally induced performance changes during the testing procedure. These changes can be the result of: (1) the instructions themselves, (2) the manner in which the instructions are given (e.g. emotional appeals, etc.), (3) the avowed purpose of the testing, (4) the testers and their displayed attitude, (5) the incentives that are offered for performance, and (6) the presence or absence of spectators. The most effective method of controlling the motivational level is through the standardization of the subject's instructions. In this research, the participants were provided with written instructions and then given the opportunity to ask additional questions to clarify any misunderstandings. In addition spectators were, to the extent possible, excluded from the test environment.

Further, strength tests should only be administered by a trained strength analyst to persons who have been medically approved for participation in a strength testing program. Very briefly, the strength testing procedure involves the following tasks:

1. Preparing Equipment
2. Verifying medical clearance
3. Recording employee history information
4. Obtaining signed informed consent
5. Answering employee questions
6. Giving instructions before and during testing
7. Recording test results (peak and average forces).

At least two repetitions of each strength test need to be conducted. More repetitions are required if the previous two tests differ more than 10 percent or if the error light on the force monitor is observed. The error indication circuit on the force monitor gives a positive indication if either of the following two conditions occurs:

1. If the applied load falls below a threshold value which is set by the analyst prior to commencement of the test.

2. If the applied load falls below 70 percent of maximum value recorded, indicating a very unsteady test.

F. Predicting Job Specific Strength

Given the ability to describe a job in terms of the torques generated on each body articulation and the ability to measure one's reactive strength capability at each articulation one issue remains to be resolved. How many tests are required to assess one's whole body capability to accomplish all tasks within a job? This problem has been researched extensively by Keyerling (1979) and Stobbe (1982). The studies of Keyserling began with a proposed set of 9 standardized whole body tests (involving multiple muscle groups) which were reducible biomechanically to 4 tests. Stobbe correlated 16 isolated muscle function tests with 24 whole body tests and found the set reducible to 7 standardized whole body tests. The mean absolute prediction error was observed to be less than 16 percent between tests. In light of the 10 to 14 percent test-retest variation inherent in such tests, this model simplification error (between 2 and 6 percent) is probably nominal in most applications.

The two most critical issues in determining an appropriate set of standardized tests are:

1. Choosing a set of tests which span the documented job requirements, and
2. Insuring that the tests accurately simulate the job.

The biomechanical model can be used directly to choose among alternative tests in terms of identifying which muscle groups are required and their respective loadings. It also provides a mechanism for extrapolating from one test posture to another within particular muscle groups.

G. Determination of Strength Test Scores

Determination of "passing" strength test scores is an equally critical aspect. These scores, based upon objectively documented job requirements, are the mechanism for partitioning employees into two groups as follows:

1. Submaximal Job Stress Group - employees who are capable of exerting isometric strength greater than required on their job.
2. Supermaximal Job Stress Group - employees who are not capable of exerting isometric strength greater than required on their job.

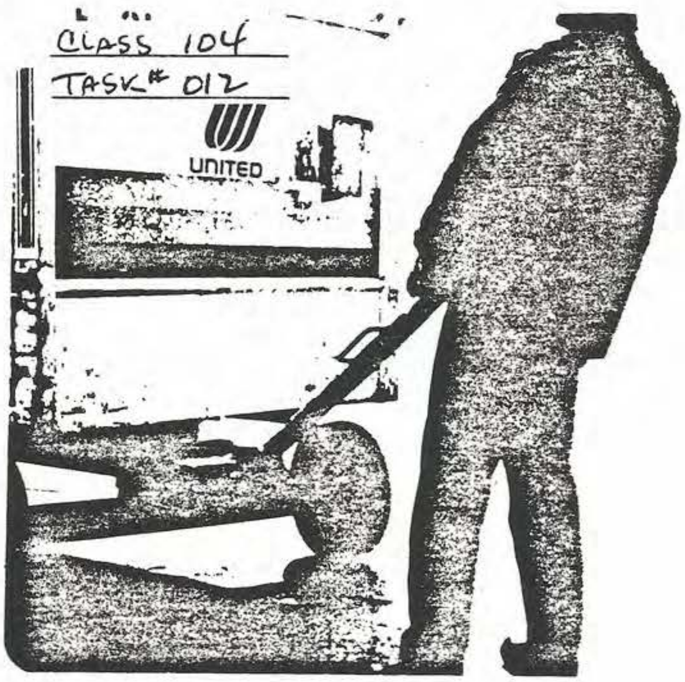
The procedures for determining the qualifying strength test scores are as follows:

1. Document all biomechanically stressful job requirements using the procedures described in Appendix A. All job elements must be carefully analyzed and rechecked to insure they are, indeed, requirements for the particular job.
2. Estimate the percent of the male and female population capable of performing each exertion.
3. Determine the equivalent forces on standaridzed test using the percentages determined in step 2.

Figures 2.6 and 2.7 illustrate this procedure for the ramp service job (class 104, task 012). Figure 2.6 shows the job requirement and the corresponding biomechanical analysis. This particular pulling task was found to be the most stressful task (in comparison to the percentages capable on all other tasks in this job classification). This job exceeds the action limit criteria specified by NIOSH (in terms of back compressive loads and strength required). Thus strength testing would be warranted. Also it should be noted that the maximum permissible criteria are not being exceeded, hence engineering controls (though preferred) are not required.

The equivalent 88% male and 24% female strength scores on the nearest standardized test (low pull, v=21, H=8) would be 95 and 115 pounds respectively, as shown in Figure 2.7. The equivalent strength score was chosen as the smaller of these two estimates (95 pounds in this case) in order to minimize the possible adverse impact.

Subsequently, any incumbent or new hire who did not demonstrate at least 95 pounds maximal force in the low pull test was deemed in the "supermaximal job stress group" relative to the ramp service job. Likewise, those demonstrating more than 95 pounds were in the "submaximal job stress group."



Job 104 - Mail Handling in Transfer Area

Task 012 (origin) - Pull, Lean Posture, Mail Cart

Force: 70 lbs.

Right Hand: V=36, L=9, H=12

Left Hand: V=0, L=-18, H=0
(relative to right)

Male: % capable = 88% L_5/S_1 Compression = 1009 lbs.

Female: % capable = 24% L_5/S_1 Compression = 954 lbs.

Limiting Muscle Group = Ankle Extension

Figure 2.6: Illustration of Job Requirement Analysis

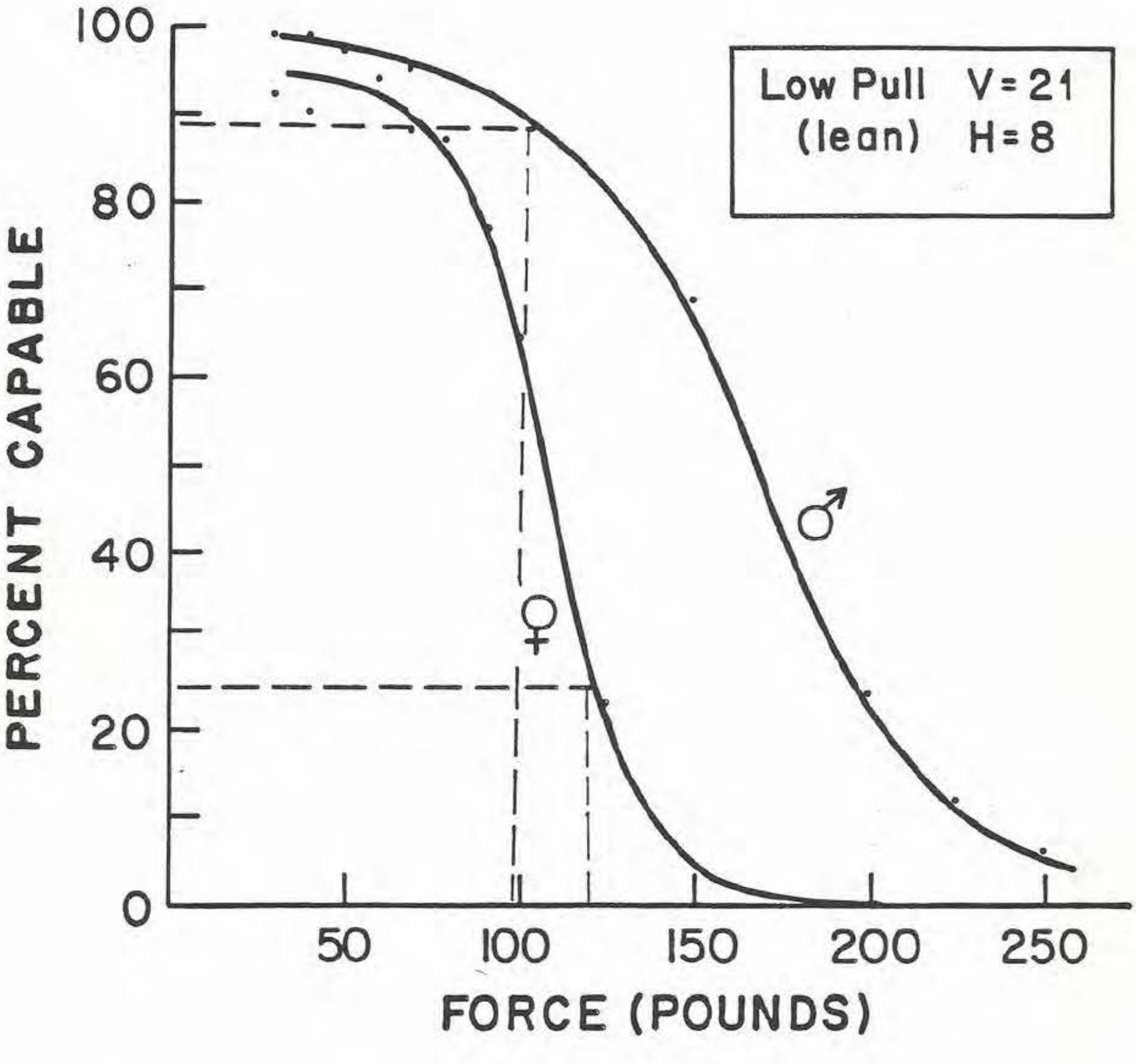


Figure 2.7: Illustration of Equivalent Standardized Test Requirement

H. Data Management Information System

In order to store, access and analyze the large quantity of job analysis, worker assessment and medical surveillance data, an Occupational Health Monitoring and Evaluation System (OHMES) was developed.

The OHMES computer software is composed of numerous sub-routines which input, edit, maintain, and report medical and exposure information required for the project. In addition, the data base is such that it can be readily used in conjunction with MIDAS (Michigan Interactive Data Analysis System), a sophisticated and extensive statistical softward package. Developed by The University of Michigan Statistical Research Laboratory, MIDAS has many data reduction and analysis capabilities and is capable of handling large data sets.

A brief description of the principal components of computer software developed for the study is given below:

1. A main program to receive input data: Job information, employee information, work history and dispensary visits.

2. Sub-programs to process and store this information in the data base.

3. Sub-programs to report all new informaton added to the data base during progress of the study, including verification of data correctness.

4. A program to produce summary reports which give the status and level of participation at any point in time during the study period.

5. Programs to produce summary statistics of the data collected. These statistics can be aggregated at a variety of levels.

6. A program to extract information from the data base and organize it into a format compatible with MIDAS and other existing statistical analysis software.

7. An on-line information retrieval system which allows medical personnel to obtain a complete description of all dispensary visits by employee or by job classification.

8. A program to produce summary reports of medical incidents by job and company. This program prints out a brief synopsis of incidence and severity rates by injury category for on-the-job, off-the-job and all incidents. Reports can be based on all dispensary visits, or just lost time incidents only.

In addition, a program was written to determine the proportion of incumbent employees passing and not-passing any strength criteria. The program also computes injury rates for any stratification of employee groups for comparison (eg. by age, gender, experience, etc.).

I. Medical Surveillance

The medical history was quantified for all employees who participated in this study. Two distinctive aspects of the medical histories documented are 1) the level of detail, and 2) the aggregation of the data.

A continuing controversy exists over what level of detail should be used for analysis of occupational injury data. Some suggest that only incidents where there are three or more days of lost time are important whereas others feel that every visit to the dispensary should be considered. The crux of the issue is that not all dispensary visits are also injuries. A second point of contention is whether to include off-the-job incidents along with on-the-job incidents. The problem here has to do with the difficulty in categorizing something like a low-back problem, which is believed by some to be a cumulative trauma arising from activities at work but becoming overt during off-the-job time, or vice-versa.

It was decided that, where practical, all job related dispensary visits would be recorded. This meant that visits for headache remedies and decongestants were recorded with as much vigor as visits related to severe low-back injuries, for instance. Part of the information collected about the incident was its on/off-the-job categorization, incident type, and time lost. With this description the medical data can be aggregated at any level of detail from all dispensary visits to only on-the-job injuries with three or more lost days.

The three basic categories of incident-types used in summarizing the results of this study are:

1. contact incidents
2. musculo/skeletal incidents excluding back problems, and
3. back incidents.

Incidents falling in any of these three categories are defined as over-exertion incidents.

Contact incidents include:

a. Chemical dermatoses
b. Lacerations
c. Abrasions and blisters
d. Contusions
e. Thermal burns
f. Contact with airborned foreign bodies (typically involving the eyes)

Musculoskeletal incidents include:

a. Sprains and strains of muscles and/or connecting tissues not including the low back
b. Diseases of the joints other than the low back
c. Fractures other than spinal fractures

Back incidents include:

a. Sprains and strains of the back
b. Spinal fractures
c. Ill-defined pains originating in the lower back, including degenerative disc diseases.

Incidents that did not fall in one of these three categories were recorded, entered into the data base, but are not included in the present analyses.

III. INCUMBENT STUDY RESULTS

The study at United Airlines followed an eight step procedure:

A. Analysis of injury data to identify problem jobs

B. Train analyst to perform biomechanical evaluations

C. Perform biomechanical job evaluations

D. Design strength tests for incumbent workforce

E. Administer tests to volunteer incumbents

F. Develop test criteria and medical monitoring procedure for the future

G. Implement strength testing for new hires

H. Monitor/evaluate potential effectiveness of the study.

The results for steps A through F are presented in this chapter. Chapter IV details the last two steps.

A. Retrospective Injury Analysis

In early 1978 a summary of all occupational injuries for United's Central Division (and the Denver domicile in particular) was completed with the assistance of H. Edwards. Table 3.1 summarizes the stratification of incidence and severity rates for 6 job classifications during 1977. Those injuries referencing "lifting", "pushing" or "pulling" in the injury reports are itemized as MMH = manual materials handling related. Likewise, for the Denver domicile (within the division) the equivalent data are summarized in Table 3.2. It is apparent from these two tables that injury rates are quite different between job classifications and that the Denver rates are considerably higher than those of the division. The reader should also note the rank differences between incidence rates (reported incidents per 200,000 man-hours) and severity rates (days lost or work restricted per 200,000 man-hours).

TABLE 3.1

ALL OCCUPATIONAL INJURIES SUMMARY (1/1/77-1/1/78)

UNITED AIRLINES
CENTRAL DIVISION

	JOB TITLE	EXPOSURE (Man-Years)	INCIDENCE (Incidents Per 100 Man-Years) MMH	OTHER	TOTAL	SEVERITY (Days Lost + Days Restricted Per Man-Years) TOTAL
1)	Air Freight Agent	587.60	2.383	10.551	12.934	1.026
2)	Flight Attndnt	1017.45	3.342	24.178	27.520	.259
3)	Food Service	1032.72	2.227	7.843	10.070	.727
4)	Mechanic	747.76	.401	6.152	6.553	.940
5)	Passngr Service	791.44	1.516	2.274	3.790	.254
6)	Ramp Service	1433.12	5.722	14.584	20.306	1.509
	TOTAL	5610.09				

*MMH = Injury attributed to Lift/Push/Pull

TABLE 3.2

ALL OCCUPATIONAL INJURIES SUMMARY (1/1/77-1/1/78)

UNITED AIRLINES
DENVER DOMICILE

	JOB	EXPOSURE (Man-Years)	INCIDENCE (Incidents Per 100 Man-Years)			SEVERITY (Days Lost + Days Restricted Per Man-Years)
			MMH	OTHER	TOTAL	TOTAL
1)	Air Freight Agent	93.600	4.274	13.889	18.163	1.207
2)	Flight Attndnt	231.300	4.756	25.508	30.264	.283
3)	Food Service	251.680	2.781	8.741	11.522	.473
4)	Mechanic	166.400	.601	7.211	7.812	1.208
5)	Passngr Service	142.480	4.913	7.019	11.932	.498
6)	Ramp Service	321.360	12.447	23.338	35.785	2.506
	TOTAL	1206.820				

*MMH = Injury attributed to Lift/Push/Pull

These data pointed out the need for a more detailed analysis of the job requirements and employee capacities to possibly explain the observed differences. They also serve as a control group for assessing the adequacy of the volunteer testing program to be discussed later. The data were also partitioned by injury type (e.g. back injury, musculoskeletal injury, contact injury, etc.). These summaries are provided in Appendix G.

B. Analyst Selection and Training

Two employees of UAL were chosen to perform the necessary job analyses; Mr. J. Medell and G. Burke. Over a period of 18 months, each job at the Denver facility was carefully evaluated using the prescribed methods described in Chapter 2 and in detail in Appendix A. The analysts were trained by G. Herrin and his associates (T. Stobbe, A. Frievalds, and C. Anderson) at the University of Michigan. These analyses consisted of:

1. Weighing and measuring 2,900 baggage and freight items for the occupations air freight, ramp servicemen, and passenger service agents at DEN, NYC, DSM, and CID.

2. The number of job classifications were expanded from 6 to 9 in an effort to define more homogeneous job classifications. In particular these included:

   a. Flight Attendant
   b. Passenger Service Agent
   c. Sky Cap
   d. Ramp Serviceman
   e. Air Freight Agent
   f. Food Service Worker
   g. Mechanic
   h. Storekeeper
   i. Fueler

3. Approximately 2,000 critical job elements were identified by:

   a. Independent measures of the lifting, pulling, and pushing forces of carts, modules, loaders, racks, drawers, trays, etc. In that the equipment used was deemed standard throughout the system, the flight attendant, sky cap, food service worker, maintenance, stores, cleaners, and fuelers positions were analyzed only at DEN. All forces were measured with a Dillion 500 pound full scale calibrated dynamometer.

b. Concurrently incumbents were asked to simulate the performance of each of the 2,000 critical job elements. Slides were taken of an incumbent performing each task. This was useful in subsequent discussions regarding accuracy and completeness of the job analyses.

4. Each task was analyzed and coded according to:

a. Direction of load and motion involved (see Figure 3.1)

b. Body posture (see Figure 3.2)

c. Maximum force in pounds required to lift, pull, or push the object. Both the average forces and the 93rd percentile forces for repetitive job elements (e.g., lifting baggage, cargo) were estimated.

d. For practical purposes only exertions of 10 pounds or more were documented, thus trivial job elements such as preparing tickets, giving a pillow to a customer, etc., were neither measured nor analyzed.

e. The location of the hands at the beginning of and completion of each job element was recorded by measuring the vertical, lateral, and horizontal displacement of each hand from the midpoint of the line joining the ankles (See Figure 3.3).

f. The distance (in feet) traversed during walking and carrying job elements.

g. The normal time required to perform the job element in fractions of a minute.

h. The number of times during an average day the job element was performed (minimum of 1 per shift).

i. The date, analyst, location, job title, and comments.

j. All data was recorded on the data input sheet shown in Figure 3.4

Figure 3.1: Task Code Summary

TASK SUMMARY

Task Code	Task	Direction Of Load	Direction Of Motion
01	LIFT	↓	↑
02	LOWER	↓	↓
03	PUSH	←	→
04	PULL IN	→	←
05	PULL RIGHT	←	→
06	PULL LEFT	→	←
07	PULL DOWN	↑	↓
08	HOLD	↓	O
09	TORQUE (R)	↺	↻
10	TORQUE (L)	↻	↺

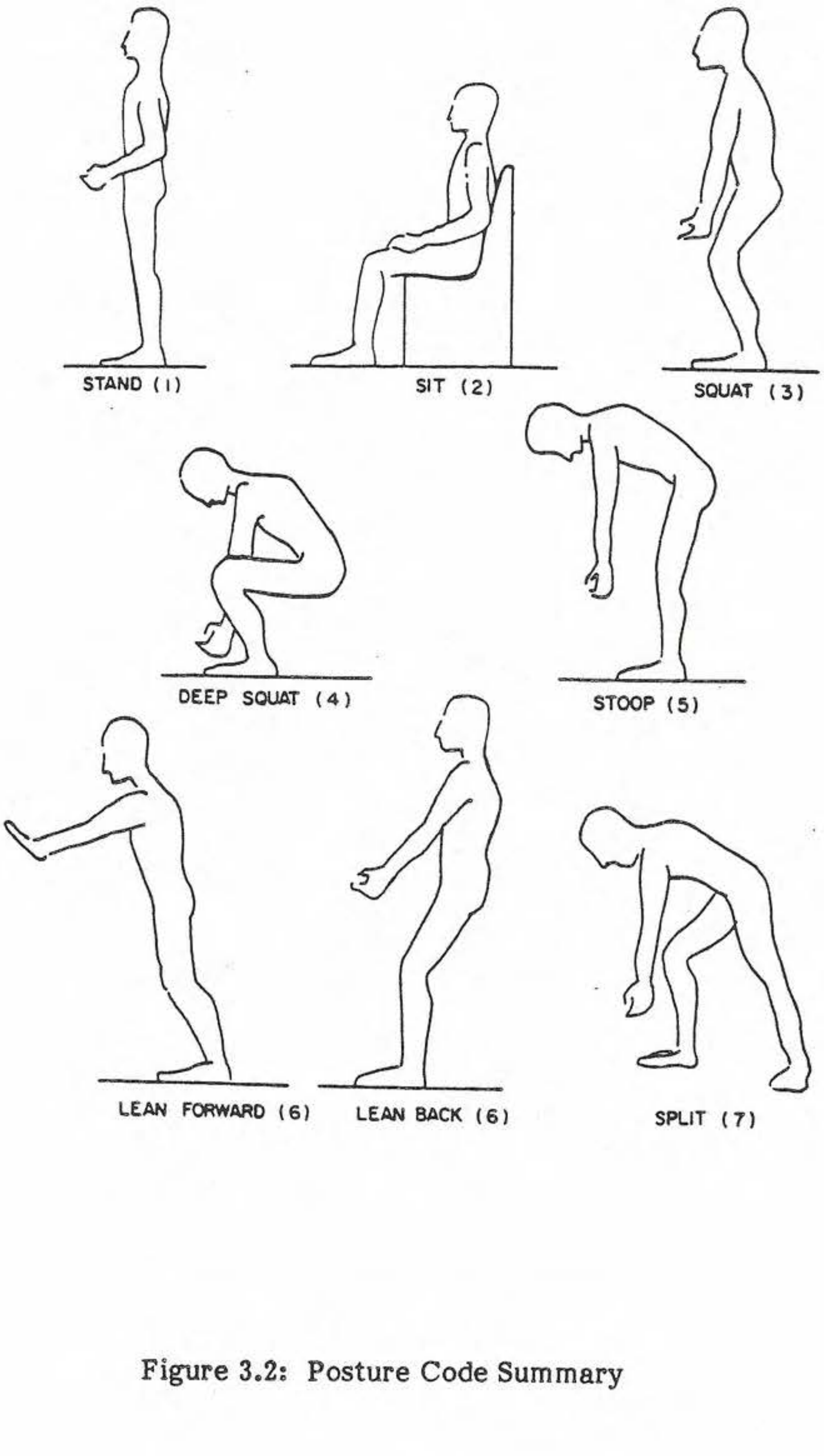


Figure 3.2: Posture Code Summary

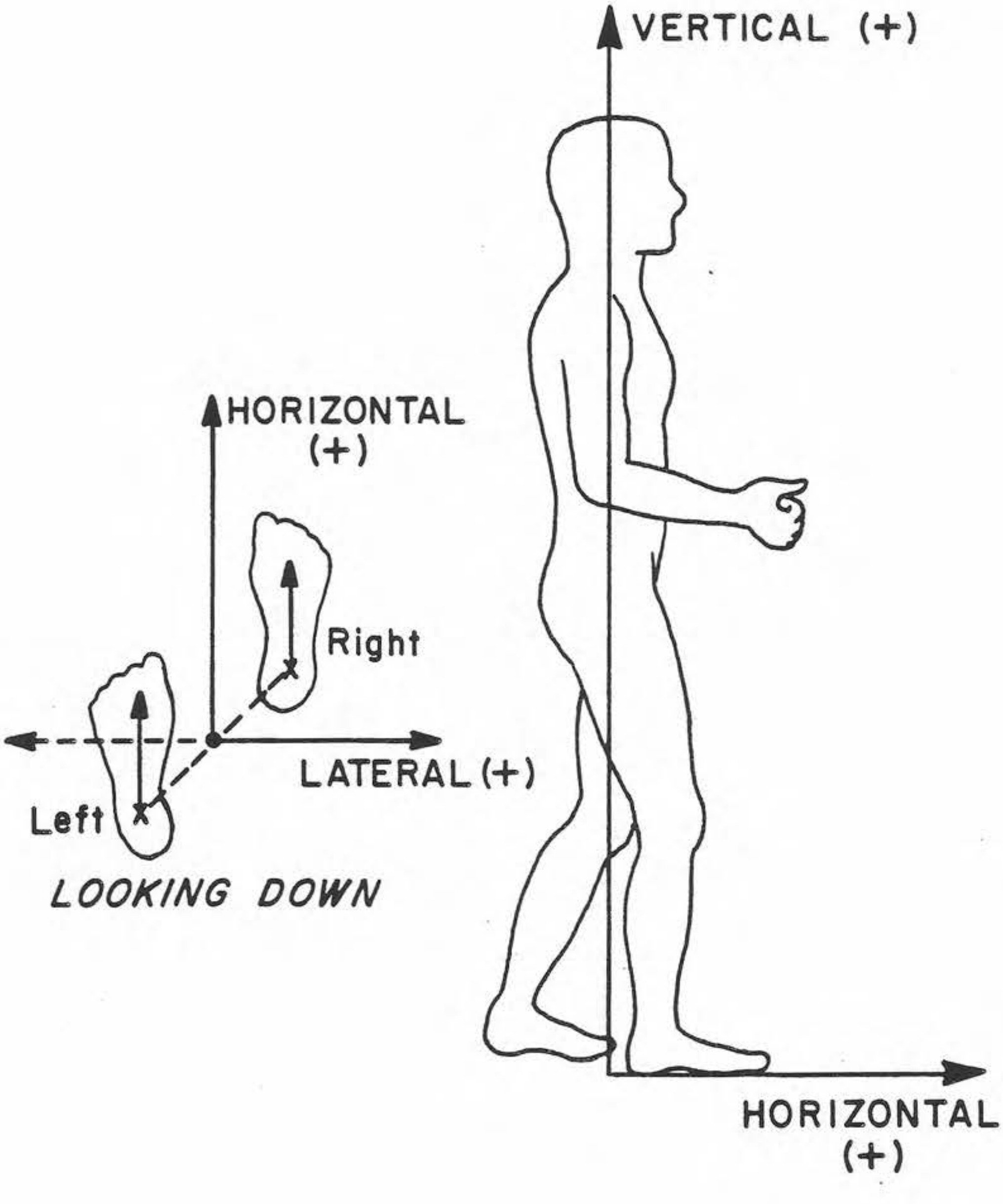


Figure 3.3: Graphic Representation of Vertical, Lateral and Horizontal Axes

BIOMECHANICAL ANALYSIS JOB CODING FORM

(1-8) COL DATE	(9-18) PLANT	(19-25) DEPARTMENT	(26-32) ANALYST	(33) REP.	(34) NON REP.	(35-42) JOB CLASSIFICATION	(43-61) JOB LOCATION	(62-81) JOB TITLE	(82-101) SUBDESCRIPTION / COMMENTS

	TASK NUMBER	TASK CODE		FORCE (lbs)		POSTURE CODE	HAND LOCATION (inches)														BODY MOVEMENT ft. (walk, carry, etc.)	TASK DURATION (minutes)	FREQUENCY				
							ORIGIN						POSTURE CODE	DESTINATION									69-71	72-74			
							RIGHT HAND			LEFT HAND DISPLACEMENT				RIGHT HAND			LEFT HAND DISPLACEMENT						REPETITION per CYCLE	CYCLES per DAY			
	1-3	4-5	6-15 OBJECT	16-18 AVG.	19-21 MAX.	22-23	24-26 V	27-29 L	30-32 H	33-35 V	36-38 L	39-41 H	42-43	44-46 V	47-49 L	50-52 H	53-55 V	56-58 L	59-61 H	62-65	66-68			75-94 REMARKS	95-102 CLASSIFICATION	

Figure 3.4: Biomechanical Job Analysis Coding Form

C. Biomechanical Job Analyses

Each job analysis was forwarded to the University of Michigan for interpretation via the biomechanical model discussed previously. Figure 3.5 shows example results for the ramp service bag handler in the bag room. For each task, the model defines:

a. The % male and female predicted to be able to perform the task based on industry norms.

b. The muscle groups most stressed during the exertion.

c. The compression at the lower back L_5/S_1 disc.

To further examine the reasonableness of these job stresses each job was subsequently analyzed using the NIOSH Work Practices Guide for Manual Lifting (1981). Figure 3.6 reflects this same job relative to the guideline. As can be seen this job is within the guideline (ie., below the recommended action limit) in general. However, task 13 exceeds the recommended action limit and administrative controls such as strength testing are warranted.

DATE: 10-24-78 PLANT: UAL JOB NUMBER: 100 TITLE: BAG HANDLER-BAGROOM
DEPT: RAMP ANALYST: MEDELL REP. X NON REP. GENERATION DATE: 07-27-82

TASK#	TASK	POST.	OBJECT	#HD	MAX FORCE		RIGHT HAND LOCATION			LEFT HAND SEPARATION			--------MALES--------		-------FEMALES-------		BACK COMPRESSION	
							V	L	H	V	L	H	PERCENT CAPABLE	LIMITING MUSCLE GROUP	PERCENT CAPABLE	LIMITING MUSCLE GROUP	M	F
O11	PULL	LEAN	BAGGAGE	2	30	ORIG	14	4	19	O	-8	O	99	ANKL EXTN R	92	KNEE EXTN R	529.	411.
O11	PULL	LEAN	BAGGAGE	2	30	DEST	30	4	10	O	-8	O	99	ANKL EXTN R	99	SHLD BACK L	673.	556.
O13	LIFT	STAND	BAGGAGE	2	70	ORIG	30	4	16	O	-8	O	88	ANKL EXTN R	42	SHLD ABD. L	1347.	1197.
O13	LIFT	STAND	BAGGAGE	2	70	DEST	42	4	16	O	-8	O	86	ELB. FLEX L	27	ELB. FLEX L	942.	889.
O23	LIFT	STAND	BAGGAGE	2	35	ORIG	30	9	8	O	-18	O	99	KNEE FLEX R	99	HIP EXTN R	549.	323.
O23	LIFT	STAND	BAGGAGE	2	35	DEST	56	9	10	O	-18	O	99	KNEE FLEX R	75	SHLD ABD. L	437.	401.
*O24	LIFT	STAND	BAGGAGE	2	70	ORIG	48	9	13	-4	-18	O	90	ANKL EXTN R	21	ELB. FLEX L	853.	809.
*O24	LIFT	STAND	BAGGAGE	2	70	DEST	56	9	13	-4	-18	O	86	KNEE FLEX R	5	SHLD ABD. R	857.	792.
O31	PULL	LEAN	BAGGAGE	2	30	ORIG	53	4	10	O	-8	O	99	ANKL EXTN R	98	ANKL EXTN R	1023.	882.
O31	PULL	LEAN	BAGGAGE	2	30	DEST	30	4	10	O	-8	O	99	ANKL EXTN R	99	SHLD BACK L	673.	556.
O41	LOWR	STAND	BAG CART	1	10	ORIG	57	O	18	O	O	O	99	TRQL TRNK R	97	SHLD ABD. R	235.	384.
O41	LOWR	STAND	BAG CART	1	10	DEST	36	O	12	O	O	O	99	TRQL TRNK R	99	TRQL TRNK R	414.	170.
O42	PULL	LEAN	BAG CART	2	70	ORIG	36	2	8	O	-4	O	95	ANKL EXTN R	32	ANKL EXTN R	1007.	929.
O42	PULL	LEAN	BAG CART	2	70	DEST	36	2	8	O	-4	O	95	ANKL EXTN R	32	ANKL EXTN R	1007.	929.
O43	PUSH	LEAN	BAG CART	2	10	ORIG	36	3	25	O	-6	O	99	KNEE EXTN R	98	KNEE EXTN R	678.	508.

DESTINATION NOT DEFINED

Figure 3.5: Example Biomechanical Analysis Output

PLANT: UAL DEPARTMENT: RAMP JOB: BAG HANDLER-BAGROOM
ANALYSIS DATE: 10-24-78 GENERATION DATE: 07-27-82
JOB#: 100 UM#:

TASK#	TASK OBJECT	HAND VERT	LOC. HORZ	DISTANCE TRAVELED	FREQUENCY (LIFTS/DAY)	AL	MPL	AVE FORCE		MAX FORCE	
013	LIFT BAGGAGE	30	16	11	300	28	85	35	EXCEEDS ACTION LIMIT	70	EXCEEDS ACTION LIMIT
023	LIFT BAGGAGE	30	8	25	300	48	145	35	WITHIN GUIDELINES	35	WITHIN GUIDELINES
024	LIFT BAGGAGE	48	13	7	300	30	92	35	EXCEEDS ACTION LIMIT	70	EXCEEDS ACTION LIMIT
AVERAGE ACROSS ALL TASKS:											
AVE	LIFT BAG CART	35	12	15	900	28	85	35	EXCEEDS ACTION LIMIT		

MOST SERIOUS REGION ACROSS ALL TASKS: EXCEEDS ACTION LIMIT

Figure 3.6: Example Work Practices Guide Output

The criteria of the guide (which only applies to "lifting" tasks) were also applied to all the jobs and job elements in this study. In particular, each task was examined relative to the action limit and maximum permissible limit criteria for pushing and pulling as well. The results of the biomechanical and work practice guide analyses are detailed in Appendices E and F respectively.

Early analyses revealed a few tasks (such as lifting the soup bowl by the cook in food service) which exceeded maximum permissible criteria. All such tasks were subsequently redesigned to insure that all tasks were below maximum permissible criteria.

D. Design of Strength Tests

For those remaining tasks which exceeded action limit criteria (in terms of strength required or back compressive forces) a set of tests were required. To determine an appropriate set of tests, the horizontal and vertical coordinates of each task were displayed by job classification as illustrated in Figures 3.7 and 3.8 for ramp service lifting and push/pulling respectively. Similar plots for other jobs are reproduced in Appendix H.

By examining the clusters of tasks across jobs a set of 6 tests were chosen to best reflect the range of exertions required while preserving the advantages of standardized tests (which could be compared with other industry norms). The six tests chosen are described in Table 3.3.

Task	Vertical Distance* (inches)	Horizontal Distance* (inches)
Low Lift	18	13
Mid Lift	44	13
High Lift	53	13
Low Pull	21	8
High Pull	48	-10
High Push	48	30

*Relative to position of feet (midpoint between ankles)

TABLE 3.3: SET OF STRENGTH TESTS ADMINISTERED IN UAL PROGRAM