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THE USE OF STRENGTH MEASUREMENT AS A DIAGNOSTIC TEST FOR LOW-BACK INJURY

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THE USE OF STRENGTH MEASUREMENT AS A DIAGNOSTIC TEST FOR LOW-BACK INJURY

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THE USE OF STRENGTH MEASUREMENT AS A
DIAGNOSTIC TEST FOR LOW BACK INJURY

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ABSTRACT

There is no more persistent, widespread and costly problem in the working world and throughout all human society than that of a disabling backache. Based on a review of worker's compensation cases and epidemiological studies, the costs of low back injuries are staggering. A major factor contributing to the high cost is the number of employees who make false claims of back injury or who prolong back pain symptoms to retain compensation payments. Reliable procedures for making definitive judgements about such claims do not exist.

The purpose of this research was to design a diagnostic technique to ascertain and monitor low back injuries involving symptomatic lumbar region disease. This was accomplished by employing strength testing of healthy and injured subjects performing maximal and submaximal strength exertions.

The approach used was to investigate differences in the rates of strength build-up and in the variability of the maintained exertions for three specific groups of subjects. The first group of healthy subjects performed maximal exertions. The second group of healthy subjects performed submaximal exertions. The third group consisted of symptomatic subjects with low back pain who performed safe maximal exertions.

Each trial consisted of a strength exertion of five seconds duration. Two standardized strength testing positions were used. These were the "Leg Lifting" and "Torso Lifting" positions commonly used in manual materials handling.

The results indicated that the rate of strength build-up provides a reliable distinction between maximal and submaximal exertions. The coefficient of variation of the strength scores as a measure of variability in the repeated exertions did not indicate significant differences between the maximal and submaximal exertions. A measure derived by dividing the within-trial range by the strength score provided a distinction between the injured and the healthy groups. Discriminant analysis was employed with partial success in distinguishing between the three groups using the various derived measures of the force exertions.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

THE USE OF STRENGTH MEASUREMENT AS A DIAGNOSTIC TEST FOR LOW BACK INJURY

CHAPTER I

INTRODUCTION

There is no more persistent, widespread and costly problem in the working world and throughout all human society than that of a disabling backache (Khalil et al., 1983). Rowe (1971) reported that it is found to be second only to the common cold as a cause for lost time due to disability. In fact, low back pain is one of the most common maladies plaguing our modern, mechanized society.

The National Safety Council (1980) has stated that back injuries are by far the most common type of injury at Trans World Airlines (TWA) in all departments (Air Transport, 1979). Wausau Insurance Companies of the United States (1980) claim that for a work force of typical national norms, somewhere between five and twenty percent of employees are suffering from low back disabilities on any given day. This means that the workers are either missing from the job, are physically impaired and cannot perform up to normal standards, or have a negative work attitude because of attendant pain or discomfort.

When the lost production days, impaired work capacity and pain related distractions, errors and accidents are translated into dollars, the costs due to low back pain syndrome are staggering. In the language of worker's compensation insurance, the terms "back injury" and "costly claim" are often used together. Wausau Insurance Companies reported that in 1980 industrial back injuries accounted for a full third of all worker's compensation claim dollars and cost American industry billions of dollars.

Exact estimates of the severity of the problem are difficult to acquire. However, statistics show that many of the work-related low back injuries have resulted in huge monetary payments. Chaffin and Ayoub (1975) reported that in 1974 these injuries were estimated to have cost three billion dollars in medical expenses and compensation payments in the United States. For the state of Washington alone, Chaffin (1974) reported the estimate of lost working days due to low back pain to be one-half million days each year. Goldberg et al. (1980) reported a loss during 1978 of approximately 14 billion dollars and 25 million work days resulting from low back pain in the United States. Nordby (1981) estimated actual medical expenses to be $18,000 per patient and the associated losses of interrupted income and related benefits to be $22,000 per back injury.

The experience of many insurance companies shows that low back pain is prevalent among white-collar as well as blue-collar employees, thus disproving the belief that white-collar workers are immune to low back injury. Although long-term disability is most pronounced in the older age groups, it is clear that back pain usually affects men and women during their most productive period from age 30 to 55. However, back injuries can strike anyone at any time. Four out of five people will suffer a disabling back injury at some time during their life (Wausau Insurance Companies, 1980). Hence, the low back pain syndrome occupies a prominent position in the statistics on sick-leave and lost work days.

An examination of several occupational groups reveals that industrial workers are often required to handle heavy loads and to maintain awkward postures on a repetitive basis as a routine part of their jobs. The activities commonly performed by these workers involve pushing, pulling, lifting and holding. It is not surprising that low back pain has been cited by Chaffin (1974) as one of the most common hazards of manual materials handling.

In both American and European industries a significant portion of industrial injuries have been attributed to manual materials handling. The National Safety Council reported that twenty-three percent of all non-permanent but compensable industrial injuries involve manual materials handling (Accident Facts, NSC, 1973).

Clearly, human suffering and high economic burdens are greatest in industries which require manual materials handling. Worker's compensation claims resulting from manual materials handling account for a major portion of employer's insurance costs in today's world of liberal benefits and rising medical costs. However, the number of these medical problems that are falsely reported in worker's compensation statistics is an open question.

Although back pain ranks among the most widely experienced ailments in western society, it is one of the least understood. The etiology of the condition is varied and does not appear to have any specific cause. Brown (1973) reported that it is generally supposed that the more severe injuries are associated with lifting heavy objects.

In most cases, low back pain syndrome is recurrent but self-limiting. Although its course is usually benign, the number of severely disabled people is still considerable owing to the widespread occurrence of the ailment. Since little is known of the causative pathology of low back pain, immediate treatment is usually palliative rather than curative and the disease must be left to run its normal course.

In a significant number of cases, a back incident can lead to a permanent reduction in working capacity and in a few cases, to permanent unemployment. It has been reported that of those off-work because of low back pain for longer than six months, only fifty percent will ultimately return to work. Many older workers are forced to change their jobs through fear of a further attack of back trouble (Davis, 1979).

Low back pain symptoms and impairment are generally slow in onset and are relentlessly progressive (Brown, 1973). It is therefore very difficult to attribute a low back injury to a specific work incident. Gunn et al. (1976) have stated, "While in some patients the diagnosis can be made with no difficulty on the basis of clinical history and physical examination, in others additional diagnostic tests including myelography and electromyography may be required. As a general rule however, such tests are reserved for patients who are expected to require surgery."

Physicians have used methods such as myelography, electromyography, lordosimetry and thermography to diagnose back injuries. However, these techniques are expensive and although positive results indicate the validity of a patient's complaint, negative results cannot invalidate the low back pain claim. In many cases, determination of low back injury and the accompanying compensation payments is based solely on the employee's complaint and response to treatment.

In view of the above difficulties, it has been relatively easy for a dishonest employee to "fake" low back pain and claim compensation. If the worker is in fact faking an injury, then the resulting loss has a dual effect on his work environment. The employer is losing valuable time, effort and money through lost work days, and truly injured co-workers suffer in the process because of the suspicion surrounding the compensation back (Daniel, 1978).

It has also been tempting for employees to malinger or prolong low back pain symptoms to retain compensation payments. Braverman (1978) states that "One-third of the injured employees may present signs of malingering." Thus, there exists a demonstrated need for development of a procedure to assess whether a worker is faking an injury and to determine when recovery is complete.

Freeman and Pratt (1977) and Daniel (1978) have explored the possibility of using strength measurement and statistical analysis to diagnose low back injuries. Their approach assumed that a subject faking injury would deliver a submaximal exertion when requested to produce maximal effort during strength measurement. It was hypothesised that repeated submaximal exertions would exhibit higher variability compared to repeated maximal exertions. Submaximal exertions could thus be identified through statistical analysis. Results of the study by Freeman and Pratt (1977) were encouraging but the researchers did not validate their findings using low back injury patients.

In a continuation of the study, Daniel (1978) included injured subjects in addition to healthy individuals. His results indicated that the variability in the submaximal efforts differed significantly from that in the maximal efforts when the coefficient of variation of the log-normal transformed data (CVLN) was used as the criterion measure.

Kroemer and Marras (1980) conducted a study to evaluate whether the rate of strength build-up could serve as an objective criterion for assessing a subject's level of effort. The hypothesis was that submaximal muscular exertions using the Caldwell regimen require a relatively lengthy strength build-up phase compared to maximal exertions where the level is achieved rather quickly.

The results of the study showed that the force onset slopes were steeper for the maximal exertions than for the submaximal exertions. The hypothesis that submaximal exertions presented by a subject as maximal efforts can be detected by their large variability in repeated tests was not supported by the results of the study. This latter finding was in disagreement with Daniel's (1978) results.

Certain points about the two studies mentioned above may explain the differing results. Daniel used the coefficient of variation of the log-normal transformed data (CVLN) as the criterion measure. However, Kroemer and Marras used the coefficient of variation of the original, non-transformed data as the criterion measure. Secondly, Kroemer and Marras measured elbow flexion strengths while Daniel measured lifting strengths in the arm lifting, torso lifting and leg lifting positions recommended by the National Institute for Occupational Safety and Health (NIOSH).

Thus, a controversy exists regarding the use of variability during repeated strength exertions as a possible diagnostic tool for low back injuries. A need for a simple and inexpensive diagnostic technique to objectively ascertain low back injuries has already been demonstrated by the discussion presented earlier. The technique could also prove useful in detecting cases of malingering. It could help the physician decide whether a patient is able to return to work and when compensation payments should be discontinued.

The current study focuses on the possibility of using the rate of strength build-up and the variability among repeated strength exertions to evaluate an employee's low back injury. A methodology based on statistical discriminant analysis is presented. It is suggested that the resulting diagnostic technique may be used to ascertain the incidence of low back injury and to detect malingering.

Problem Statement

The purpose of this research was to develop a diagnostic technique to ascertain and monitor low back injuries involving symptomatic lumbar spine disease. The approach used was to measure the lifting strengths of healthy and injured subjects and, with the aid of statistical analysis, identify possible discriminating features of the lifting force patterns. Two lifting positions, which were variations of the "Leg Lifting" and "Torso Lifting" positions commonly employed in manual materials handling, were examined in the study.

Subjects were classified into three groups. The first group consisted of healthy individuals performing maximal strength exertions in the two positions. The second group consisted of healthy individuals performing submaximal strength exertions at an estimated level of 50% of each subject's maximal voluntary contraction. The third group consisted of injured subjects performing "safe" maximal exertions.

In each position, strength exertions at the requested level were recorded over ten trials for each subject. The recording interval included the strength build-up phase and maintenance of the attained force level. The possible discriminating factors that were examined included (1) the rate of strength build-up, (2) the within-trial variability in force as measured by the range of the forces exerted during the maintained phase, (3) the ratio of this range to the strength score, and (4) the between-trial variability in strength scores.

The primary objective of the study was to explore the feasibility of using these factors to diagnose an employee's low back injury. To accomplish this, differences in the values of the above criteria among the three groups were identified through analysis of variance. Discriminant analysis was then used to predict the specific group to which an individual subject belonged based on the criteria.

A secondary objective of the study was to resolve the differing results of Kroemer and Marras (1980) and Daniel (1978) with respect to the variability among repeated trials for maximal and submaximal efforts.

In summary, the specific questions addressed by this research were:

(1) Is it possible to discriminate between healthy individuals and individuals with low back injury using strength measurement?

(2) Is it possible to distinguish between maximal and submaximal efforts using rate of strength build-up and between-trial variability in repeated exertions?

CHAPTER II

LITERATURE REVIEW

Studies related to low back injury can be classified into the following topic areas:

(1) Epidemiology

(2) Etiology

(3) Biomechanics

(4) Treatment

(5) Prevention and control

(6) Compensation and legal aspects

(7) Diagnosis

In addition to these topics, a background in the area of strength measurement is essential as it forms the basis of the current study.

Epidemiology

Knowledge of the incidence and prevalence (epidemiology) of low back pain is useful for personnel planning in industry. It also aids the planning of hospital services and social welfare in certain European countries such as Sweden. It can provide important information about the work factors and individual factors that are associated with low back injury.

Andersson (1979) studied the epidemiological aspects of low back pain in Sweden and reported that between 65 and 80 percent of the Swedish population had suffered from low back pain on some occasion. Data was obtained on sickness absence due to back pain during the 1955 to 1971 period. About 31 percent of Swedish citizens and 46 percent of immigrants had suffered a period of back sickness with compensation. The length of sickness averaged 39 days for citizens and 31 days for immigrants. Women had fewer and shorter sickness periods than men, mainly because of the fewer sickness periods and shorter average periods among housewifes. In 1971, the total number of sick days due to back pain was calculated to be 11 million and, as a result, the national product was estimated to be 1.8 billion crowns lower.

Andersson quoted Swedish National Health Insurance Office statistics which indicated that back pain is one factor in the large increase in the number of early retirement pensions and disability pensions granted through 1971. Andersson also pointed out that the incidence of back pain in various Swedish industries has been estimated to be as high as 40% to 70%.

Studies from the Swedish building industry show that in 1974, 22 percent of the population had suffered from work-preventing low back pain and 33.5 percent received sickness allowance. In lumber workers the incidence was

37.5 percent. Andersson stated that the frequency of occupational injuries to the back in Sweden is low compared to many other countries.

Andersson claimed that, independent of work conditions, there is an increase in the incidence and prevalence of back pain with increasing age. Education, related to jobs available, seemed to be of importance also. This was reflected in the fact that "sick listing" was the lowest among those who had the highest degree of education. The incidence of low back pain appeared unrelated to gender even though disc herniations were more common among men than among women (Spangfort, 1972).

To obtain a diversified picture of the magnitude of the problem, Bergquist et al. (1977) conducted a study at VOLVO International. They examined several factors including the frequency of acute and subacute patients in the population, various treatments and prognoses, the age distribution, the number of patients with serious disability and inability to work, and the economic consequences. They stated that evaluation of the epidemiology of low back pain is hampered by incomplete statistics and a lack of uniform definitions.

From the study they found back pain to be most common between the ages of 30 and 55 and found recurrences to be frequent. They reported no significant difference in the occurrence of low back pain among office employees compared to manual workers. However, a higher incidence was demonstrated among heavy industry workers than among people in less strenuous occupations.

Office employees often work in seated postures which may predispose them to low back pain. However, they perform physically light work which can be managed even with some pain. A high incidence of back ailments has been found in occupations with prolonged sitting (more than four hours daily) or with prolonged standing and no sitting (Magora, 1972).

Chaffin (1974) reported a high incidence of back disorders in tasks involving frequent strenuous lifting. In his study, he followed the weekly medical status of over 500 people working on jobs with various amounts of required manual lifting and found a greater incidence rate (by over 8:1) in workers on jobs requiring high lifting strength.

The distribution of psychological traits in populations of low back pain patients has also been studied, usually without etiological implications. Bergquist et al. (1977) reported a relationship between certain indices of emotional and psychological problems and the occurrence of back pain. In another socio-medical investigation on back pain, Westrin (1970) observed a high incidence of various social problems. For example, there was an association between sick-leave for back pain and abuse of alcohol. A high percentage of broken marriages, family problems and financial difficulties was also noted among back patients.

In his epidemiological evaluation of low back pain

Nordby (1981) reported it to be the single most common cause of worker's compensation payments in the U.S. and the most common cause of low productivity due to inability to work. The U.S. Social Security Administration has found that among people under the age of 40 years, the prolapsed disc is second only to schizophrenia as the most frequent condition for which worker disability payments are allowed (Kelsey and White, 1980).

Data from the National Center for Health Statistics indicate that among chronic conditions, impairment of the back and spine is the most frequent cause of activity limitation in persons under age 45 in the United States. A study of an industrial population over a ten year period indicated that 35% of sedentary workers and 45% of heavy handlers at the plant visited the medical department with complaints of back pain. In this particular plant, an average of four hours per person per year were lost because of low back pain (Kelsey and White, 1980).

Etiology

Low back pain is a clinical manifestation that can be caused by a variety of known diseases and morphological changes. It is occasionally caused by infections, tumors, fractures and rheumatoid arthritis. Certain radiological abnormalities also have a definite association with low back pain. However, the majority of low back pain patients do not fall into any of the above-mentioned categories. As a general rule, low back pain is a complaint where the underlying pathophysiology is unknown.

Since the etiology of low back pain is not known in most cases, classification of the disease must be based upon symptoms and clinical findings. Unfortunately, there is a lack of general agreement as to the definitions and basic terminology of low back pain (Bergquist et al., 1977). Factors observed to contribute to the high incidence or to the triggering of low back pain are summarized in Table 1.

Table 1.

Factors Contributing to the Incidence or Triggering of Low Back Pain.

Incidence	Triggering
(1) Heavy Industry Work	(1) Weight Lifting
(2) Frequent Lifting Occasional Lifting	(2) Bending
(3) Excessive Bending Accidental Bending	(3) Rotation
(4) Sudden Maximal Efforts	
(5) Prolonged Postures	
(6) Forceful Movements	

(from Bergquist et al., 1977)

In his study, Andersson (1979) found an increased sickness absence because of low back pain in jobs with

(1) high physical demand

(2) prolonged static work postures

(3) primarily bent-over work postures

(4) sudden (unexpected) high physical work loads

(5) vibration.

He suggested that poor strength in the abdominal muscles and back muscles may increase the susceptibility to back injury. The theoretical reason for this is a lessened ability to increase the intra-abdominal pressure.

Bergquist et al. (1977) reported a combination of flexion, rotation and lifting to be the most common cause of back injuries. However, a moderate amount of daily lifting was not found to influence the rate of back injury.

Kelsey and White (1980) mentioned heredity as a possible causative agent in certain cases of low back injury. However, definitive evidence of the role of heredity would require further extensive studies. They also reported three studies to expose a possible relationship between low back pain and vibration, associated with occupational driving of truck, buses. It has been speculated that repeated small trauma due to the vibrations may give rise to permanent damage to the structures of the spine. The high frequency of radiographic changes in the spine and the high incidence of low back pain among truck drivers confirms this suspicion.

Brown (1973) reported "It would appear that low back pain occurs much more frequently as a result of natural or pathological processes than as a result of lifting. This point must be kept in mind by the examining physician when first interviewing the patient who claims that he developed low back pain following the lifting of any object no matter what shape, weight or size. There is a real need for better understanding of low back pain, by both the physician and the patient. Undue emphasis tends to create a psychological state of mind in which low back pain becomes persistent and often intractable. It is often useful to obtain a previous history of the patient's health profile. It is estimated that low back pain of psychosomatic origin frequently occurs and may be unrecognized. This is important if any headway is to be made in the reduction of compensation cases."

Brown also claimed that postural fatigue is an important element in the production of low back pain. Bad postures can lead to accidents and to severe back injury due to muscular imbalance and torque on the intervertebral space. This may result in a rupture of the annulus fibrosus which could press on the dorsal nerve roots giving rise to low back pain.

Nachemson (1979), a pioneer in the field of back pain commented "It seems clear that some anatomical structure must be diseased or at fault in order for the patient to elicit pain". Having been engaged in research in the field of low back pain for 25 years he says he can only state that for a majority of patients the true cause of the low back pain is unknown.

From a theoretical point of view, the intervertebral facet joints seem to be a likely site of origin for back pain. However, patho-anatomical changes have always been found in these joints secondary to degenerative changes in the intervertebral disc. The medical literature does not show facet sublaxation or dislocation as being more common in individuals with back pain than in normal individuals.

Decreased motion of the facet joints is always secondary to disc degeneration according to some researchers. In a few older patients it is possible that this is responsible for back pain. A majority of scientists suspect that the origin of the pain is most likely in the lumbar disc or its close surroundings, the longitudinal ligaments. However, there is still lack of direct conclusive evidence of the part played by the disc in the etiology of low back pain.

Nachemson (1979) observed that :

(1) The disc hernia is usually preceded by one or more attacks of low back pain.

(2) Eventually all individuals will have degenerative changes in the discs, characterized by increased fibrosis in the nucleus and ruptures in the annulus. It is likely that certain stages in the aging process are significant in the production of the pain syndrome.

(3) A recent study indicates that a single disc degeneration is as common in those that never experience back pain as in those who have.

Nachemson concluded that the trouble seems to start during the stages of degeneration and that these occur before the changes are clearly visible on the roentgenograms of the back.

Biomechanics

The vertebral column or spine has the shape of an elongated S. At chest level the spine has a slight backwards curve called a kyphosis. In contrast, the lumbar region is curved slightly forward. This is identified as the lumbar lordosis. The loading on the vertebral column increases from top to bottom and is at its greatest in the lowest five lumbar vertebrae (Grandjean, 1982).

An intervertebral disc acts as a cushion which separates adjacent vertebrae. The disc consists of a viscous fluid enclosed in a tough fibrous ring. This construction collectively gives the spine elasticity and flexibility to absorb shocks caused by various human activities.

Lifting stresses induced in the low back region are not solely the result of the weight of the object handled. These stresses are due to a combination of factors including the weight lifted, the size, shape and location of the object, the method of lifting and the individual's anthropometric measurements and physical condition.

The mass of the human body itself causes a bending moment to be exerted on the axial skeleton even when no object is handled (Tichauer, 1978). The muscles erecting the trunk counteract this moment and help maintain an upright posture. It is important to note that the heaviest object normally handled by a human at work is the body itself including its segments. Variations in body posture and trunk-limb configuration may change the forces exerted on the lumbar spine according to the contribution of the individual body segments to the total moment sum.

Thus, the external load and the person's body segments create moments or rotational torques at the various articulations of the body. The skeletal muscles are positioned to exert forces at these articulations to counteract these torques. Due to the length of the moment arm, a light but bulky object will often impose a greater lifting stress on the spinal column than a heavy load of high density.

Biomechanical analysis of a lifting task involves the calculation of moments, most commonly the sagittal lifting moment on the lumbar spine. This can be derived by graphical methods. First, the weights of the body segments involved in a specific task are obtained from reliable tables (Young, J.W., et al., 1983, Williams and Lisner, 1962). Then, a stick figure of proper anthropometric dimensions is drawn, and the locations of the centers of mass for all body segments and the external load are marked. Finally, the sum of all moments acting on the lumbosacral joint is computed. This becomes the sagittal biomechanical lifting equivalent of the specific task under consideration.

Tichauer (1978) suggested that the only way to reduce the lifting stress exerted by an object is to devise a handling method that will bring the center of mass of the article as close to the lumbar spine as possible. This reduces the magnitude of the biomechanical lifting equivalent. He stated that the relative severity of material handling operations and differences in lifting methods can be evaluated only by using biomechanical analysis. In fact, he claimed that many incidents of low back injury are avoidable and are the consequence of inadequate or simplistic biomechanical task analysis.

Clinical and biomechanical data indicate that the greatest risk of injury is located at the lumbosacral joint (L5/S1 disc) due to the large stresses observed in this region (Chaffin et al., 1973). To counteract the torques at the lumbosacral joint due to body segments and the external load, the muscles of the lower back region (primarily the erector spinae group) must exert high forces because of their short moment arms. The high forces generated by the lower back muscles are the primary source of compression and shear forces on the lumbosacral disc. Excessive compression and shear forces can cause rupture of the disc. This may squeeze the viscous internal fluid outward, exerting pressure on the spinal cord or the nerves running out from it and resulting in low back injury and pain (Grandjean, 1982).

The compression and shear forces on the disc during static equilibrium can be calculated using free body diagrams. These computations are illustrated using Figure 1.

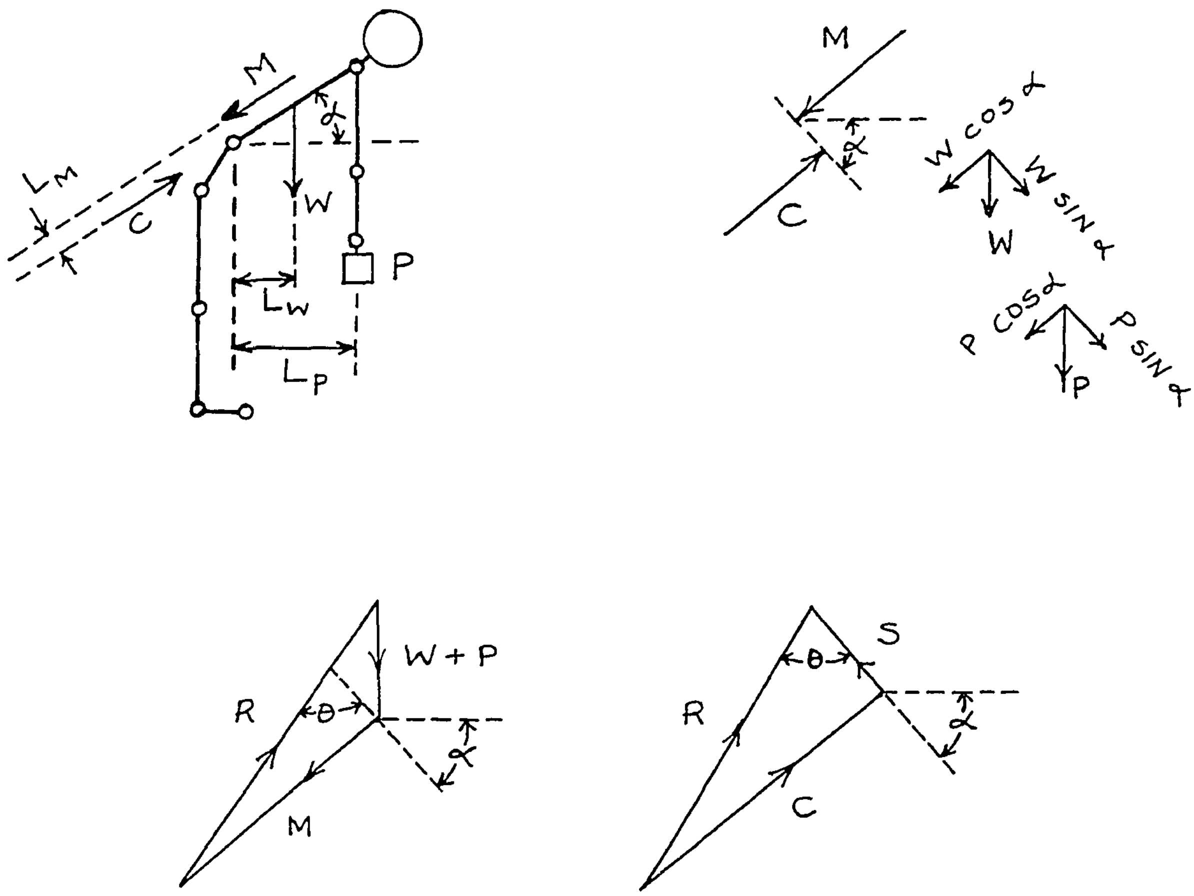


Figure 1. Biomechanical Analysis for Saggital Plane Lifting.

The three main forces acting on the lumbar spine at the lumbosacral level are defined as follows:

W = weight of the upper body

P = weight of the object lifted

M = contractile force exerted by the erector spinae muscles.

Forces W and P produce forward bending moments with the counterbalancing moment being produced by M. The magnitude of the force M can be computed from the following equilibrium equation.

$$\Sigma \text{ moments about the lumbosacral joint} = 0$$

$$(W \times L_w) + (P \times L_p) - (M \times L_m) = 0$$

$$M = (W \times L_w + P \times L_p) / L_m$$

The forces W and P may be resolved into their respective compression components ($W \cos\alpha$ and $P \cos\alpha$) and shear components ($W \sin\alpha$ and $P \sin\alpha$). Then, the total compressive force exerted on the disc can be calculated by equating the sum of all the forces along the spine to zero.

$$W \cos\alpha + P \cos\alpha + M - C = 0$$

$$\text{Thus,} \quad C = W \cos\alpha + P \cos\alpha + M$$

Similarly the shear force on the disc can be calculated by equating the sum of all the forces perpendicular to the spine to zero.

$$W \sin\alpha + P \sin\alpha - S = 0$$

$$\text{Thus,} \quad S = W \sin\alpha + P \sin\alpha$$

Since the forces C and S act at a right angle, the total reaction force R on the disc can be computed from

$$\vec{R} = \vec{C} + \vec{S}$$

The magnitude of the force is calculated as

$$R = \sqrt{C^2 + S^2}$$

The direction of the force is determined using

$$\sin\theta = C/R$$

$$\theta = \sin^{-1}(C/R)$$

The magnitude and direction of the resultant force (R and θ) may alternatively be computed by constructing vector diagrams using W, P and M as shown in Figure 1.

Two other moments in addition to the one in the sagittal plane must be included in the biomechanical analysis when they are present in the task. These are the lateral bending moment such as in a side-stepping task and the torsional moment such as the one caused by rotation of the body in the transverse plane along the vertical axis. Tichauer (1978) warns that a lifting task imposing a torsional moment on the lumbar spine, in a seated position can be a serious hazard to the person. This condition is conductive to great mechanical stress on the vertebral column and may aggravate pre-existing back pain.

Treatment

Since the exact cause of low back pain is unknown in most cases, only symptomatic treatment is available for many patients. In the early stages it is difficult to distinguish between musculo-tendinous strain and early lumbar disc protrusion (Edger, 1977). Acute low back pain produced as an apparent result of lifting strain usually responds well to rest followed by graded isometric exercises for the spine and abdomen. If the strain is severe, then bed rest should be strictly followed for two to three weeks.

With regard to manipulative treatment, Nachemson (1979) stated that the few existing studies do not demonstrate that it is superior to nature's own course or to non-manipulative treatment. He reported several epidemiological studies which have demonstrated that nearly 50 percent of all patients improve in a few weeks irrespective of the treatment rendered and some 80 percent are well within two months. It was suggested that a careful clinical examination is of benefit.

Some of the other treatments besides bed rest and exercise are radiation therapy, ultrasound, shortwave diathermy, traction, and injection of various drugs including hydrocortisone. However, these have not been proven to be more effective than rest and exercise, and are primarily used for patients with chronic back pain.

For a true disc hernia pressing on a nerve root, removal of the disc gives 90 to 95 percent successful results. Conservatively, a true herniated disc may be successfully treated with bed rest, controlled manipulations under anesthesia, or traction. It remains to be demonstrated that the results of these treatments are as good as those obtained by surgical removal.

Chymodiactin (chymopapain) intradiscal injection has been recommended recently for the treatment of patients with documented herniated lumbar intervertebral discs whose symptoms and signs have not responded to conservative therapy. Chymopapain is derived from the crude latex of carica papaya. Chymopapain is injected into the herniated nucleus pulposus of the lumbar intervertebral disc. This results in rapid hydrolysis of the noncollagenous polypeptides. This lessons the intradiscal osmotic activity and reduces intradiscal pressure, thus relieving the pain.

In a study reported by Smith Laboratories (1983), approximately 75% of the patients responded successfully to this treatment.

It must however be noted that only a few patients develop symptoms, signs and pathology of a true herniated disc. For the vast majority, the origin of the pain and the proper treatment are unknown.

Khalil et al. (1983) have initiated a multidisciplinary approach to the evaluation, treatment and rehabilitation of people with low back pain. A team of more than 70 professionals including psychiatrists, neurosurgeons, physical therapists and ergonomists participated in a comprehensive program to eliminate back pain and restore function to the pre-injury level. The program used several treatment methods including patient education, detoxification, physical conditioning, psychological conditioning, and vocational rehabilitation. The researchers have concluded that pain in itself is not a good reason to limit activities and that their approach was very effective for regaining functional capability within a short period following an injury.

Prevention and Control

The prevention and control of low back injuries in industry has been attempted by :

(1) Selection and Assignment of workers to the tasks

(2) Job Design

(3) Training and Conditioning

Selection and Assignment

This approach has been based on predicting the susceptibility of prospective employees to low back injury. The information can then be used for assigning employees to material handling tasks. Predictive techniques have included:

(1) X-Rays

(2) Medical history and physical examination

(3) Lordosimetry

(4) Intra-abdominal pressure measurement

(5) Strength testing

X-Rays. In the early part of the twentieth century reports began appearing that congenital abnormalities of the lumbar spine structurally weakened the back, predisposing it to low back injury and prolonging the recovery. Based on the fact that some of these abnormalities may be detected by X-rays, researchers explored the possibility of using lumbar X-rays to develop a means of predicting the incidence of low back pain. The theory of this approach was that the load bearing capacity of the spinal column in many different configurations is highly dependent upon the geometry of the column as assessed by detailed radiological evaluations of the erect, relaxed column.

Lysis and olisthesis of lumbar vertebrae are relatively common roentgenological findings. It was believed that these cause instability of the lumbar spine and earlier degeneration of the inter-vertebral disc which may result in low back pain, or cause proneness to it. Based on this prevalent opinion, some applicants were eliminated from occupations with stressful physical requirements if either of these conditions were detected in preplacement screenings. This was shown to be an unjustified and arbitrary decision by Redfield (1971) who did not find any proneness to lower back injury in the subjects with "high risk" (lysis and olisthesis).

Magora and Schwartz (1980) studied 1024 low back pain and healthy subjects to determine the incidence of lysis and olisthesis in the two groups. Based on their findings, it was concluded that lysis should not be considered grounds for the exclusion of applicants, regardless of the occupation. However, olisthesis should be accepted as a factor which causes proneness to low back pain and should be given weight in the selection of an occupation for an individual. They also concluded that both of the above abnormalities should be accepted as roentgenological findings in which the severity of low back pain may be higher.

Gunn and Milbrandt (1976) conducted studies on four groups of 50 people each. The groups were classified as follows:

Group A: 50 patients with low back pain

Group B: 50 patients with disc involvement

Group C: 50 patients with no history of back pain

Group D: 50 patients with no previous medical treatments for back pain but with occasional back pain after unusual stress or activities.

The primary purpose of their study was to determine the sensitiveness to pain upon pressure of the points where certain motor nerves enter the muscles or in other words, the tenderness of motor points. However, it is interesting to note the results pertaining to the X-rays for the four groups:

Group A: X-rays were within normal limits, showed no more abnormalities than those associated with age, or showed minor abnormalities.

Group B: 39 patients had roentgenographic changes which included disc space narrowing with or without associated degenerative changes.

Group C: 31 patients had normal X-rays and the remaining 19 showed minor degenerative changes consistent with their age.

Group D: 22 patients had normal X-rays, 18 had minor degenerative changes and the remaining 10 had minor degenerative changes and disc-space narrowing.

From the X-ray findings of the four groups in relation to the results of the study, it can be concluded that the use of X-rays as a possible diagnostic or predictive tool for back injuries is of limited value.

Montgomery (1976) claimed that the use of pre-employment X-rays has been based upon the assumption that inherent back abnormalities cause an increased incidence of low back injury. For all practical purposes, the evidence collected over the years leads one to believe that this is not the case. In his study, an initial evaluation of a random group of X-rays revealed more roentgenographic abnormalities among asymptomatic individuals than were noted in those suffering from back pain. A closer look at low back compensation cases revealed that most of their X-ray reports were essentially normal. In addition, a majority of the abnormal films from these cases showed disc disease and degenerative arthritis but no congenital abnormalities, the main reason for rejecting job applicants.

Onishi and Nomura (1973) report that a large number of the low back pain claims by industrial workers are known to be of non-organic origin and produce no definite X-ray findings. Brown (1973) warns of a possibility that continued spinal radiographs may give rise to leukemia or anemia. The use of X-rays for screening applicants is therefore not only of limited value but also poses some serious inherent dangers.

The alternative to X-ray based screening for predicting the incidence of low back injury appears to rely on acquiring a better history of low back health and on better functional evaluation which may include strength testing.

Medical History and Physical Examination. Rowe (1971) suggested that the single most important factor when considering a person for employment for manual material handling jobs is a good medical history with concentration on low back dysfunctions. The value of this suggestion is certainly evident from the data disclosing the recurrent nature of the low back episodes. However, it must be realized that a person could easily distort his own medical history, intentionally or unintentionally, to acquire a job.

Krain et al. (1970) presented a method to quantify pre-employment history characteristics of those persons who might exaggerate their future work-caused disability. They designed a history form and concluded that the number of "yes" items checked on such a questionnaire has a high correlation with the percentage disability rating for workers in certain occupations. No prediction could be made from the number of items checked as to whether disability compensation would be issued in a given case.

Nordgern et al. (1980) reported a study involving the evaluation and prediction of low back pain among individuals who were to undergo two to four weeks of military field service in Sweden. A standardized physical examination of the back concentrating on mechanical function and tenderness in the different parts of the spine was performed to assess its validity for prediction of work tolerance during field service. The predictive value of self-reported back pain history was also studied.

The physical examination of the lumbar spine best predicted the occurrence of low back pain during field service (83% of the cases). Thus, it was more efficient in separating subjects who experienced back pain in field service than information on earlier sick-listing due to back troubles. Subjects who experienced back pain during the also field service were found to have an average lower isometric strength in abdominal and back muscles during the physical examinations.

Lordosimetry. The effects of lifting stresses on the back are highly dependent upon postural configuration and vice-versa. This relationship led Tichauer et al. (1973) to investigate lordosimetry as a technique for direct simple evaluation of stresses acting on the back. In lordosimetry, changes in the configuration of the spinal column, specifically the position and curvature in response to the static holding of loads, are recorded and evaluated.

Using a lordosimeter, a tracing of the shape of the vertebral column is produced as a stylus is run along the column. A potentiometer and an analog computing module provides a permanent record on a recorder. The procedure is fast, does not require any special training for its use, and also gives reproducible results. However, further work and testing has been needed to determine its potential usefulness for diagnosing low back injuries.

Intra-abdominal Pressure Measurement. Davis (1979) at the Manual Handling Research Unit at the University of Surrey, England has examined the use of pressure measurement within the abdominal cavity for preventing and controlling the incidence of low back injuries. He claimed that there is a linear relationship between the forces acting on the lower spine in the L4/L5 region and the magnitude of the pressures within the abdominal cavity.

Development of "radio pill" techniques has enabled intra-abdominal pressures to be measured with minimum interference with the subject's comfort and freedom of movement. In tests using the radio pill at Surrey University, rods are attached to the subject's back and an aerial is placed around the waist. A tiny, pressure sensitive radio transmitter is swallowed 15 minutes before the tests by the subject. This ensures that the transmitter is in the right position internally. The frequency output of the pill responds to abdominal pressure changes when the subject lifts, pushes and pulls. The signals are picked up by the waist aerial and relayed to a chart recorder. The short rods attached to the person's back are markers which are used in conjunction with an overhead mirror and a calibrated floor and wall to assess the angle of the spine and the degree of flexion or extension during the lifting exercises.

The data collected using this equipment and technique can be analyzed to determine the weights that can be safely lifted by the subject in various positions. The experimenter can obtain continuous records of abdominal pressures over a working period and deduce the degree of spinal stress involved in the work at any particular time.

Using this method, the Manual Handling Research Unit has been able to identify those occupations in which pressure peaks of over 100mm of Hg occur regularly and frequently. These are also the occupations with a significantly higher risk of back injury. Davis concluded that, in general, the greater the peaks and the more frequently they occur, the higher the low back injury rate.

The above finding lends strong support to the hypothesis that a large majority of back pathologies must be regarded as cumulative injuries. Davis suggests that if one can alter the work in high risk occupations in such a way that the high peaks are avoided or at least reduced in frequency, one should be able to reduce the risk of back injury considerably. Further research is needed in this area before the technique can be effectively used in preventing and controlling the incidence of low back injury in industry.

Strength Testing. Some industrial physicians have adopted informal methods of strength testing to evaluate what a person can safely lift without risking an injury. One test is simply to ask the person to lift a tote box filled with lead shot. If the person appears capable of easily lifting the load, then he or she could perform a task with similar lifting requirements (Chaffin, 1974). Some limitations of such procedures are that they rely on a subjective estimate of how well the person handled the load. Also, there are inherent dangers of subjecting a person to potentially high stresses which he or she cannot easily sense and control due to the dynamics of the lifting act.

Chaffin and Park (1973) studied five personal risk factors involved in manual materials handling. Two of the factors which provided an increased risk of injury in material handling tasks were (1) a previous history of low back pain syndrome and (2) an inability to demonstrate an isometric lifting strength equal to that required on the job. The other potential risk factors of age, weight and stature did not correlate with increased incidence of low back pain.

Chaffin and Park (1973) suggested the use of isometric strength tests to predict a person's ability to perform manual material handling tasks. Their objective was to determine if a person's ability to lift weights would correlate with the incidence rate of low back pain. They studied 103 jobs with various amounts of required lifting and evaluated 411 workers populating these jobs. All incidents of low back pain for a period of one year were recorded.

The primary result of this field study was that the incident rate of low back pain was found to correlate with higher lifting strength requirements as determined by the location and the magnitude of the load lifted. Chaffin and Park concluded that inability to demonstrate an isometric lifting strength in the medical test equal to that required on the job, increased the risk of low back injury in manual materials handling tasks.

Chaffin, Herrin and Keyserling (1978) conducted an investigation to evaluate the practicality and potential effectiveness of pre-employment strength testing in reducing the incidence and severity of low back pain in manual materials handling jobs. Prior to assignment to new jobs, 551 employees were given a series of strength tests and then monitored for approximately 18 months. All medical incidents were recorded. Analysis of these incidents revealed that a worker's likelihood of sustaining a back injury increased with the lifting requirements of the job. Because strength was found to be weakly correlated with other individual characteristics (age, gender, weight and stature), the authors recommended employee selection using the strength performance criterion.

Job Design

Designing the job to fit the worker was the approach selected by Liberty Mutual Insurance Company. Snook (1978) claimed that this approach represents a more permanent solution to the low back injury problem. He concluded that proper design of manual handling tasks can reduce industrial back injuries by one-third.

Snook, Campanelli and Hart (1978) analyzed 191 low back injuries to determine the effectiveness of several approaches to controlling the incidence of low back injury. No significant reduction in low back injuries was found for employers who used medical histories, medical examinations or low back X-rays in selecting the worker for the job. In addition, equal employment opportunity laws often prevent the use of selection techniques in hiring or placing employees. The researchers claimed that even if selection techniques were used in hiring or placing employees, only 10% of those employees who will suffer low back disability can be identified at the time of hiring by present diagnostic methods.

Physical Conditioning and Training

Medical researchers in the area of low back pain generally agree that the overfed, overstressed and underexercised condition of many individuals contributes significantly to the epidemic of low back pain syndrome. Low back pain is but one of several "sedentary diseases" resulting from our society's labor-saving devices, too-well-nourished bodies, and a life-style with too little exercise and too much stress (Wausau Insurance Companies, 1980).

Kraus (1980) analyzed the histories of his low back pain patients and found that 95 percent of his patients engaged in no regular exercise of any kind. He cited surveys indicating that at least 80 percent of all disabling low back pain is primarily caused by overtensed and under-used muscles and ligaments. The pain seldom involves a "slipped disc" or other conditions that might require surgery.

Kraus claimed that effective prevention and control of low back pain involves the individual's private off-job life as well as his working life. He recommended regular exercise programs and control of weight as a possible approach for reducing the incidence of low back injuries.

Snook, Campanelli and Hart (1978) reported no significant reduction in low back injuries for employers who trained their workers with proper and safe lifting procedures. Just as many injuries were experienced by employers who provided training as by employers who did not provide training. These results were consistent with those of Brown (1972). They suspected that perhaps the training procedures were not effectively utilized. Snook et al. recommended "Strength Testing" as a possible future selection technique.

Compensation and Legal Aspects

The statutory conditions for a claim to qualify for compensation under the Worker's Compensation Act are (1) the injury must arise out of and in the course of employment and it must render a certain degree of disability. These statutes are easily applied for obvious overt trauma with documented external force and demonstrable damage (Hadler, 1978).

Low back injuries, however, are "invisible", difficult to diagnose and treat, and often cumulative. They can be caused by repeated stress and many times cannot be traced to a single verifiable incident. Thus, pain that begins away from the job can still be related to job stress and injury.

No procedure has been developed to identify people prone to claiming worker's compensation or to identify situations where an employee is faking an injury. A significant percentage of low back injury patients consciously prolong their symptoms for self-serving purposes giving rise to the term "compensation back" (Finneson, 1973).

There is a significant prognostic difference between patients who are likely to receive monetary compensation (secondary gain) and those who are not in a position to be compensated for their injury. The former group is disabled for significantly longer periods (Finneson, 1977).

For a number of reasons, physicians are hesitant to label a patient with the diagnosis of malingering. Many doctors are justifiably concerned about erroneously considering the patient's complaint as a case of malingering in the presence of organic disease. The tendency then is to employ a conservative approach by prescribing work stoppage with medication, exercise and therapy and also recommending compensation claim benefits (Hadler, 1978).

Diagnosis

The following techniques have been used by physicians for diagnosis of low back pain:

(1) Myelography

(2) Electromyography

(3) Abdominal pressure

(4) Tender motor points

(5) Thermography

Myelography

A common method of diagnosis is "Pantopaque Myelography in which Pantopaque (an X-ray opaque fluid) is injected into the spine through a lumbar puncture needle (Jequier and Adams, 1974). The patient is then tipped on a tilt table and the entire spinal subarchanoid space may be visualized using an X-ray. Care must be taken to see that the Pantopaque is completely removed after the examination to prevent any harm to the patient.

Electromyography

Nordby (1981) recommends the use of vascular studies and electromyography along with myelography to be definitive in the diagnosis. He points out that electromyography provides measures of muscular lifting stress but is time consuming, awkward to use in an industrial setting and requires sophisticated skills in electrode placement and data interpretation. It is also used to confirm or rule out the possibility of neural involvement which is usually not the cause in most patients.

Abdominal Pressure

The abdominal cavity has an important function in providing support for the lumbar spine. Fairbanks et al. (1980) cited Davis (1979) as the first person to observe a rise in intra-abdominal pressure with manual activity. Biomechanically, this rise is assumed to relieve the load on the lumbar spine. It has been postulated that a patient with low back dysfunction who experiences pain while lifting might be expected to have an increased intra-abdominal pressure response. This response may be related to the intensity of the pain the patient is suffering.

A study by Fairbanks et al. (1980) demonstrated a method of evaluating patients with chronic low back pain using abdominal pressure measurement, both in differential diagnosis and in monitoring progress after treatment. However, measurement of intra-abdominal pressure is not simple and further studies are needed for validation of the procedure.

Tender Motor Points

Gunn et al. (1976) postulated that tender motor points may be useful in assessing low back injuries, particularly when no positive physical signs are detectable. The search for tender motor points may be easily incorporated into a regular examination of the low back but a knowledge of the locations of the motor points is essential. Sufficient pressure is applied with the thumb or one finger against the underlying bone to compress the motor end-plate zone. The degree of tenderness is determined by the patient's response.

According to Gunn et al., the degree of tenderness and the number of tender points tend to parallel the patient's condition and may serve as progress indicators.

The presence or absence of tender motor points might also be of value in pre-employment medical examinations.

An important finding of their study was that patients with low back pain but no tender motor points were disabled for an average of 6.9 weeks while those with the same diagnosis but with tender motor points were disabled for an average of 19.7 weeks.

They concluded that patients diagnosed as having simple low back sprain but demonstrating acutely tender points will have a longer period of disability approaching that of patients with signs of radicular (nerve root) involvement (25.7 weeks). Patients with no tender motor points can be expected to do much better.

The absence of tender motor points in patients with severe complaints and equivocal physical findings should raise doubts as to the presence of significant lesions in the lumbar spine (Gunn et al. 1976). Thus, this method seems to be promising in confirming a low back injury and assessing the period of disability in certain cases of low back pain.

Thermography

Tichauer (1977) investigated the use of thermography as an aid to the diagnosis of low back pain in occupational settings. The approach was based on the phenomenon that any object, including the human body, which is not at absolute zero temperature emits invisible infrared radiation. A thermograph uses infrared sensors as scanning photon detectors to produce images of the warm areas of the body. These images provide pictorial representations of the temperature patterns in the body muscles.

Tichauer found that patients in pain exhibited a paravertebral area asymmetric in shape and lacking in continuity. They also exhibited "cold patches" over the gluteal region. These conditions are generally absent in pain-free individuals.

Thus, thermograms of individuals can be studied to diagnose low back pain of unknown origin. The technique is of potential value in occupational medicine but no further studies have been reported which demonstrate its usefulness and reliability.

Strength Measurement

The following discussion of strength measurement has been adapted from Schlegel (1980).

Accurate and objective measurement of strength is difficult. One definition of static strength currently in use is that proposed by Kroemer (1970): "Strength is the maximal force muscles can exert isometrically in a single voluntary effort". This is often referred to as the Maximum Voluntary Contraction (MVC). Voluntary strength must be used since there is no safe method of determining absolute muscle strength.

The amount of external force which can be applied is a function of the length of the muscle and the prevailing mechanical advantage. These in turn depend on the joint angles for the muscle group considered. For any strength measurement to be meaningful, it is essential that the joint angles and the point of application of the force be accurately specified and controlled.

Previous studies have shown that human strength measurements are dependent on the level of motivation and the particular instructions given to the subjects (Caldwell et al., 1974). Chaffin (1975) recommends that emotional appeals not be used in the instructions to the subjects.

Even though the muscular exertion during strength measurement is maintained for a relatively short period of time, muscle fatigue can occur which reduces the maximum tension. Hence, adequate rest periods between repeated exertions are necessary to minimize fatigue and its effect. Various studies have shown that two-minute rest periods appear adequate if no more than fifteen measurements are taken in a test session.

Various procedures have been used in an attempt to improve the reliability of strength measurements. Chaffin (1975) recommended that the voluntary force be maintained over a period of four to six seconds. This provides adequate time to assume a steady state exertion and still minimize the effects of fatigue.

Caldwell et al. (1974) recommend the following regimen.

(1) Static strength should be assessed during a steady exertion sustained for four seconds.

(2) The transient periods of about one second each before and after the exertion should be disregarded.

(3) The strength score is the mean value recorded in the first three seconds of the steady exertion.

Once the strength exertion is recorded, the strength score may be obtained graphically from the chart recording. If the strength exertion can be recorded electronically, a more precise analysis can be achieved by sampling the data using an analog-to-digital converter. After this conversion, the raw data consists of a sequence of values stored as a function of time. Various time series analyses can then be applied to the converted data.

Several time averaging techniques have been investigated by Owings et al. (1975). Their approach was to find the "maximum moving point average" during the exertion period. The procedure was as follows:

(1) Perform analog-to-digital conversion of the five seconds of data at the rate of 20 points per second.

(2) Divide the entire time period into intervals of n points in length.

(3) Calculate the average for the 1st through the nth point.

(4) Calculate the average for the 2nd through the n+1 th point.

(5) Continue until the average is found for the final n points.

(6) Select the maximum of these averages as the strength score.

This procedure yields the maximum of all possible sets of contiguous intervals of length n. Owings et al. recommend 20 points as the interval length. Thus, the strength score they selected is the maximum one-second moving point average found after analyzing five seconds of data.

Maximal vs. Submaximal Exertions

Hunnebelle and Damoiseau (1972) studied the reproducibility of maximal and submaximal muscular effort in the small muscle groups of the hands. Their subjects were 23 male basketball players with a mean age of 23.5 years (s=3.96), mean weight of 66.9 kilograms (s=9.5) and a mean height of 175.3 centimeters (s=6.37). A Bettendorf dynamometer was used for the strength measurements.

The task consisted of compressing the handles with the four fingers of the hand, while the thumb rested on a fixed point. The subjects exerted the requested effort following a verbal command. Each exertion lasted for a period of three seconds and was followed by a rest period of ten seconds. Exertions were made with both the right and left hands.

For the maximal efforts their study revealed that (1) maximal effort was greater in the right hand and (2) the strength tended to decrease with each subsequent test, for both the right and left hands. For the submaximal efforts, they found that (1) subjects who had the tendency to overshoot their submaximal effort also had the ability to develop a higher maximal effort and (2) no correlation existed between the hand used and the order of the tests.

In comparing maximal and submaximal efforts, the authors concluded that (1) the reproducibility of submaximal efforts was lower than that of maximal efforts and (2) although a subject cannot estimate an isometric contraction with quantitative precision, he can remember and reproduce the same contraction immediately after because of his proprioception. The authors added that it would be interesting to study submaximal efforts involving larger muscle groups.

Researchers have investigated strength measurement as a possible diagnostic tool for low back injury. The characteristic of strength measurement commonly employed was the variability among repeated exertions.

As mentioned in Chapter I, Daniel (1978) conducted a study involving three groups of subjects and three lifting positions. The first group of ten healthy subjects were asked to exert their maximum strength. The second group of ten healthy subjects were asked to exert a force of 50 percent of their maximal effort after being initially trained to exert this level of force. The four injured subjects in the third group were asked to exert their safe maximal effort or until they started experiencing pain. The positions used were the standardized arm, leg and torso lifting strength measurement positions recommended by NIOSH (1981). Five trials were conducted in each lifting position for each subject in a randomized sequence.

The objective of the study was to find out through statistical analysis whether the group of healthy subjects exerting 50 percent of maximum strength was distinguishable from the other two groups. The variability in repeated exertions (between-trial variability) was examined for the three groups. Statistical analysis using the coefficient of variation (CV) as the criterion measure did not yield significant results. However, an analysis using the coefficient of variation of the log-normal transformed data (CVLN) as the criterion measure did show significant differences between the groups.

Kroemer and Marras (1980) claimed that the rate of strength build-up may be the only objective criteria to distinguish between maximal and submaximal strength exertions. They studied routine strength measurements of elbow flexion to determine if the subjects exerted full muscular strength or a submaximal level of effort.

In their study, Kroemer and Marras discussed a model of human force exertion that assumes a stereotypical mental "executive program" which regulates the muscular contraction according to the intended strength output. Based on this model, they suggested that submaximal muscle strength exertions require a relatively lengthy build-up phase until the intended level of force is achieved. In contrast, a maximal exertion is achieved rather quickly. They also compared the variability of strength scores in repeated submaximal efforts with the variability of MVC's during the maintained phase of strength exertion.

Their experimental procedure followed the standard Caldwell regimen described earlier. Thus, subjects were required to increase muscle tension smoothly to the desired level within about two seconds and to maintain this level for an additional three seconds. The average value for the three seconds was calculated and recorded as the strength score.

Thirty subjects exerted elbow flexion strengths at 100%, 75%, 50%, and 25% of their individual maximal capability. The subjects did not receive any external feedback about their actual strength scores. Each subject exerted ten contractions under each condition. In addition to the strength-scores, the onset slopes of the force build-up were recorded.

The slopes of force build-up showed a consistent pattern being flatter for the submaximal exertions and steeper for the maximal exertions. The hypothesis that postulated larger variability in repeated submaximal exertions was not supported by the results.

CHAPTER III

EXPERIMENTAL METHODOLOGY

Independent Variables

The primary independent variable was the group classification consisting of the three groups of subjects: the healthy maximal group, the healthy submaximal group and the injured maximal group. Other independent variables were the lifting position and the trial number.

Group and Subject

The variable Group was studied at three levels. Different subjects were assigned to each group. Healthy subjects were assigned to the first two groups, and individuals with low back injury were assigned to the third group. Selection of the healthy subjects was random from the population of healthy students at the University of Oklahoma and the residents of Norman, Oklahoma.

The selection of symptomatic subjects for the third group was from the population of patients seen in low back clinics in the Oklahoma City area with the exclusion of acute low back pain patients. For this study, a patient was considered "acute" if the initial onset of the back pain had commenced within ten days of the trial. The risk of aggravating the acute back pain patients with the testing was sufficient to warrant their exclusion from the study. Thus, only the subjects examined by an orthopedic surgeon, and subsequently diagnosed to be suffering from low back pain were considered for assignment to the third group of subjects.

Thus, sixteen healthy subjects not suffering from any symptoms of low back pain or injury were assigned to the first group. These subjects were requested to exert their maximal strength during the experimental trials (Healthy Maximal Category). This group is identified as "HLTHMAX" for discussion and presentation of results. Table 2 illustrates the characteristics of this group. The average height, weight and age for the HLTHMAX group were 176.9 centimeters (69.65 inches), 71.28 kilograms (156.81 pounds) and 28.5 years respectively.

Sixteen healthy subjects were assigned to the second group. They were requested to exert fifty percent of their maximal voluntary contraction (MVC) strength during the testing, (Healthy Submaximal Category). This group is identified as "HLTHSUB". Individual subject characteristics for this group are shown in Table 3. The average height, weight and age for the HLTHSUB group were 172.39 centimeters (67.87 inches), 68.07 kilograms (149.75 pounds) and 33.37 years respectively.

Sixteen injured subjects currently suffering from low back pain and diagnosed by an orthopedic surgeon to be suffering from low back injury were assigned to the third group. These subjects were requested to exert their safe maximal effort without incurring additional pain or discomfort, (Injured Maximal Category). This group is identified as "INJMAX" and the characteristics of individual subjects are presented in Table 4. The average height, weight and age for the INJMAX group were 176.12 centimeters (69.34 inches), 76.99 kilograms (169.37 pounds) and 39.37 years respectively.

Table 2. Subject Data for HLTHMAX Group.

Subject code	Height (Cm)	Weight (Kg)	Age (Years)	Sex	Exercise
A	177.8	69.1	33	M	None
B	162.6	56.4	32	F	None
C	175.3	72.3	29	M	None
D	170.2	61.8	25	F	Light
E	163.9	70.0	40	F	None
F	180.4	86.8	26	M	Moderate
G	177.8	63.6	24	M	Light
H	179.1	60.9	23	M	None
I	184.2	74.5	26	M	Light
J	177.8	61.4	23	M	None
K	180.4	59.1	23	M	None
L	180.4	83.2	28	M	Heavy
M	182.9	67.3	19	M	Moderate
N	177.8	89.6	24	M	Heavy
O	180.3	82.7	20	M	Moderate
P	180.3	81.8	61	M	Light

Table 3. Subject Data for HLTHSUP Group.

Subject code	Height (Cm)	Weight (Kg)	Age (Years)	Sex	Exercise
A	177.8	67.3	32	M	Light
B	157.5	59.1	51	F	Light
C	175.3	66.4	36	M	None
D	142.3	62.7	33	F	None
E	162.6	67.3	40	M	None
F	179.1	81.4	20	M	Moderate
G	185.4	61.8	20	M	Light
H	170.2	61.4	44	F	Light
I	174.0	67.7	29	M	None
J	167.4	95.5	21	F	None
K	182.9	65.9	24	M	Light
L	175.3	64.1	31	M	None
M	179.1	72.7	33	M	None
N	177.8	62.7	38	F	None
O	174.0	64.5	45	M	Light
P	177.8	71.8	37	M	None

Table 4. Subject Data for INJMAX Group.

Subject code	Height (Cm)	Weight (Kg)	Age (Years)	Sex	Exercise
A	179.1	95.5	61	M	Moderate
B	176.5	68.2	50	M	Light
C	180.3	75.0	63	M	Light
D	182.9	72.7	23	M	Moderate
E	185.4	75.0	37	M	Moderate
F	167.4	84.1	39	M	Moderate
G	182.9	103.6	54	M	Moderate
H	179.1	75.5	33	M	Light
I	165.1	61.4	28	M	Moderate
J	174.0	64.6	27	M	Moderate
K	163.9	59.1	36	F	Light
L	177.8	77.3	34	F	Light
M	195.6	117.7	24	M	Heavy
N	161.3	60.0	52	F	None
O	158.8	70.5	45	F	None
P	182.9	72.8	24	M	Light

Lifting Position

The third factor selected for the study was Lifting Position. The two lifting positions used were variations of the Leg Lifting Position (SQUAT) and the Torso Lifting Position (STOOP) illustrated in Figure 2. These positions have been used by Chaffin et al. (1976) and Daniel (1978) and have been recommended by NIOSH for strength testing. The use of these testing positions provides a common basis to compare the results of this study with those of similar strength studies conducted by other investigators.

In a simple sagittal plane model for lifting, the body is considered as a system of eight rigid links which are articulated at the ankles, knees, hips, lumbosacral disc (L5/S1), shoulders, elbows and hands (Chaffin and Baker, 1970).

For consistency, the knee angle in the leg lifting position and the trunk angle in the torso lifting position were controlled for all subjects in all the trials. The knee angle in the leg lifting position was defined as the included angle between the lower leg and the upper leg measured at the knee joint center. The knee joint center was taken as the midpoint of a line between the centers of the posterior convexities of the femoral condyles (Chaffin and Baker, 1970).

The trunk angle in the torso lifting position was defined as the included angle between the hypothetical link from the center of the hip joint to the center of the

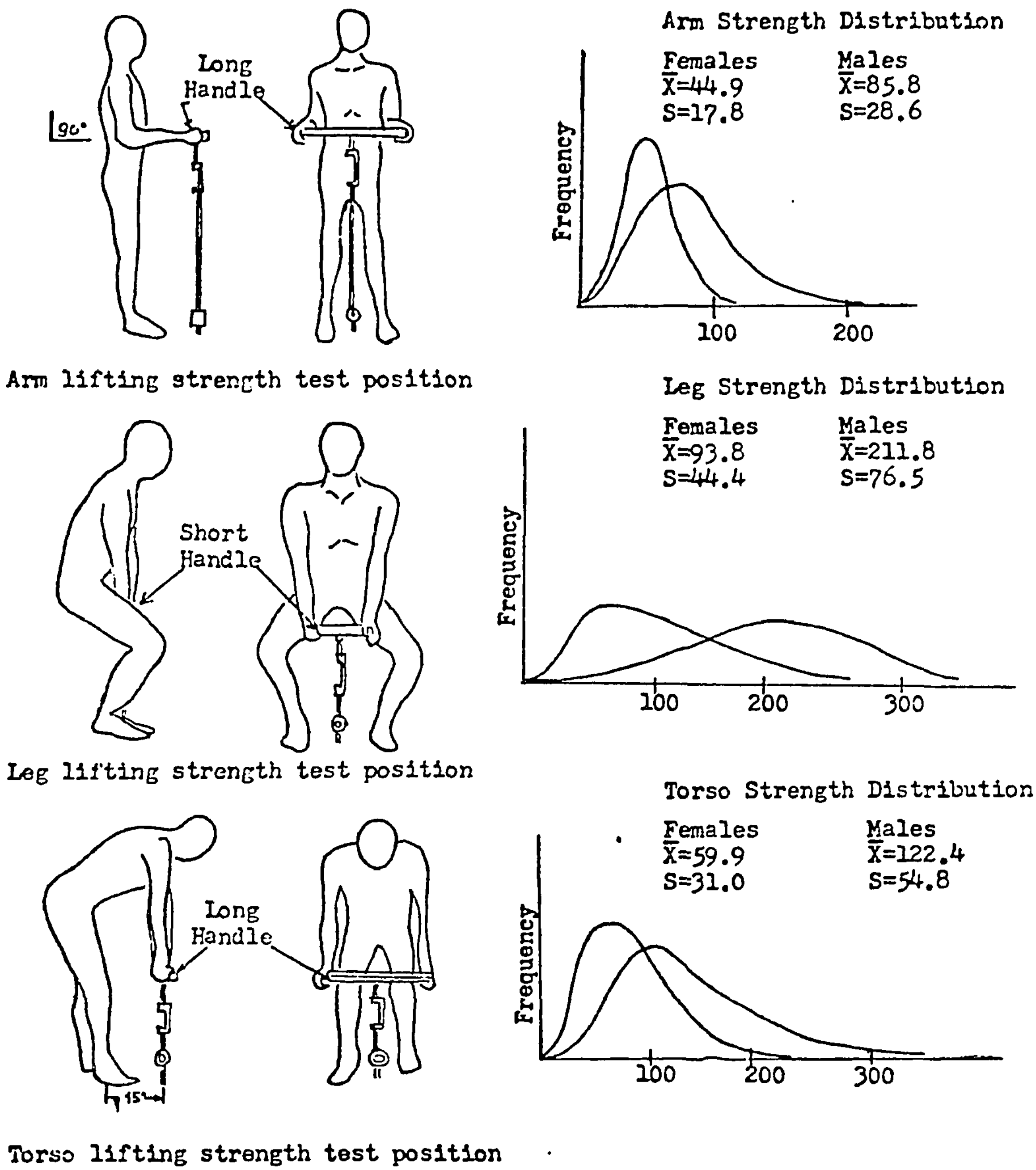


Figure 2. Standardized Strength Testing Positions and Results from Chaffin et al. (1976).

shoulder joint, and the upper leg measured at the hip joint. In this position, the legs are extended and for the first 27 degrees of trunk flexion, the pelvis usually does not rotate. For each additional degree of trunk rotation, the pelvis contributes about two-thirds of a degree (Garg and Herrin, 1979). The position used in this study involves partial pelvis rotation.

The knee angle (90°) and the trunk angle (110°) are illustrated in Figure 3. These angles were measured and checked using a special protractor with two long arms.

The two positions used in this study are described below. In both positions, the subject stood on a wooden platform and exerted force on a handle attached to the platform with an adjustable chain. There was no actual vertical movement of the chain.

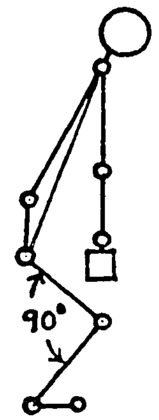
Leg Lifting Position (SQUAT). For the SQUAT position, the handle was located above the platform at such a height as to obtain

(1) a 90 degree angle at the knee

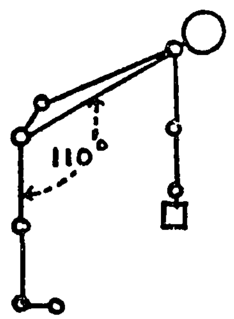
(2) the back as upright as possible

(3) the arms extended at the elbow.

The subject squatted and straddled the handle as depicted in Figure 2 on page 58. The subject positioned his/her feet against the lateral edges of the platform in such a manner as to be able to maintain the arms vertical. The subject pulled upward on the handle by attempting to ex-



Leg Lifting (SQUAT) Position



Torso Lifting (STOOP) Position

Figure 3. Link Diagrams for Lifting Positions.

tend the legs from the flexed position, while maintaining the 90 degree angle at the knees.

Torso Lifting Position (STOOP). For the STOOP position, the handle was located 11 inches in front of the ankles at such a height as to obtain a 110 degree trunk angle. The subject bent the back to reach the handle keeping the legs straight at the knee joint. The subject pulled upward on the handle by attempting to straighten the back while maintaining the 110 degree trunk angle. Again it must be noted that there was no actual vertical movement of the handle.

In the torso lifting position used by Chaffin et al. (1976), the handle was located 15 inches above the floor and 15 inches in front of the ankle of the leading foot. For the position used in this study, the handle was located 11 inches in front of the ankles because of the difficulty in maximal exertion for injured subjects using Chaffin's position.

Trial

Ten trials were conducted for each subject in each position. The trials were not randomized. Each subject performed ten trials in a randomly selected position followed by ten trials in the other position. This minimized adjustment of the handle heights, thus reducing error due to variation in the subject postural configuration.

Dependent Variables

The primary dependent variable in this study was the strength output over time. Figure 4 shows a sample record of the force output obtained in a single trial. The record documents the period of strength build-up and maintenance of the requested effort level according to the Caldwell regimen. Each measurement (trial) lasted for a duration of five seconds.

The following dependent variables were derived from the primary dependent variable:

(1) strength-score (SCORE)

(2) rate of strength build-up (SLOPE)

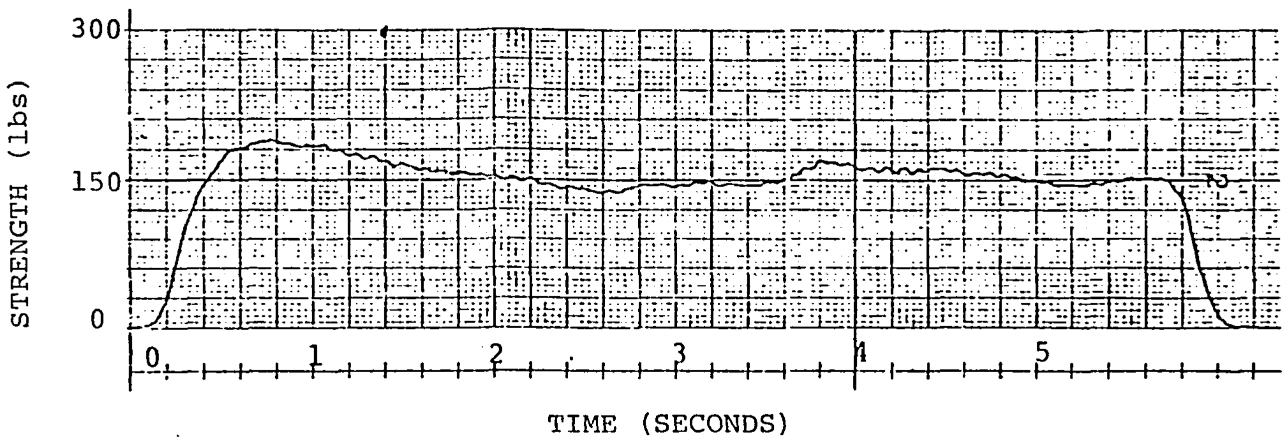
(3) range (RANGE)

(4) standardized range (RATIO).

Strength Score

The strength score for each trial was computed from the middle three seconds of the strength exertion record. The first and fifth seconds were ignored for this computation.

As seen in Figure 4, the smallest division markings on the recording paper were one millimeter (1 mm). The speed of the recording paper was 25 mm/second. Thus, it was possible to read 25 strength values in a one second period. The recording for each trial was examined manually to read the strength values at a resolution of 25 points per second.



SCALE:

X-Axis: 1 Major Div.=0.2 sec.

Y-Axis: 1 Major Div.=30 lb.

Figure 4. Strength Exertion Record.

A FORTRAN program was developed to compute the strength score from this raw data using a modification of the procedure of Owings et al. (1975) as described below.

(1) The strength output was sampled at a rate of 25 points per second instead of 20 points per second. This was done to take advantage of the resolution of the chart paper.

(2) A value of n=5 instead of n=20 was chosen as the number of points in the interval for averaging.

The value of n=5 enabled adaptation of the modified procedure to computation of slopes as explained later. The strength score determined with the procedure was the maximum moving point average over one-fifth of a second based on the middle three seconds of the strength exertion record.

Slope

The rate of strength build-up or slope was defined as

$$\text{slope} = \frac{\text{change in force}}{\text{change in time}}$$

The modified Owings et al. procedure used to compute strength score was extended to compute rate of strength build-up. The slope value for each trial was computed from the strength build-up phase of the record (0-2 seconds maximum). From examination of the data it was observed that the shortest time interval in which significant changes in the slope occurred was approximately one-fifth of a second. Thus n = 5 (five intervals of one-fifth of a second) was chosen as the number of points for the for the calculation of slopes.

The method of linear regression was used to obtain a least square estimate of the parameters (slope and the intercept) of the line passing through the set of these five points. This was continued for successive sets of five points as required by the modified Owings et al. procedure. The scoring procedure required selection of the maximum of these slope values computed for the strength build-up phase.

Range

Range was computed as the difference between the maximum and minimum strength values recorded during the middle three seconds of the strength exertion record.

Standardized Range

An additional dependent variable was constructed by dividing "Range" by "Strength score" for each trial. This derived measure was referred to as "Standardized Range" (RATIO).

Several other measures were derived from the dependent variables of strength score, slope, range and standardized range. The values of these measures consisted of the mean, standard deviation and coefficient of variation across trials for each of the four dependent variables for each subject in each position. These are summarized in Table 5.

Thus, the measures SCOREMN, SCORESD and SCORECV were derived from the strength score values for ten trials, for a given subject in a given position. Similarly, SLOPEMN, SLOPESD and SLOPECV were derived from the slope values for ten trials, for each subject in each position. Measures RANGEMN, RANGESD and RANGECV were derived from the Range values for ten trials and RATIOMN, RATIOSD and RATIOCV were derived from the Standardized Range values for ten trials.

Table 5. Derived Measures.

Original Dependent Variable	Derived Measure	Definition
STRENGTH SCORE	SCOREMN	Mean for ten trials
	SCORESD	S.D. for ten trials
	SCORECV	(SCORESD/SCOREMN)
SLOPE	SLOPEMN	Mean for ten trials
	SLOPESD	S.D. for ten trials
	SLOPECV	(SLOPESD/SLOPEMN)
RANGE	RANGEMN	Mean for ten trials
	RANGESD	S.D. for ten trials
	RANGECV	(RANGESD/RANGEMN)
STANDARDIZED RANGE (Range/Score)	RATIOMN	Mean for ten trials
	RATIOSD	S.D. for ten trials
	RATIOCV	(RATIOSD/RATIOMN)

S.D. = Standard Deviation

An additional derived measure was SCORECVLN. This represents the coefficient of variation for the data following a log-normal transformation, the basis of which is described below.

Chaffin et al. (1976) suggested that the usual "normal approximation" may be inadequate for predicting the tails (5 percent and 95 percent) of the lifting strength distributions shown in Figure 2 (Page 58). The argument was that since strength is bounded by zero (a negative strength score cannot exist) and the variance tends to increase with the mean, it would be reasonable to speculate that a lognormal distribution would more adequately represent the underlying distribution. They found that for most cases, the error in predicting a particular percentile strength was less than 4% using the lognormal distribution assumption with errors most evident in the central portion of the distribution rather than in the tails. It was concluded that these strength distributions were better approximated by the lognormal distribution.

If the means and variances are computed from the observed data for each subject in each lifting position, then the means and variances for the corresponding data assuming a lognormal distribution can be computed by using the following lognormal transformation equations :

$$\sigma^2 \text{(lognormal)} = \ln(1 + \exp(\ln \sigma^2 - 2 \times \ln \mu\ )$$

and

$$\mu\text{(lognormal)} = \ln \mu - \sigma^2 \text{(lognormal)}/2$$

where μ and σ^2 can be estimated from $\overline{X}$ and s^2 of the observed data from the experiment. CV(lognormal), which is coefficient of variation of the data following lognormal transformation, can be computed from the values of μ(lognormal) and σ(lognormal), using,

$$SCORECVLN = SD(LN)/\overline{X}(LN) \times 100$$

where LN is used to represent lognormal.

Choice of Criterion Measure.

The rationale for the selection of any criterion measure should be based upon the hypothesis being tested. Three hypotheses were tested in this study. Expressed in null hypothesis terms, they are as follows:

Hypothesis 1: The rate of strength build-up does not differ between the three groups.

Hypothesis 2: The within-trial variation in lifting strength does not differ between the three groups.

Hypothesis 3: The between-trial variability in repeated lifting strength exertions does not differ between the three groups.

The rate of strength build-up (SLOPE) was used as the criterion measure to test the first hypothesis using a nested factorial analysis of variance design. Correlation coefficients between the rate of strength build-up and the strength score were also calculated for the three groups of subjects.

RANGE was used as one criterion measure to test the second hypothesis.

The standardized range (RATIO) was also used as an additional criterion measure to test the second hypothesis.

The coefficient of variation (CV) is a measure of relative variation and is defined as the ratio of the standard deviation to the mean, expressed as a percentage. It is thus independent of the scale of measurement. To compare the variability associated with different measures, it is desirable to use measures of relative variation such as CV rather than measures of absolute variation. Also, since CV is a measure of relative variation, it does not increase as the mean strength increases from one lifting position to the other.

The measure SCORECV, the coefficient of variation for the strength scores was computed from the ten trials for each subject in each position, and was used as a criterion measure to test the third hypothesis.

Daniel (1978) used CVLN as a criterion measure and found that the variability in the lifting strengths exerted by maximal and sub-maximal groups was statistically distinguishable. Hence, analysis of variance using SCORECVLN as a criterion measure was also performed to test the third hypothesis.

Equipment

It was initially planned to record all data in analog form on magnetic tape using an FM recorder. This data was to be later processed using an analog-to-digital converter and DECLAB mini-computer system to obtain digitized values for the computation of rate of strength build-up, strength score and range.

However, due to malfunctioning of the FM recorder, the system was replaced with a strip chart recorder.

The strength measurement system actually used in the study consisted of the following components:

(1) Lifting Handles and Wooden Platform

(2) Strain Gage Model SM-250 Load Cell (Interface Inc.)

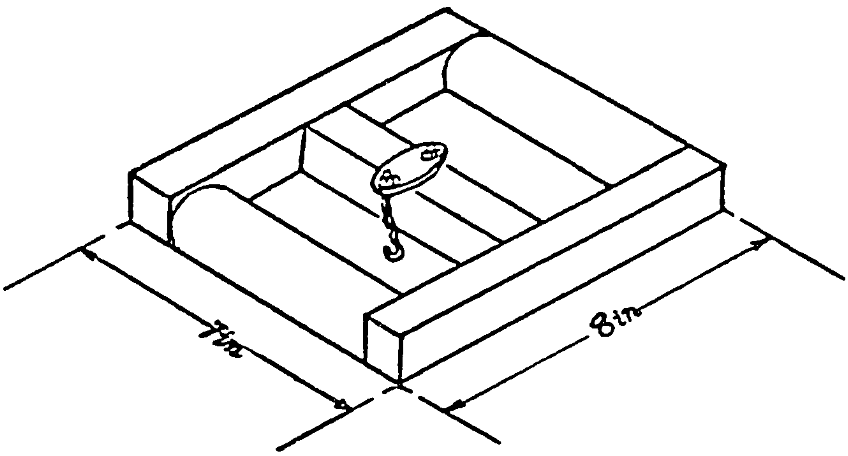
(3) VISHAY/ELLIS-20 Digital Strain Gage Indicator

(4) Brush Chart Recorder Model 220 (Gould Inc.)

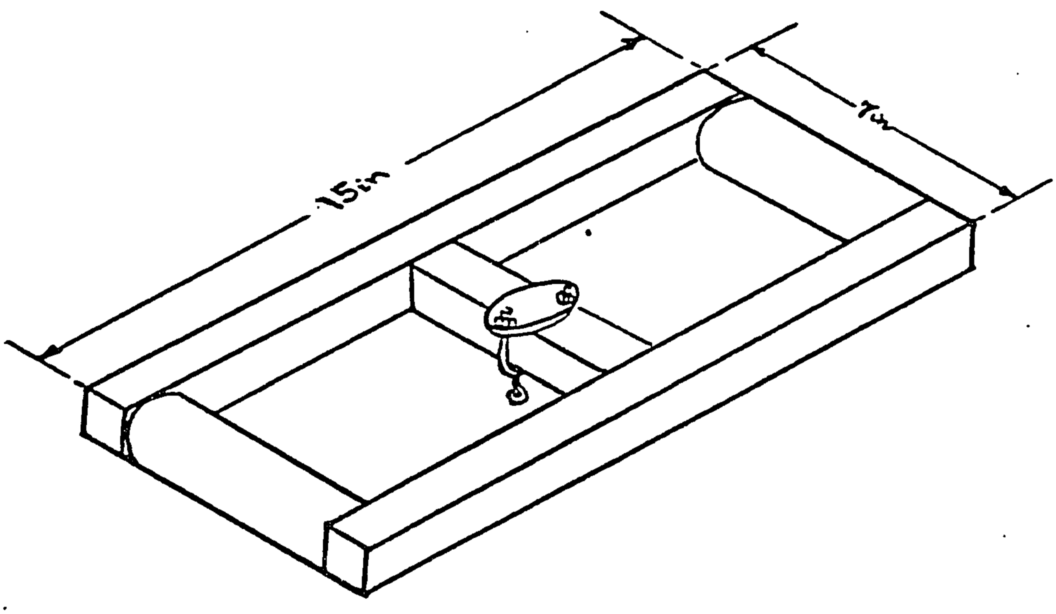
Lifting Handles and Wooden Platform

The strength exerted by any muscle is dependent upon several factors including muscle length, the position of the various joints, the involvement of other muscles and overall body posture. Special handles (Figure 5) made of aluminum and suitable for standard arm, torso and leg lifting strength measurements were used in this study. These enabled the experimenter to exercise precise control over the position of the subject's hands. For the torso lifting position (STOOP), the longer handle weighing 4.875 pounds was used. For the leg lifting position (SQUAT), the shorter handle weighing 3 pounds was used.

The wooden platform used in the study was constructed from solid two-by-four bars. The overall dimensions measured 30 x 30 x 5 inches. An eyebolt with two washers and a wingnut was attached to the platform for connecting chain and handles during the experiment.



Pictorial View of Short Handle



Pictorial View of Long Hanndle

Figure 5. Lifting Handles

Strain Gage Model SM-250

The strain gage used in the study was a Model SM-250 Load Cell manufactured by Interface, Inc. The gage was electrically connected to the digital strain gage indicator. For each lifting position, the appropriate handle was connected by a chain to the strain gage transducer which was attached to the wooden platform.

VISHAY/ELLIS Digital Strain Gage Indicator Model 20

This unit provided a highly precise value of the force exerted on the strain gage by the subject at any instant in time. The force value was presented in the display window and was recorded on the strip-chart recorder external to the unit. The output of the strain gage was used as an input to the digital strain gage indicator.

Brush Chart Recorder Model 220

The recorder has eight available chart speeds and was set at 5 mm/second. The output of the digital strain gage indicator was directed to the Model 220 Brush chart recorder.

Figure 6 shows the view of the recording apparatus, that is the strain gage, the digital strain indicator and the chart recorder used in the study.

Experimental Routine

Power was applied to the apparatus for one-half hour

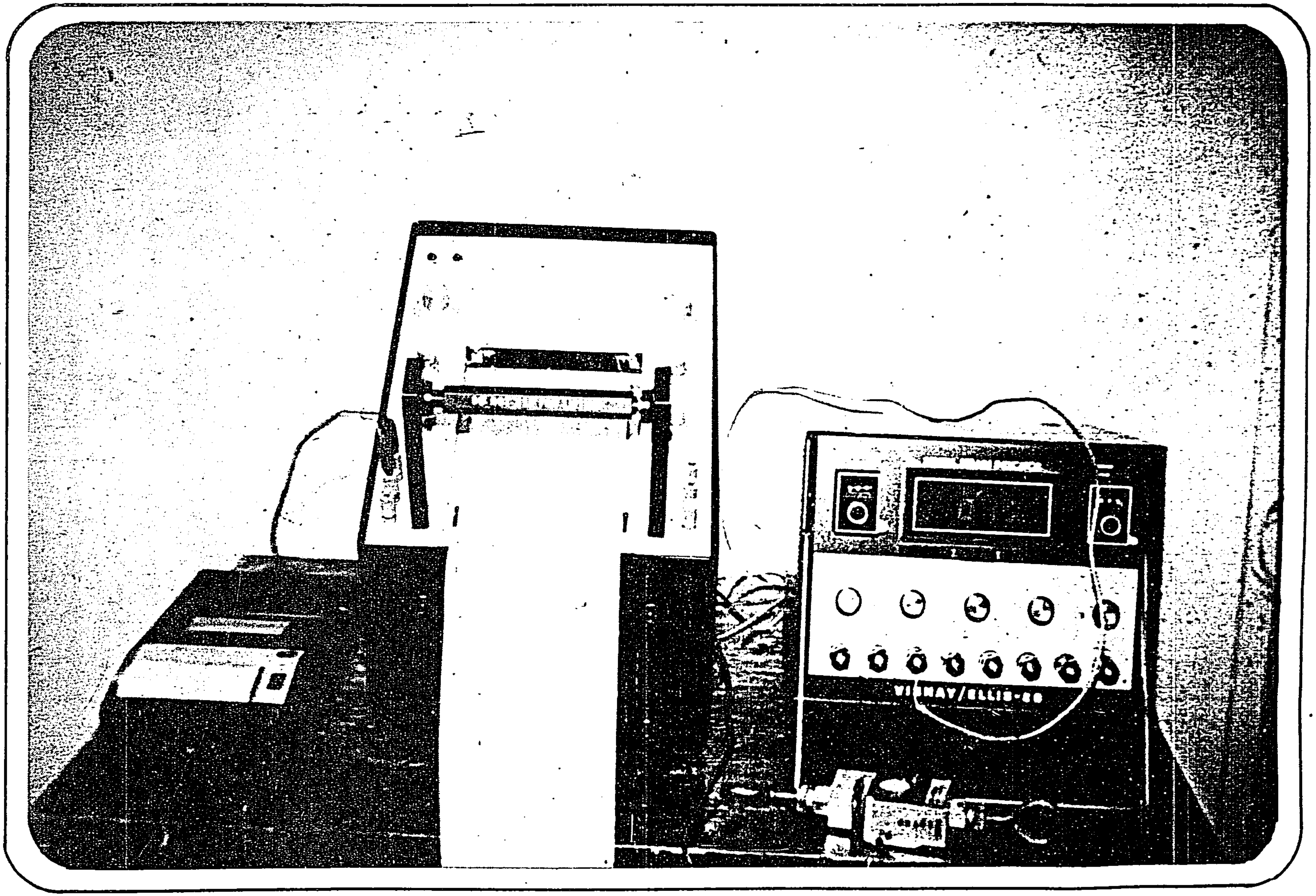


Figure 6. View of Recording Equipment.

prior to the arrival of the first subject to stabilize the equipment and minimize the possibility of drift. Upon arrival, each subject was first asked to read and sign the consent form. Before testing, the subjects were briefed about the experimental procedure and were supplied with written instructions (Appendices A1, A2, A3).

It was ensured that the subject understood that he/she would be allowed to terminate the experiment at any time if became uncomfortable or fatigued or in pain as a result of the experiment. The injured subjects exerting safe maximal effort during the trial were asked to exert effort only to the point where they began feeling additional or increased pain. This was considered a threshold for exertion and subjects were instructed not to exceed it under any circumstances. This is explained in the instructions for the injured subjects (Appendix A3).

Chapanis (1969) points out that the most important way of controlling subject attitudes and expectancies in an experiment is through good instructions. He states that in order to have data with good consistency, it is important that the experimenter provide good instructions.

For this experiment, three sets of instructions were used, one for the healthy maximal group, one for the healthy sub-maximal group and one for the injured maximal group. The subjects were questioned prior to the data collection to make sure that the instructions were clear to them. The subjects were allowed to practice in order to become familiar with the equipment and the experimental procedure.

Next, the anthropometric measurements and a medical history were recorded using the form in Appendix B. The medical histories of the healthy subjects were used to ensure that none of the subjects in the healthy category had previously suffered from back injuries or other abnormalities which could result in any risk during the experimental sessions. Any subject considered for the healthy groups who had a previous history of low back injury or other reported medical abnormality was excluded from participation in the study.

The medical histories of the injured subjects were recorded in order to ascertain that none of them suffered from medical abnormalities other than back injury. Those subjects reporting other medical abnormalities were also excluded from participation in the study. Again, for the injured group of subjects, only patients diagnosed by an orthopedic surgeon as suffering from low back pain were considered.

Experimental Trials

The standard Caldwell regimen was followed for strength exertion in each trial for all subjects. Thus, the subjects were asked to increase muscle tension to the requested level without a jerk and maintain this level of exertion for a five second period as indicated by audio signals. Each trial was preceded by a countdown so that the subject could get ready for the exertion. The following audio signals were recorded on a cassette tape and played for each trial so that the subject could begin and end the strength exertion according to the cues. *... "Three... Two... One.. Go.... ....Stop". No attempt was made to control the period of strength build-up. In addition, the subjects were not given any feedback about the rate of strength build-up or the level of strength exerted in any trial.

Ten trials were conducted in each position for each subject. The height of the handle in each position was adjusted so that all subjects maintained a 110 degree angle at the waist in the torso lifting position (STOOP), and a 90 degree angle at the knee in the leg lifting position (SQUAT). A large protractor was used to check these angles during each trial. After each trial, the subject was given 2 minutes of rest before the next trial. After ten trials, the subject was given a ten minute break for recovery and relaxation.

An effort was made to minimize the effects of all extraneous variables on the force exertion. Measurements were made in an air-conditioned room at 72 degrees F. All trials were performed in private to avoid any motivational influences due to witnesses. Adequate and constant lighting was used, and noise and external distractions were kept to a minimum.

Experimental Design

Table 6 summarizes the sources of variation (factors), and the factor levels used in the design.

Table 6. Outline of Experimental Design.

FACTOR	LABEL	LEVELS	EFFECT
Group	G	3	Fixed
Subject (Group)	S(G)	16	Random
Position	P	2	Fixed
Trial	T	10	Fixed

The statistical model is:

$$Y_{ijkl} = u + G_i + S_{j(i)} + P_k + T_l + GP_{ik} + SP_{jk(i)} + GT_{il} + e_{(ijkl)}$$

where:

Y_{ijkl} = dependent variable observed for the ith group, jth subject in the ith group, kth position and the lth trial

u = mean effect for entire experiment

G_i = effect due to group; $i=1,2,3$

$S_{j(i)}$ = effect due to subjects; $j=1,\ldots,16$

P_k = effect due to position; k=1,2

T_l = effect due to trials; l=1,...,10

GP_{ik} = group x position interaction

$SP_{j(i)k}$ = subject x position interaction

GT_{il} = group x trial interaction

$e_{(ijkl)}$ = random error

The Expected Mean Squares (EMS) table was constructed to determine the testability of the factors and the reduced data was analyzed using the Statistical Analysis System (SAS) package on the University of Oklahoma IBM 3081 computer. There were no replications in the experiment, with the result that the error term was confounded with the higher order interactions. However, exact F tests were obtainable to test the effects of different factors as follows. (1) The expected mean square of Subject(group) was used as the denominator to test the factor Group (G). (2) The expected mean square of the Subject(group) x Position interaction was used to test the factors of Lifting Position (P) and the Group x Position interaction.

The model used for evaluating the dependent variables SCORECV and SCORECVLN was:

$$Y_{ijk} = u + G_i + S_{j(i)} + P_k + GP_{ik} + SP_{jk(i)} + e_{(ijk)}$$

with the terms as defined previously.

In conducting the analysis of variance on SCORECV and SCORECVLN, exact F tests for Subjects (S) and the Subject x Position interaction could not exact F tests for subjects (S) and the PxS interaction could not be computed as there were no terms available which could be used as error terms to test these two effects.

CHAPTER IV

RESULTS

The experimental results and their interpretations are presented in this chapter. Discussion of each of the dependent variables includes (1) description of the data (2) analysis of variance (ANOVA) for the dependent variable, and (3) results of a Duncan multiple range test for fixed factors. Finally, discriminant analysis is performed for classification of individuals into one of the three groups.

The dependent variables are covered in the following sequence.

(1) Strength score (SCORE)

(2) Rate of strength build-up (SLOPE)

(3) Range (RANGE)

(4) Standardized range (range/strength score; RATIO)

(5) Coefficient of variation for strength scores (SCORECV)

(6) Coefficient of variation for the lognormal transformed data (SCORECVLN)

A summary of the important results is provided at the end of the chapter.

Overall Description of the Data

The actual recording of the strength exertion during a trial consisted of the force exerted over time. From the original chart recording, values were derived for strength score, slope, range and standardized range as defined previously. These values averaged across trials are presented in Appendix C for each subject and position.

Table 7. Strength Measures by Group.

Measure	HLTHMAX	HLTHSUB	INJMAX
Strength Score (lbs)	160	62	159
Slope (lbs/sec)	490	160	410
Range (lbs)	24	10	37
Standardized Range	.15	.16	.23
Coef. Var. (score)	2.6	4.8	4.5
Coef. Var. (log-norm)	51	117	94

Table 7 shows the mean values of the different strength measures obtained from the data for the three groups.

Figure 7 shows a simplified representation of this strength exertion using the maximum rate of strength build-up (slope) and the subject's strength score. The slopes and the strength scores were aggregated across all trials and positions for all subjects. Both the healthy maximal and

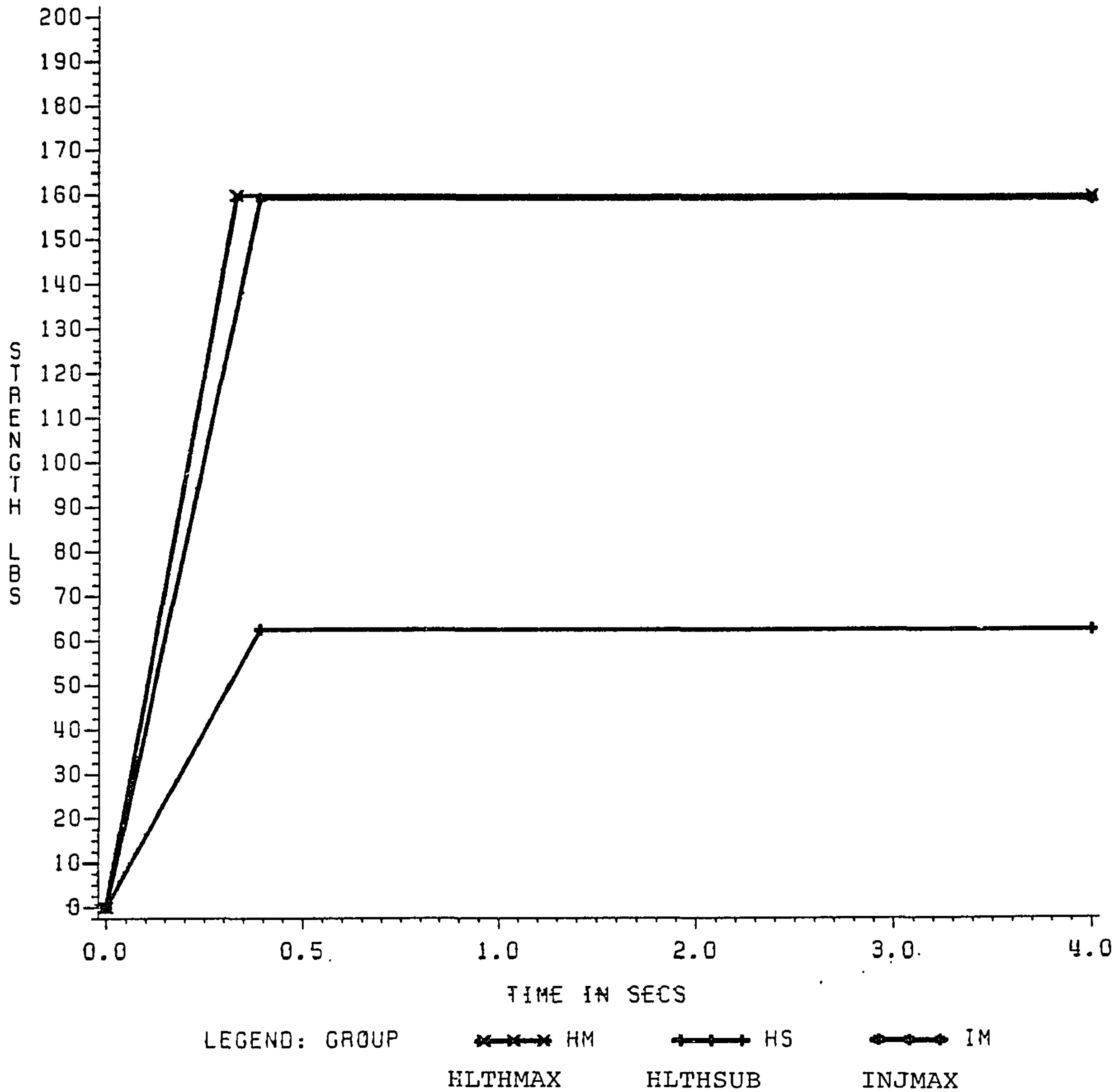


Figure 7. Strength Exertion Record - Simplified.

the injured maximal groups exhibited steeper slopes than those of the healthy submaximal group.

Strength Score

Figure 8 shows the overall strength scores plotted by group and collapsed across all trials, subjects and positions. Figure 9 shows the strength scores plotted by group and position for all subjects and trials. As expected, the strength scores for the SQUAT position were slightly higher for all groups than the strength scores for the STOOP position.

Chaffin (1976) reported a ratio of mean strength scores for the standardized "Squat" and "Stoop" positions of 1.73 for the data collected in his study. However, in the current study, the ratio of the mean strength scores was found to be 1.22. This can be explained as follows.

Both studies used the same "Squat" position for maximal strength exertion. However, in the "Stoop" position, Chaffin maintained a moment arm distance of 15 inches compared to 11 inches maintained in the present study to alleviate difficulty in trunk flexion for the injured subjects. Thus, for a specific limiting torque at the lumbosacral joint, a subject for the position configuration used in this study could exert 15/11 or 1.36 times as much force than for the configuration used in Chaffin's study.

Assuming that the effect of the weight of the upper body can be neglected for this calculation, the expected

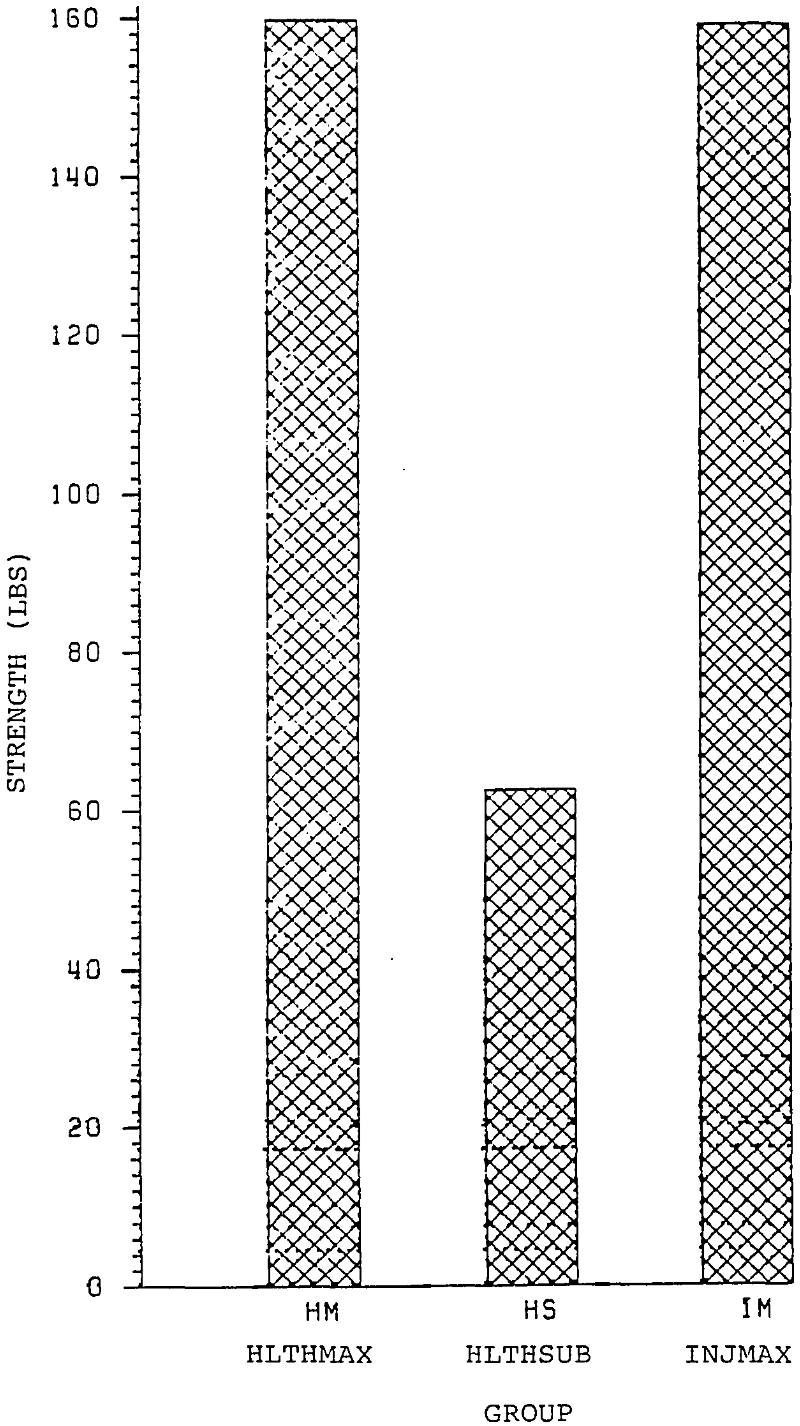


Figure 8. Strength Score vs. Group

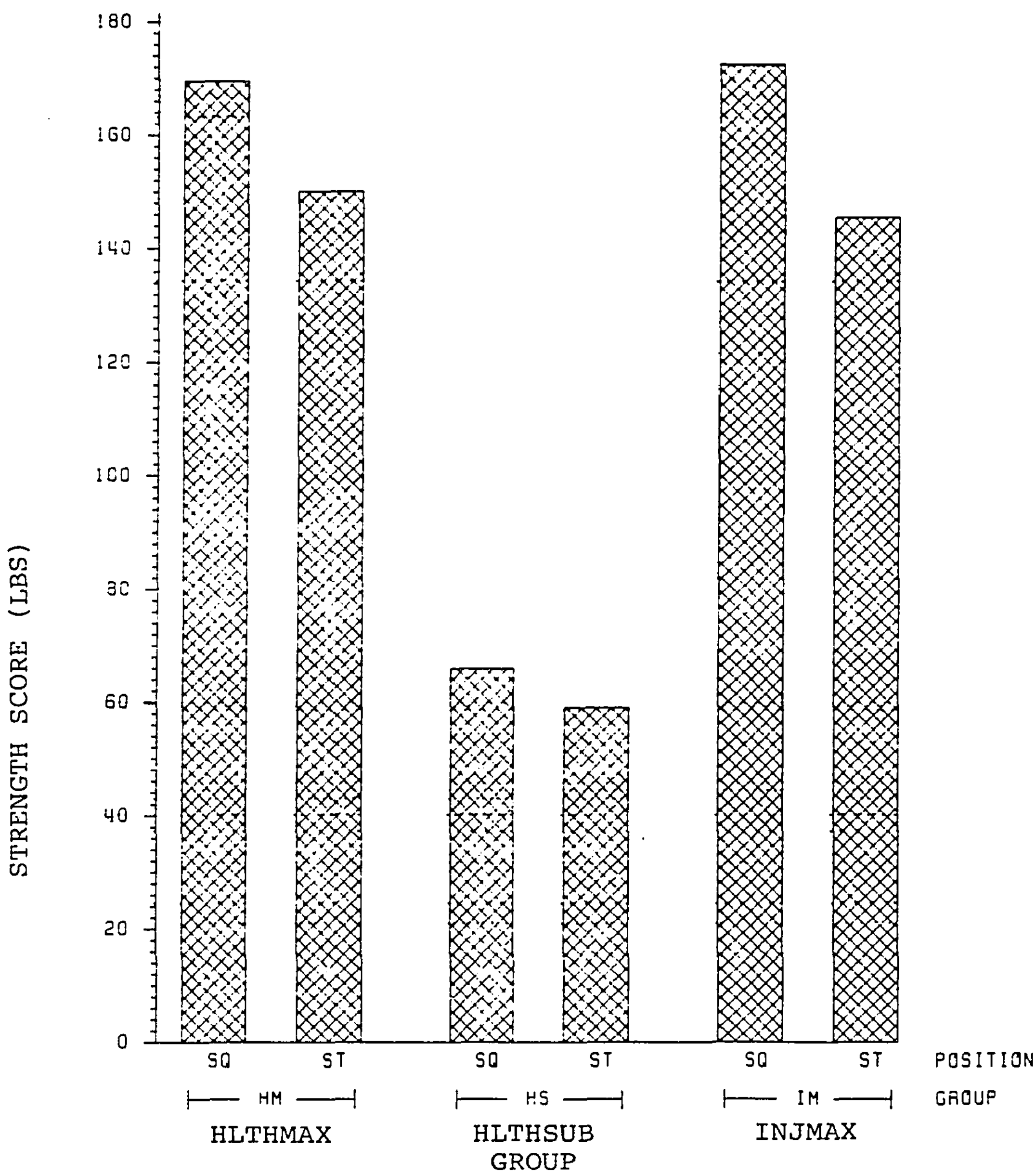


Figure 9. Strength Score Vs. Group By Position

ratio of the mean strength scores for the two positions in this study should have been $F(sq)/F(st)=1.73/1.36=1.27$

This compares favorably with the ratio of 1.22 observed in this study. It must be pointed out that many of the details of the configuration used by Chaffin, such as angles between various body segments, are not known. Also as mentioned in Chapter III, Chaffin fixed the distance of the handle from the floor compared with controlling the trunk angle by varying the distance of the handle from the platform. This may also account for some of the variation in the results of the two studies.

As seen from Figure 9, the overall strength scores for the healthy maximal group and the injured maximal group were very close in both positions (150 to 170 lbs). One would expect a poorer performance (lower strength exertion) from the injured group due to the pain. This contradiction may be explained as follows.

The subjects in the injured maximal group were selected from the population of chronic low back pain patients at a low back clinic in Oklahoma City. All had been suffering from low back pain over a period ranging from five months to twelve years, including recurrences. They were undergoing different treatments for pain.

It is suspected that most of the subjects had learned to live with a certain level of pain and have continued their activities except during periods of increased pain. As seen from the subject data, the average height and weight for the injured maximal (INJMAX) group were higher than the averages for the healthy maximal (HLTHMAX) group. Also, the INJMAX subjects, when questioned about their exercise habits, indicated higher levels of exercise and activity compared to the HLTHMAX group subjects. This can be confirmed from the subject data. Therefore, it is reasonable to believe that the INJMAX subjects could produce an effort comparable to the effort produced by HLTHMAX subjects.

It may have been more appropriate for the groups to have been matched. However, it was not possible to match the groups based on conditioning and physical characteristics of the subjects due to limited availability of the injured subjects and the difficulty in obtaining a large number of volunteers for this study.

Figure 10 shows the overall strength scores for the ten trials, averaged across all groups, subjects and positions. It may be concluded from reviewing Figure 10 that there were no significant effects of fatigue or learning from trial to trial. Figure 11 shows the overall strength scores for the ten trials for each position-group combination for all subjects.

Table 8 summarizes the results of an analysis of variance using strength score as the criterion measure. Group, subject, and position were all found to be significant at the 1% alpha level. The subject by position interaction was also significant. The effect of this interaction may be noticed in the higher values of strength scores

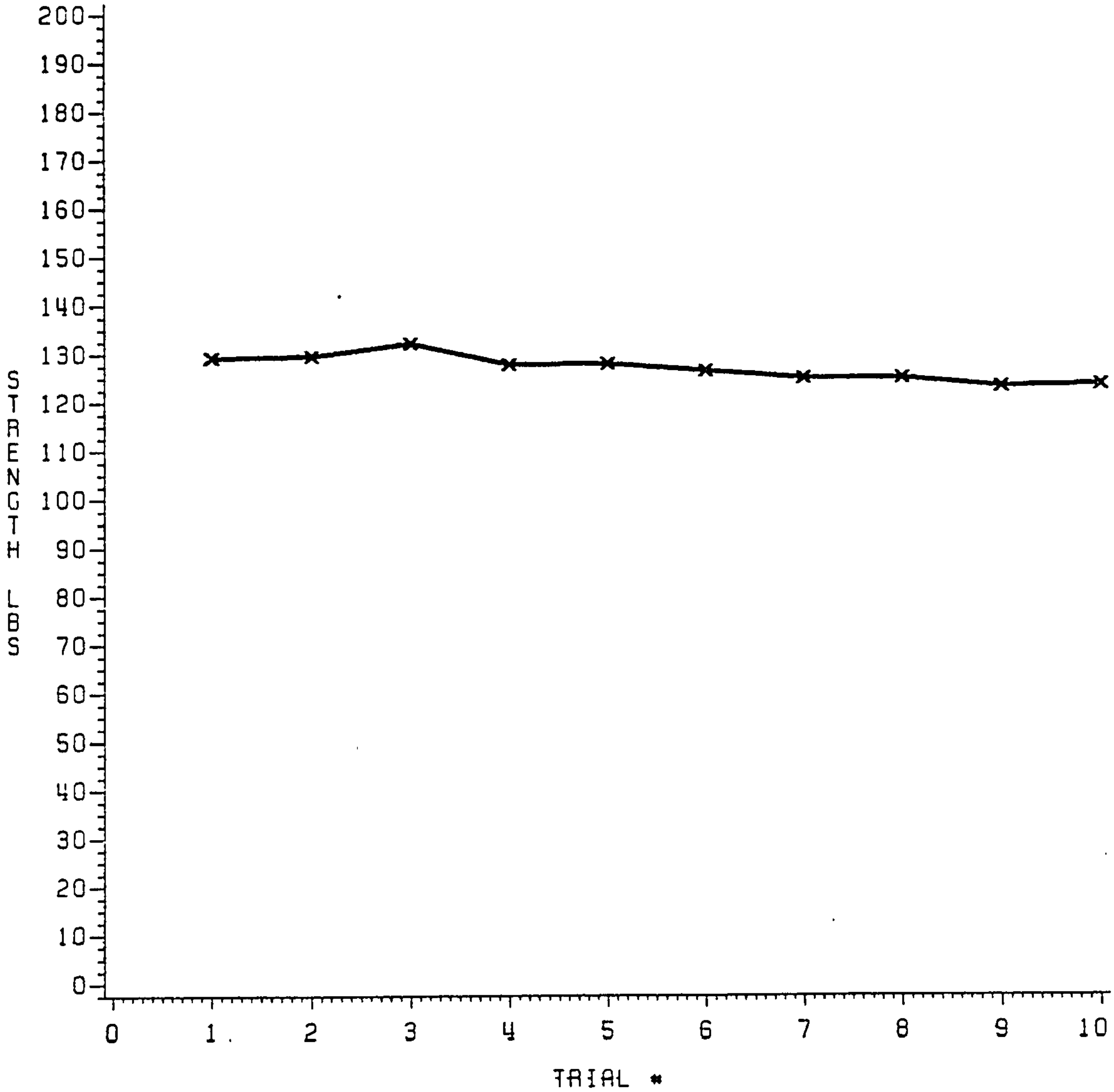


Figure 10. Strength Score Vs. Trial (Overall)

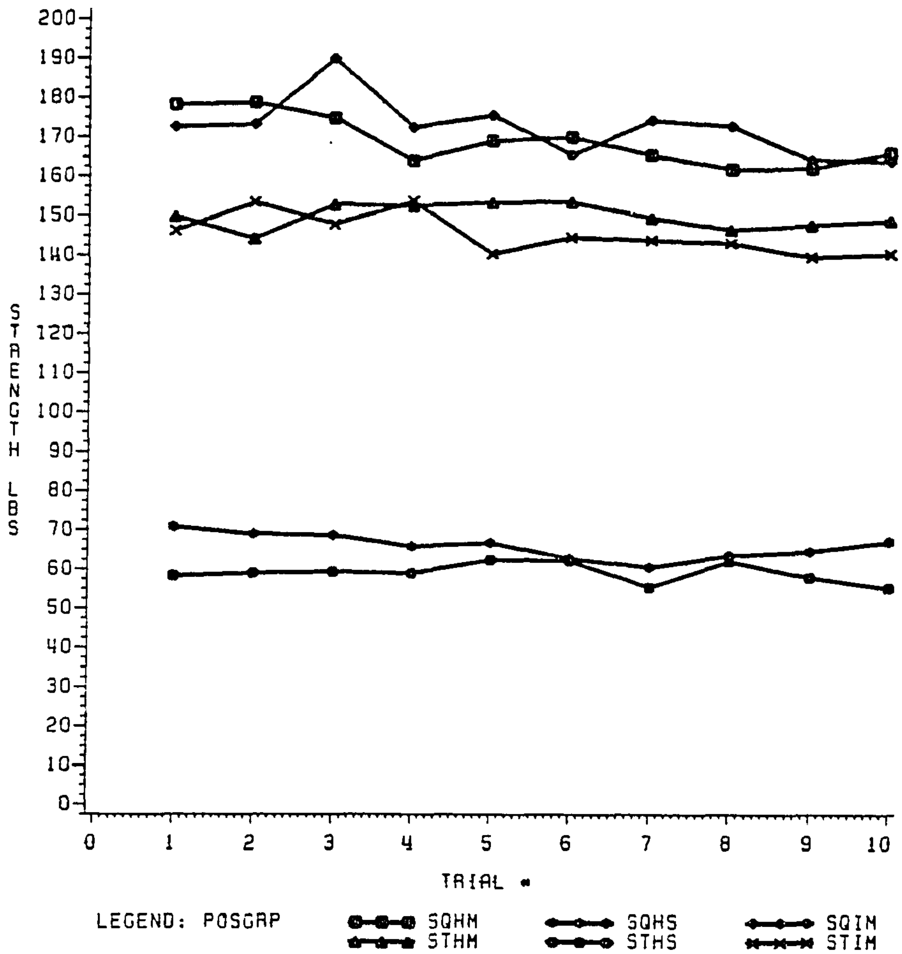


Figure 11. Strength Vs. Trial by Group Position

in the stoop position recorded for a few subjects, compared to the strength scores in the SQUAT position. The interaction may be the result of the intersubject variability in the subject sample.

Table 8. ANOVA Table for Strength Score.

Source	d.f.	Sum of Squares	Mean Square	F-Ratio
Group	2	2003022.40	1001511.20	27.18**
Subject(Group)	45	1658054.60	36845.66	177.70**
Position	1	76004.22	76004.22	15.84**
Group*Position	2	16623.89	8311.94	1.73
Subject(G)*Position	45	215826.15	4796.14	23.13**
Trial	9	7096.10	788.45	3.80
Error	855	178622.35	208.92	
Total	959	4200959.84		

**Significant at 1 percent alpha level

A Duncan multiple range test revealed that the mean strength scores for the HLTHMAX and INJMAX groups were significantly higher than the mean strength score for the HLTHSUB group. The mean strength score for the SQUAT position was significantly higher than the mean strength score for the STOOP position.

Rate of Strength Build-up (SLOPE)

Figure 12 illustrates the differences in the slope values for the three groups and the two positions, for all subjects and trials. The healthy maximal group exhibited the highest values for slope (450 to 535 lbs/sec) and the healthy submaximal group the lowest (140 to 185 lbs/sec).

Table 9. ANOVA Table for SLOPE.

Source	d.f.	Sum of Squares	Mean Square	F-Ratio
Group	2	29885.07	14942.54	18.27**
Subject(Group)	45	36801.01	817.80	10.30**
Position	1	1266.73	1266.73	7.36**
Group*Position	2	148.69	74.34	0.43
Subject(G)*Position	45	7742.22	172.05	2.17
Trial	9	817.93	90.88	1.14
Error	855	67869.54	79.38	
Total	959	144531.19		

**Significant at 1 percent alpha level

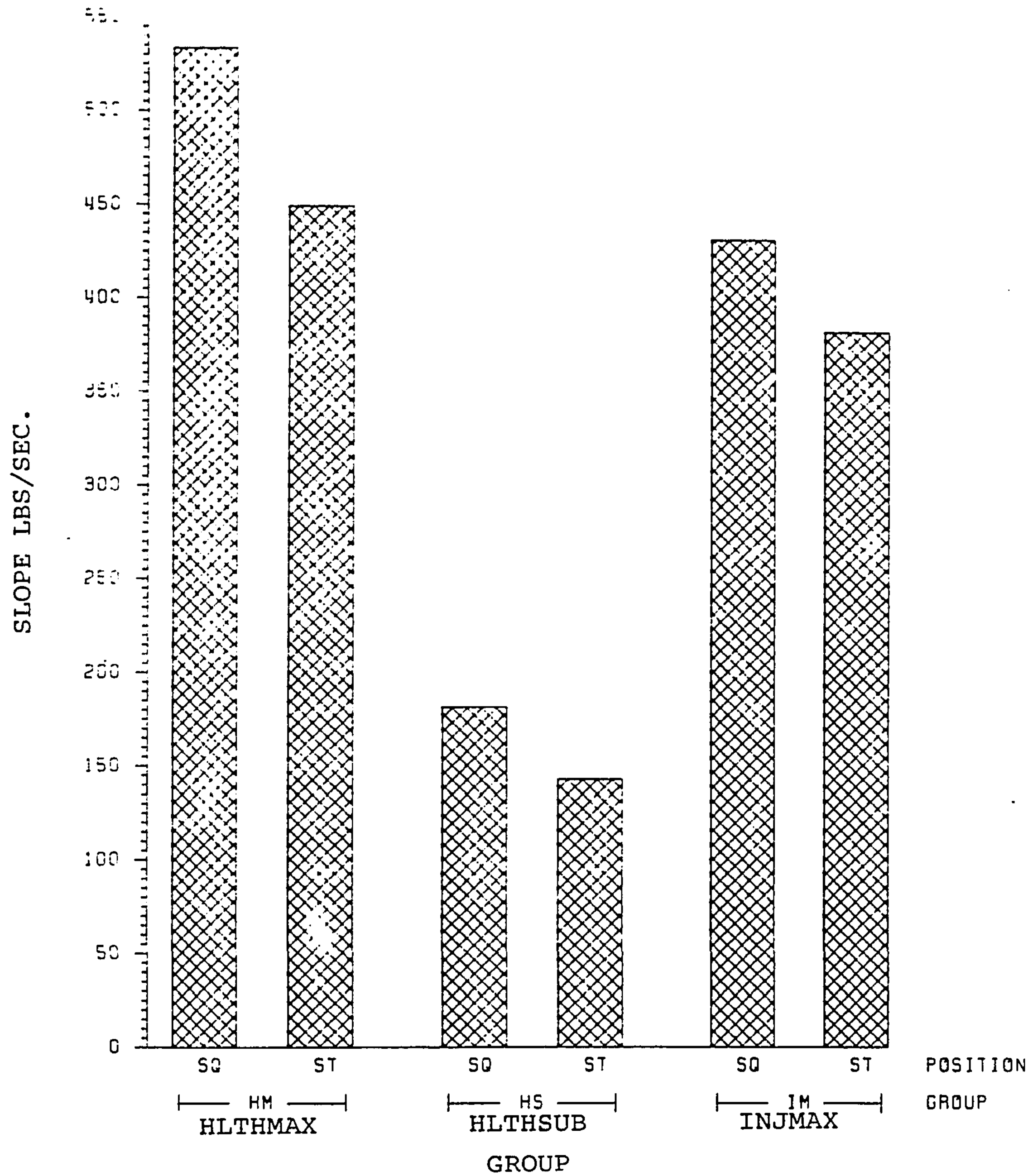


Figure 12. Slope vs. Group by Position

The injured maximal group, even though lower, exhibited slopes (380 to 435 lbs/sec) comparable to those of the healthy maximal group. Figure 13 shows a plot of overall slope values for the ten trials by group, for all subjects and positions.

Table 9 summarizes the results of an analysis of variance using rate of strength build-up (SLOPE) as the criterion measure. The three main effects were found to be significant. However, no interactions were significant.

A Duncan multiple range test revealed that the "healthy submaximal" group was significantly lower (alpha=0.05) than the other groups with respect to the slopes. Slope for the stoop position was significantly lower than the slope for the squat position.

Range

Figure 14 shows the overall range values observed for each group for all subjects, positions and trials. The injured maximal group exhibited the highest value (37 lbs) for this dependent variable and the healthy submaximal group the lowest (10 lbs). There was a considerable difference between the range exhibited by the three groups. This is especially evident in Figure 15, which illustrates variation in this dependent variable with trials for the three groups.

Table 10 summarizes the results of an analysis of variance using RANGE as the dependent variable. The effects of Group and Subject were found to be significant at the 1%

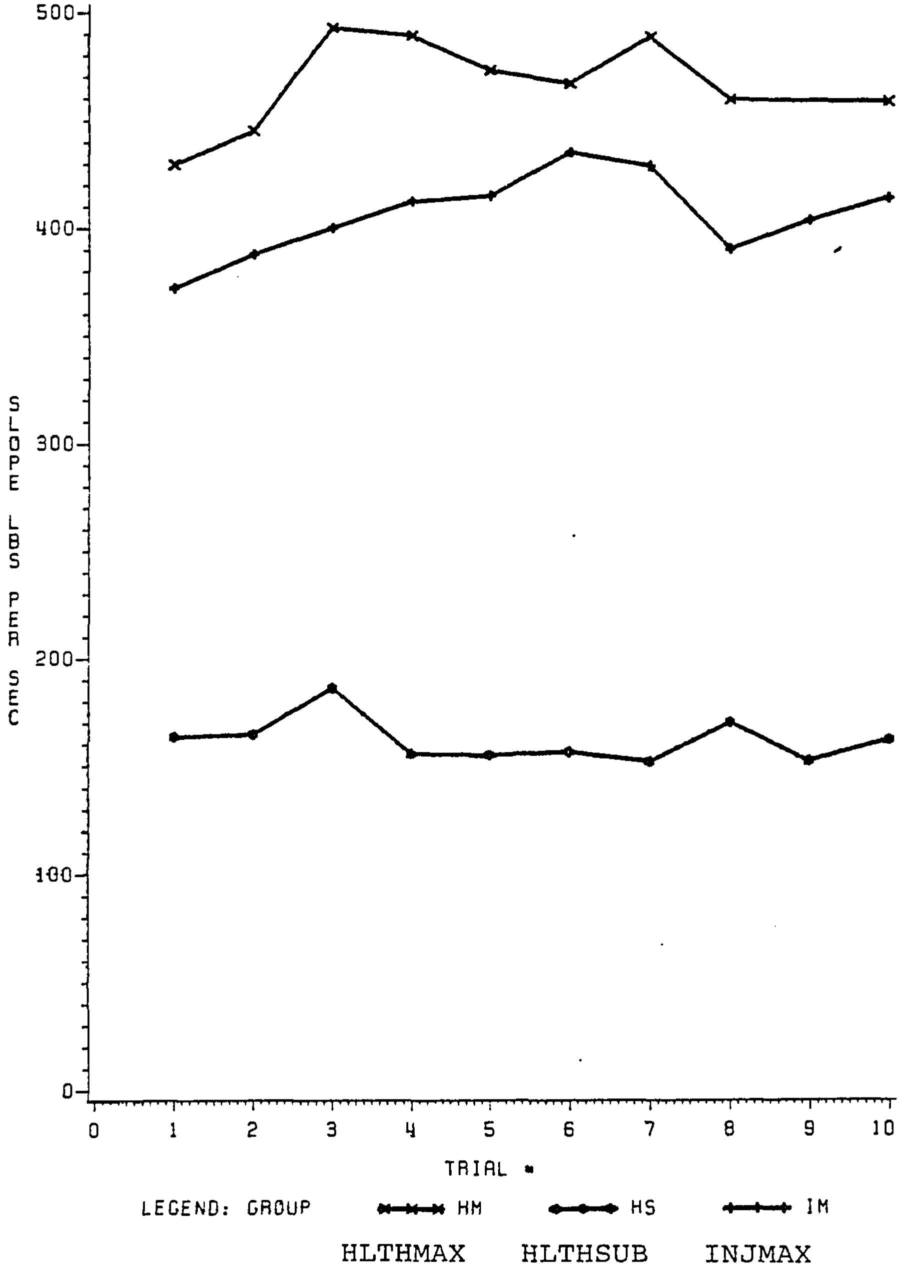


Figure 13. Slope vs. Trial by Group

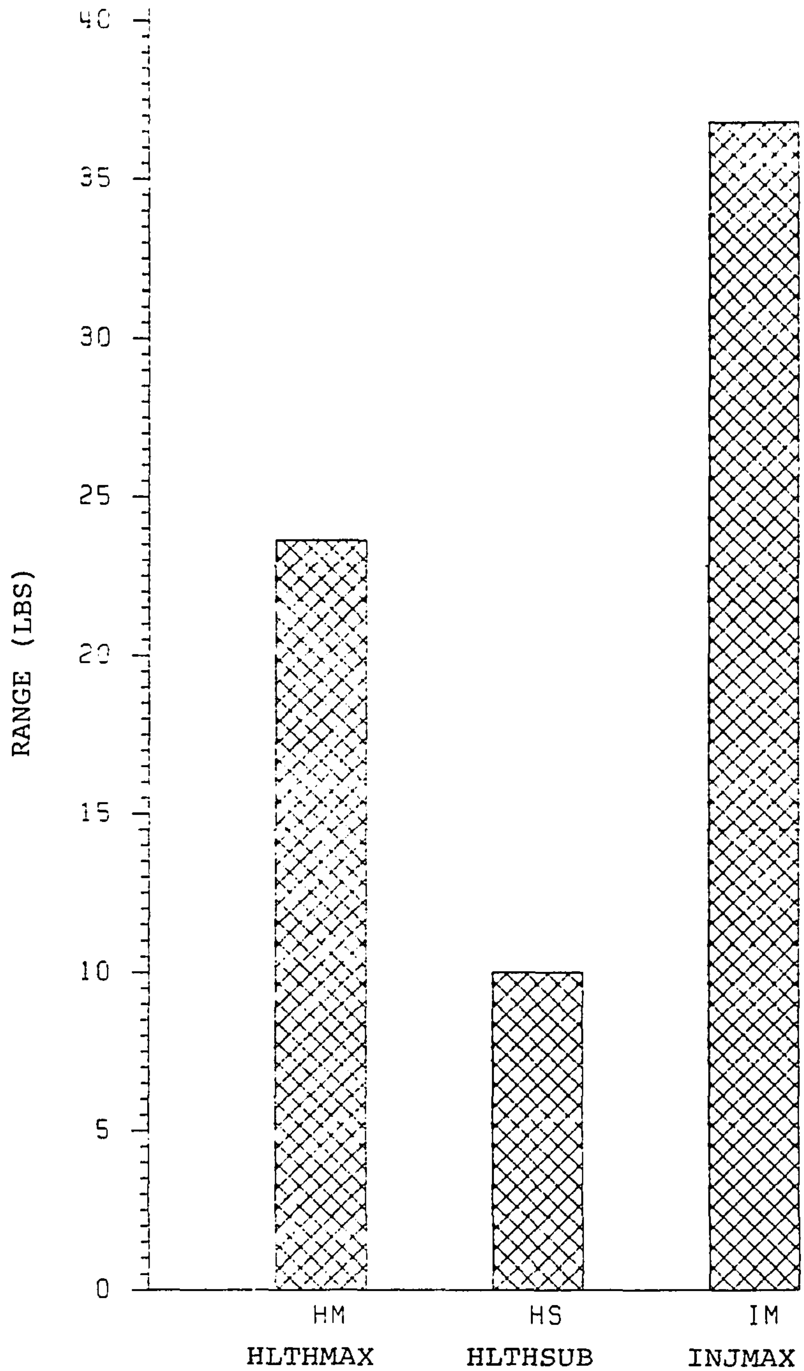


Figure 14. Range vs. Group

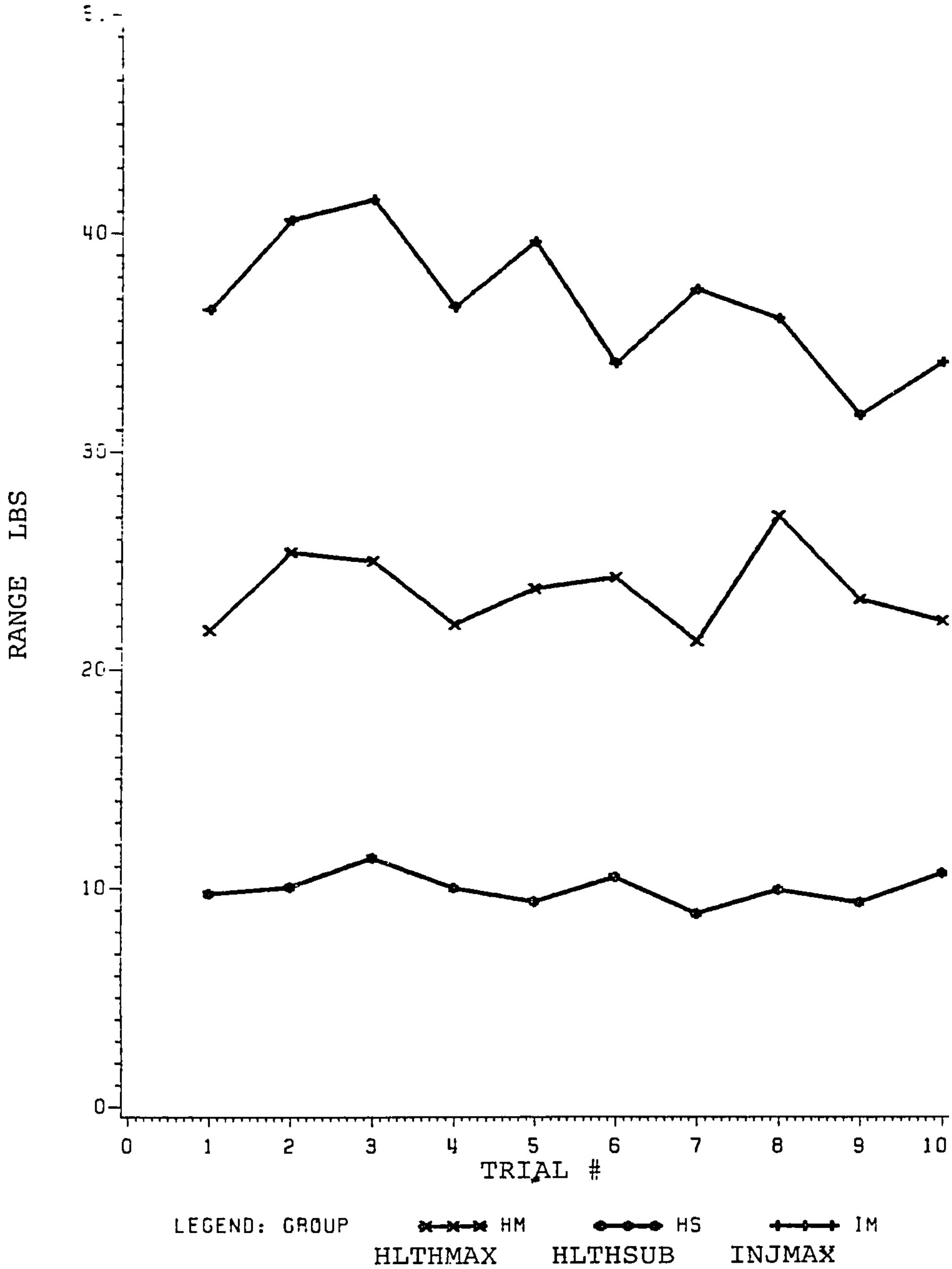


Figure 15. Range vs. Trial by Group.

alpha level, and the effect of Position was found to be significant at the 5% alpha level.

A Duncan multiple range test indicated that the means for all three groups were different from each other with respect to RANGE. The SQUAT position was significantly different from the STOOP position (alpha=0.05) and exhibited higher RANGE. Trials were not significantly different.

Table 10. ANOVA Table for RANGE.

Source	d.f.	Sum of Squares	Mean Square	F-Ratio
Group	2	115571.85	57785.92	14.08**
Subject(Group)	45	184727.20	4105.05	34.93**
Position	1	2957.53	2957.53	5.03*
Group*Position	2	1535.00	767.50	1.31
Subject(G)*Position	45	26447.32	587.72	5.00
Trial	9	1805.19	200.58	1.71
Error	855	100485.41	117.52	
Total	959	433529.50		

** Significant at 1 percent alpha level

* Significant at 5 percent alpha level

Standardized Range (RATIO)

As mentioned in Chapter III, the dependent variable "Standardized Range" was defined as the ratio of the "range" to the "strength score" for a given trial. Figure 16 shows the overall values of this measure for each of the three groups collapsed across all subjects, positions and trials. It indicates that the value of "standardized range" was considerably larger for the injured maximal group (.234) compared to the two healthy groups (.149 and .164). This is also evident in Figure 17 which illustrates the variation in "standardized range" with respect to trials for the three groups. Thus, this measure may qualify as a criterion to distinguish between healthy and injured groups.

The results of the analysis of variance using "Standardized Range" as the dependent variable are summarized in Table 11. The main effects found to be significantly different at an alpha level=0.01 were Group and Subject. The position effect was not significant. The subject by position interaction was significant at an alpha level of 0.05. A Duncan multiple range test revealed that the mean for the injured maximal group was significantly different from the means for the two healthy groups with respect to this variable. However, there was no difference indicated between the means for the healthy maximal and the healthy submaximal groups.

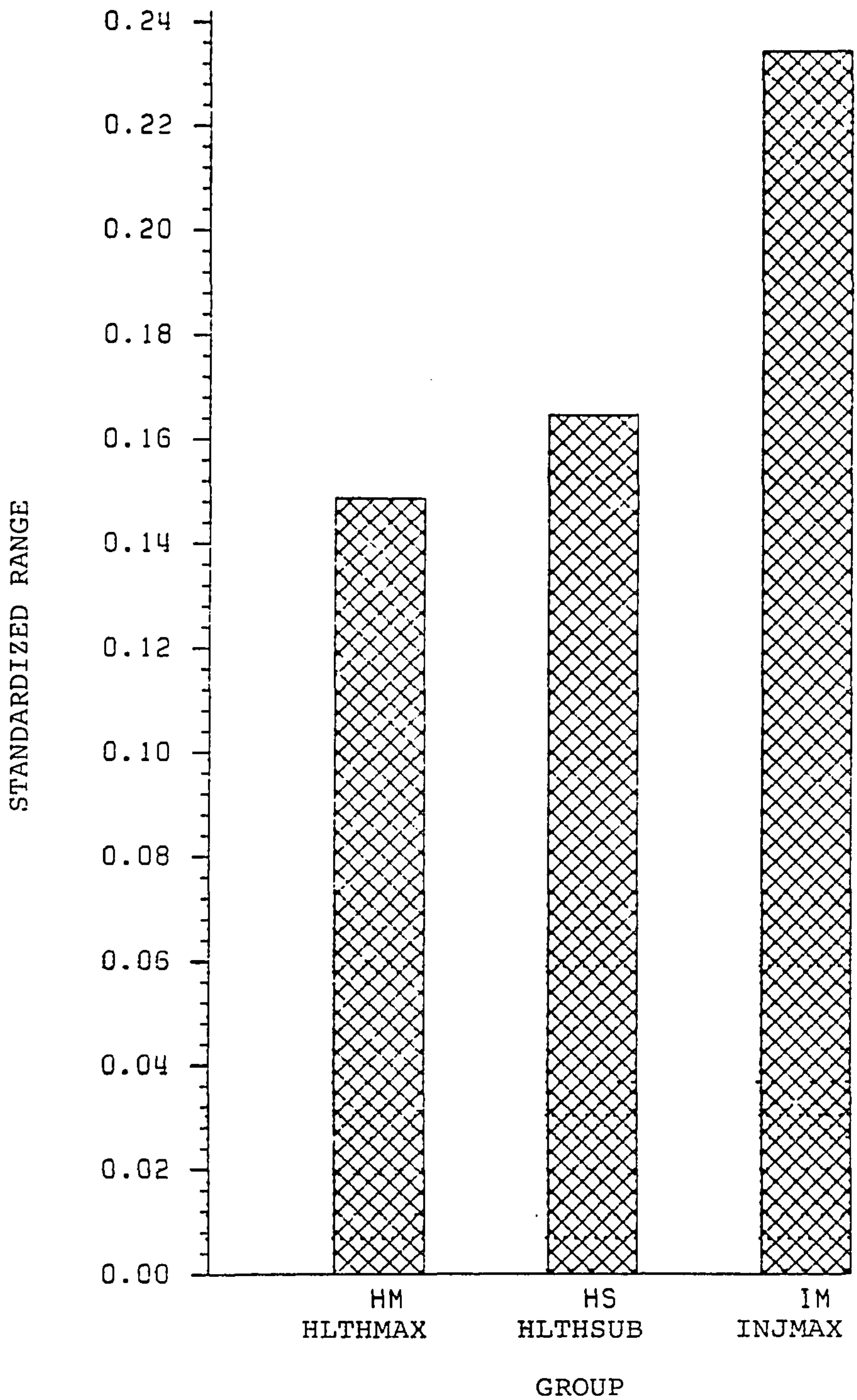


Figure 16. Standardized Range vs. Group.

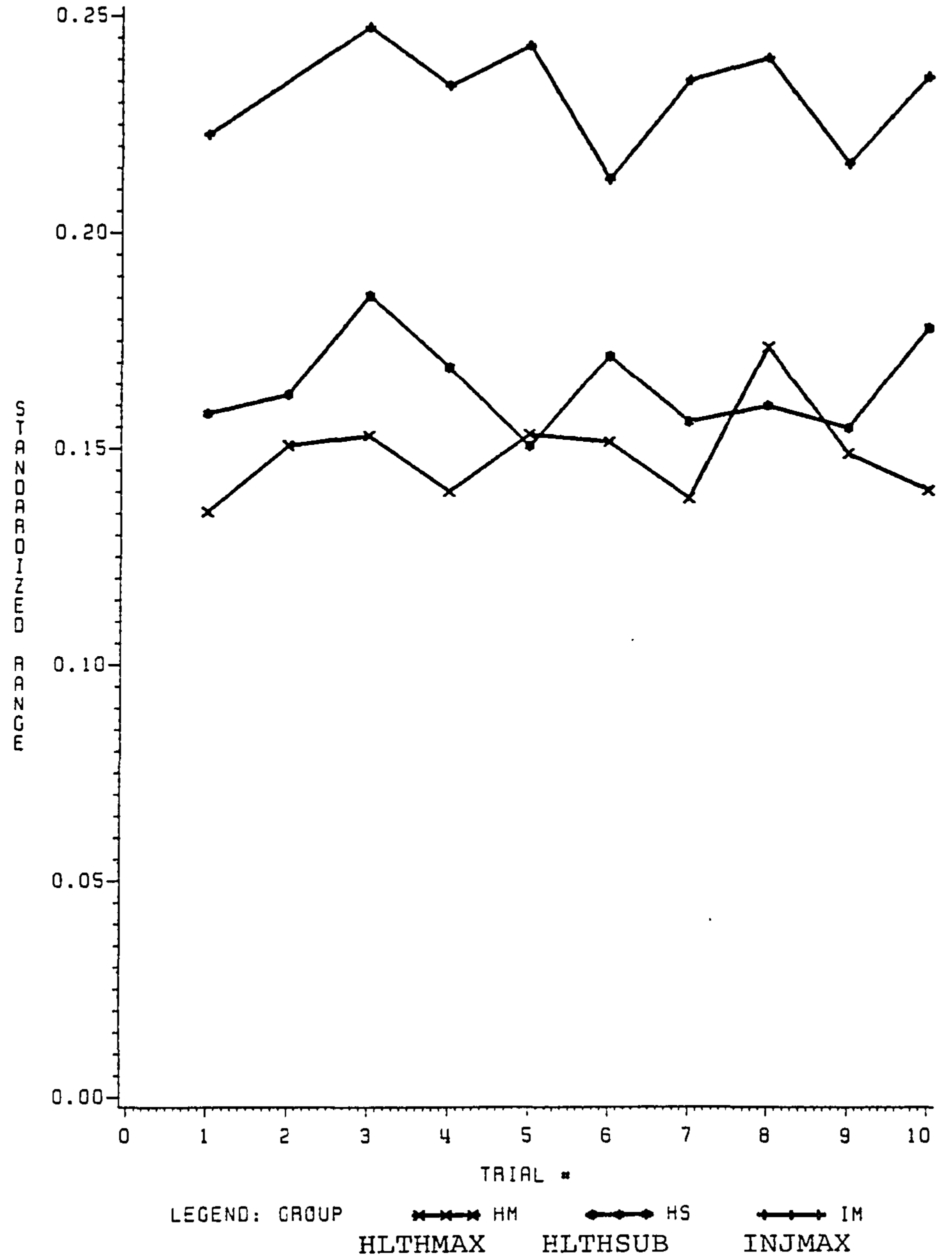


Figure 17. Standardized Range vs. Trial

Table 11. ANOVA Table for Standardized Range (RATIO).

Source	d.f.	Sum of Squares	Mean Square	F-Ratio
Group	2	1.3311	0.6655	7.27**
Subject(Group)	45	4.1189	0.0915	19.82**
Position	1	0.0166	0.0166	1.01
Group*Position	2	0.0596	0.0298	1.80
Subject(G)*Position	45	0.7442	0.0165	3.58*
Trial	9	0.0526	0.0058	1.26
Error	855	3.9491	0.0046	
Total	959	10.2721		

** Significant at 1 percent alpha level

* Significant at 5 percent alpha level

SCORECV

Figure 18 shows the plot of overall values of the dependent variable SCORECV. The healthy maximal (HLTHMAX) group exhibited the smallest value of this measure (2.55). The healthy submaximal (4.8) and the injured maximal (4.55) groups exhibited values very close to each other though quite different from the healthy maximal group for this dependent variable.

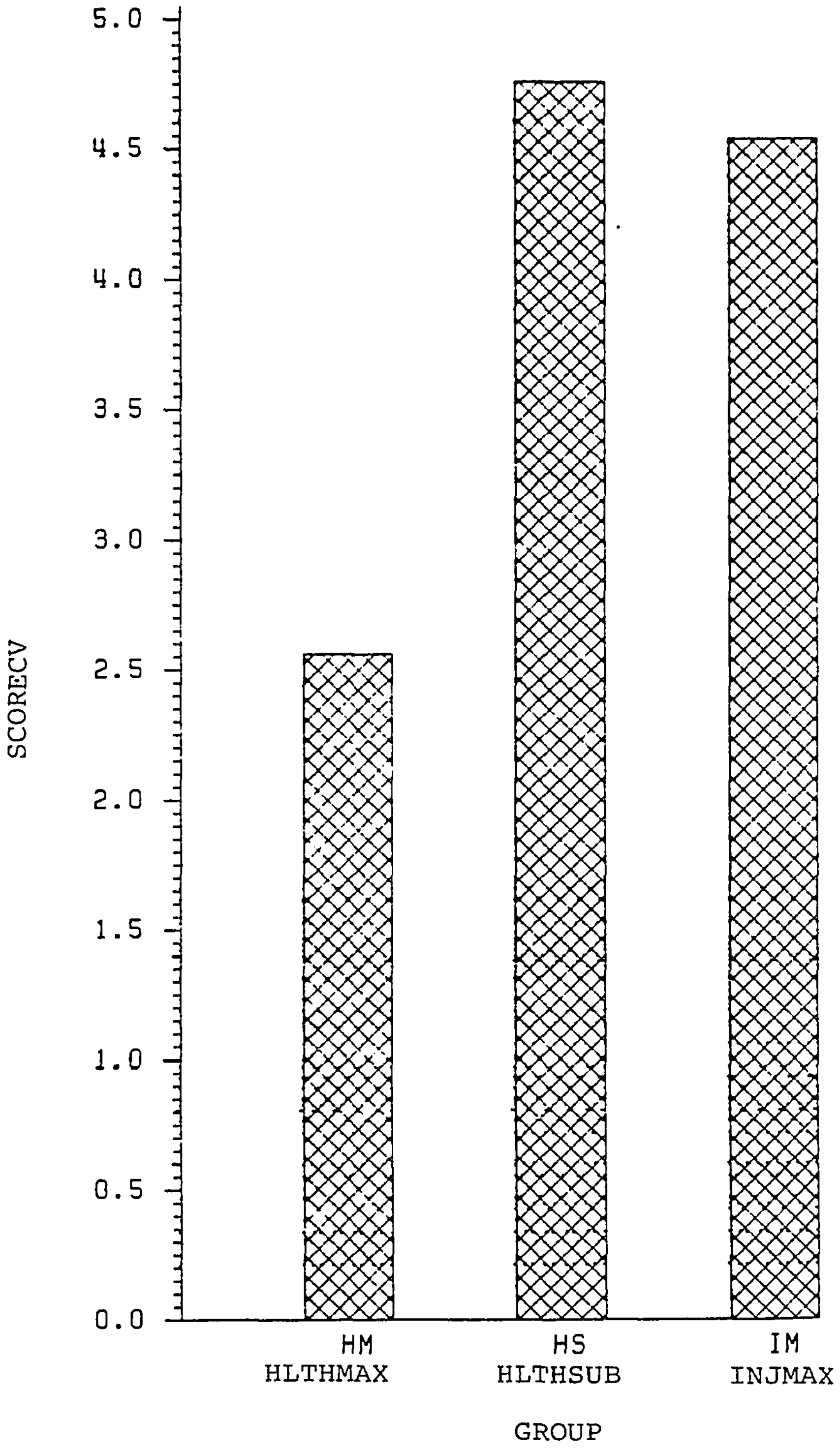


Figure 18. SCORECV vs. Group

However, the differences were not statistically significant as seen from the results of the analysis of variance shown in Table 12.

Table 12. ANOVA Table for SCORECV.

Source	d.f.	Sum of Squares	Mean Square	F-Ratio
Group	2	0.009558	0.0048	0.06
Subject(Group)	45	3.765225	0.0837	
Position	1	0.065104	0.0651	0.78
Group*Position	2	0.178533	0.0892	1.07
Error	45	3.740562	0.0831	
Total	95	7.758983		

SCORECVIN

Figure 19 illustrates the dependent variable SCORECVIN for the three groups. Again, the healthy submaximal (117) and the injured maximal (94) groups indicated higher values of this variable compared to the healthy maximal group (51).

The results of the analysis of variance using SCORECVIN as a dependent variable are shown in Table 13.

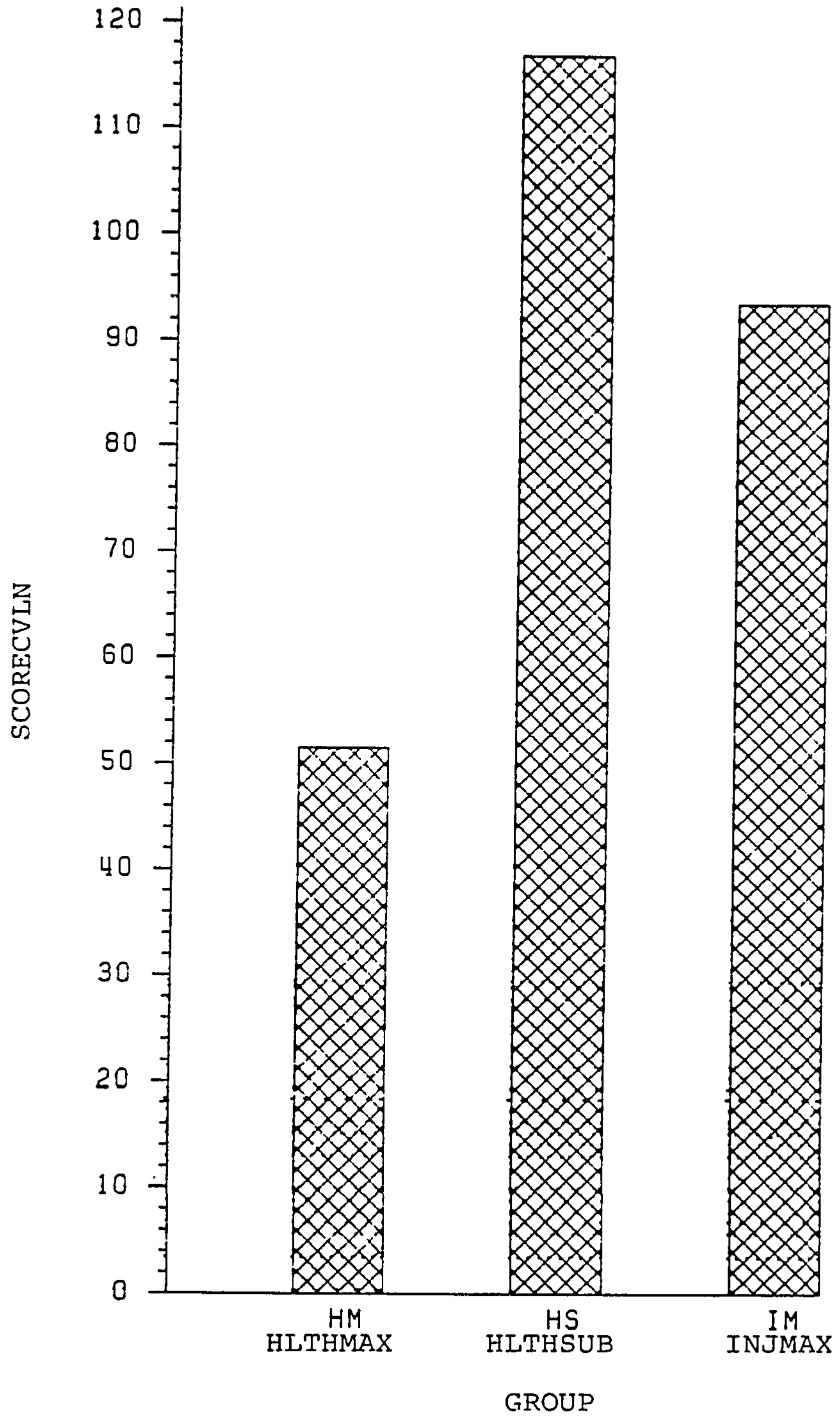


Figure 19. SCORECVLN vs. Group

Group was found to be a significant factor at the 1% level of significance. None of the other main factors or interactions were significant.

Table 13. ANOVA Table for SCORECVLN.

Source	d.f.	Sum of Squares	Mean Square	F-Ratio
Group	2	68.6514	34.3257	12.95**
Subject(Group)	45	119.3083	2.6513	
Position	1	0.9483	0.9483	0.86
Group*Position	2	1.1309	0.5655	0.51
Error	45	49.5411	1.1009	
Total	95	239.5800		

** Significant at 1 percent alpha level

A Duncan multiple range test indicated that the mean for the healthy maximal group was significantly lower than the means for the other groups. The healthy submaximal and the injured maximal groups were not found to be significantly different from each other with respect to this variable.

There was no significant difference between the two positions with respect to SCORECVLN.

The results are in disagreement with the results obtained by Daniel (1978). A Duncan test using CVLN as the dependent variable on Daniel's data showed significant difference between means for the HLTHSUB and HLTHMAX groups and between means for the HLTHSUB and INJMAX groups. It did not indicate significant difference between HLTHMAX and INJMAX groups.

Discriminant Analysis of the Data

This study will have a practical significance if the results can be used to classify individual subjects into one of the three groups based on data from their strength exertions. This would verify if the subjects were delivering a maximal effort and if they are healthy or injured. The appropriate statistical procedure that could accomplish this is "Classificatory Discriminant Analysis" described in Appendix D.

Discriminant analysis was performed on the original data by testing different sets or groupings of the dependent variables in the model. The first set included all the thirteen dependent variables (shown in Table 5 in Chapter III along with the variable SCORCVLN).

The second set of variables was determined by applying stepwise discriminant analysis, using the SAS procedure STEPDISC. This reduced the number of variables in the variable set for the discriminant model from thirteen to seven.

The procedure STEPDISC used seven steps to select the most relevant of the dependent variables. The summary of stepwise selection is given in Table 14. Thus, the variables SCOREMN, SCORESD, SLOPEMN, RANGEMN, RATIOMN, RATIOSD and RATIOCV were used to develop the best discriminant model.

Table 14. Optimum Discriminant Model Variables.

Step	Variable entered	Variable removed	No. of vars. in model	Cannonical Correlation
1	SCOREMN		1	.2591
2	SCORESD		2	.4285
3	SLOPEMN		3	.4644
4	RANGEMN		4	.5122
5	RATIOMN		5	.5478
6	RATIOSD		6	.5480
7	RATIOCV		7	.5901

Table 15 shows the results of classification of observations in the original data set using the discriminant model with all thirteen dependent variables. The overall accuracy of classification achieved was 90.6%.

Two subjects from the HLTHMAX group were misclassified, one into the HLTHSUB category and one into the INJMAX category. The HLTHSUB misclassifications were for a female subject in both the positions.

Table 15. Performance of the Thirteen Variable Model.

From Group	To Group HLTHMAX	HLTHSUB	INJMAX
HLTHMAX	90. 62%	6.25%	3.13%
HLTHSUB	0%	100%	0%
INJMAX	15.62%	3.13%	81.25%

Table 16. Examination of Misclassified Subject Data.

Dep.Var.	Membership Group HLTHMAX	Subject B	Classified Into Group HLTHSUB
	Position: Squat		
Strength score	169.55	73.85	66.02
Range	26.54	14.00	9.99
Slope	19.87	11.69	7.25
Std. Range	.1417	.1748	.1754
	Position: Stoop		
Strength score	150.11	68.56	59.14
Range	20.73	12.00	10.00
Slope	17.96	10.21	5.71
Std. Range	.1555	.1899	.1539

The average values of the dependent variables for the female subject in general, were closer to the averages of the HLTHSUB group than to the averages of the HLTHMAX group. This is illustrated in Table 16.

The HLTHMAX group subject classified as INJMAX exhibited an average "Standardized Range" of 0.2427. The average value of this dependent variable in the stoop position for the HLTHMAX group was 0.1417 and for the INJMAX group was 0.2430. This is likely to be the reason for misclassification. However, why the subject exhibited such a high value for "standardized range" is not clear.

Five subjects from the INJMAX category were misclassified, four into the HLTHMAX category and one into the HLTHSUB category. The way discriminant analysis was set up, data was analyzed considering each subject separately in the two positions. Thus, a total of six observations for these five subjects were misclassified. It was observed from the data that the INJMAX subjects classified as HLTHMAX exhibited dependent variable values closer to the averages for the HLTHMAX group. It is suspected that they had made significant progress towards the healthy status.

One INJMAX group female subject was classified as HLTHSUB. This subject exhibited dependent variable averages comparable to the HLTHSUB group averages rather than to the INJMAX group averages.

The results of classification of the observations in the original dataset using the discriminant model with the variables listed in Table 15 (obtained from STEPDISC procedure) are shown in Table 17. All the observations in the HLTHMAX group were classified in the HLTHMAX group. All the observations in the HLTHSUB group were classified in the HLTHSUB group. 75 percent of the INJMAX group observations were classified into the INJMAX group. 12.5 percent of the INJMAX group observations were classified into the HLTHMAX group and 12.5 percent were classified into the HLTHSUB group. Thus, the overall accuracy of classification was 91.6%.

Table 17. Performance of the Seven Variable Model.

From Group	To Group HLTHMAX	HLTHSUB	INJMAX
HLTHMAX	100%	0%	0%
HLTHSUB	0%	100%	0%
INJMAX	12.5%	12.5%	75%

Here, two INJMAX observations were misclassified as HLTHMAX group observations. Also, two female INJMAX subjects were classified as HLTHSUB subjects. The probable reasons for such misclassifications have already been explained in the discussion of the thirteen variable discriminant model.

Thus, the thirteen variable model provided lower overall accuracy compared to the seven variable model. This confirms the statement by Klecka (1974) that "By sequentially selecting the next best discriminator at each step, a reduced set of variables can be found which is almost as good as and sometimes better than the full set."

Several other combinations of the dependent variables were used to develop discriminant models which were used for data classification into groups. None of the other combinations produced better classification of the original data than that shown in Table 17.

A data set containing observations on all male subjects was tested using a discriminant model with all the dependent variables except SCCBECVLN. The classification results are shown in Table 18. The overall accuracy of classification achieved for the male data set was 95.8%. Thus, higher accuracies may apparently be obtained by using separate models for males and females.

This discriminant model classified two subjects from the INJMAX category into the HLTHMAX category. These subjects are the same subjects that were classified by other models (thirteen- and seven-variable models) as HLTHMAX group subjects.

Table 18. Performance of the Twelve Variable Model Male Data Set.

From Group	To Group HLTHMAX	HLTHSUB	INJMAX
HLTHMAX	100%	0%	0%
HLTHSUB	0%	100%	0%
INJMAX	12.5%	0%	87.5%

Predictibility of the Model

The results of the study show that it is possible to achieve a high level of predictability of the discriminant model by proper selection of the discriminating variables. An overall accuracy of classification of over 90% was obtained using the optimum set of dependent variables to develop the discriminant model.

In applying the model, an industrial engineer or an industrial physician must consider the misclassifications in light of the type of error he is willing to accept. The overlapping portions of the distributions of the discriminant scores of the three groups represent the areas in which errors of misclassification are most likely to occur.

From the insurance company perspective, one would want to minimize classifications of true HLTHSUB observations into the INJMAX category. A classification of an individual claiming INJMAX status, into the HLTHSUB category should provide additional evidence in cases of malingering or a person faking an injury. As seen earlier, the model did classify all the HLTHSUB observations correctly.

It is important to realize that the technique itself cannot confirm a low back injury. However, it will classify subjects into the healthy or injured categories, and evaluate if the maximal effort was delivered. The results of the technique then can be a clue as to whether further tests are warranted to evaluate a person's claim of low back injury. Thus, in spite of its shortcomings, the technique does provide an additional diagnostic test.

Tables 19 and 20 summarize the important results of this study. Table 19 provides the Pearson correlation coefficients for the experimental variables.

Table 19. Table of Correlation Coefficients.

	Trial	SS	Range	Slope	SR
Trial	1.000	-0.037	-0.033	0.025	-0.006
SS	-0.037	1.000	0.635	0.655	0.041
Range	-0.033	0.635	1.000	0.330	0.706
Slope	0.025	0.655	0.330	1.000	-0.043
SR	-0.006	0.041	0.706	-0.043	1.000

SS - Strength score SR - Standardized Range

The correlations between the trials and the other dependent variables were essentially zero. However, the dependent variable strength score correlated fairly well with the dependent variables range and slope. The correlations were of the order of 0.65 which were significant at an alpha level of 0.01. This reinforced the findings of Kroemer and Marras (1980) who also reported a high positive correlation (0.775) between strength scores and slopes.

The dependent variables range and standardized range also indicated a high correlation of the order of 0.706.

Table 20 summarizes the factors that had a significant effect on each of the dependent variables.

Table 20. Summary of Significant Effects.

Criterion Measure	FACTOR Group	Subjects (Group)	Trial	Position
Strength score	**	**		**
Slope	**	**		**
Range	**	**		*
Standardized Range	**	**		*

* -Marginally Significant

** -Highly Significant

The factors Group and Subjects(Group) were found to be highly significant for the dependent variables strength score, slope, range, and standardized range. The factor Position was highly significant for the dependent variables strength score and slope but was marginally significant for range and standardized range.

None of the factors were found to be significant for the dependent variable SCORECV. Only the factor Group was found to be significant for the dependent variable SCORECVIN.

The seven variable discriminant analysis model correctly classified subjects with an overall accuracy of 91.6%. The classification accuracy of the twelve variable model on the all male subjects data set was 95.8%.

The following chapter presents the conclusions and recommendations for further research.

CHAPTER V

CONCLUSIONS

The purpose of this research was to develop and test a procedure for discriminating between healthy individuals and individuals with low back injury using specific strength measurements. This was accomplished by measuring the lifting strengths of healthy and injured subjects and by identifying possible discriminating factors of the lifting force patterns using statistical analysis.

The secondary objective of the study was to develop and test a procedure for distinguishing between maximal and submaximal efforts, using rate of strength build-up (slope) and between-trial variability in repeated exertions as criterion measures. This was undertaken to resolve the differing results reported by Kroemer and Marras (1980) and Daniel (1978).

The results of the study indicated that the rate of strength build-up (onset slope) during the strength measurements may provide a reliable distinction between the maximal and submaximal strength exertions. The factor Group was highly significant in the analysis using Slope as a dependent variable. The rate of strength build-up exhibited a high positive correlation with the dependent variable Strength Score for all groups. This was in agreement with the results reported by Kroemer and Marras (1980).

Although strength exertion is highly individual, it was revealed by the study that in general, submaximal exertions were associated with "flatter" slopes in comparison with the maximal exertions which were characterized by "steeper" slopes. This also confirms the finding of Kroemer and Marras (1980).

An observation was that subjects tend to build-up force over a fixed period of time regardless of the final sustained level. This explains the higher slopes associated with the higher strength scores. It also indicates that slope provides little additional information beyond that provided by the strength score itself.

The analysis indicated that the healthy submaximal group (HLTHSUB) was significantly different from the other groups with respect to slope. This resulted in rejection of the first null hypothesis of the study that there are no differences among the three groups with respect to this dependent variable. However, no significant difference was indicated between the healthy maximal (HLTHMAX) and injured maximal (INJMAX) groups.

The results indicated that, in general, the subjects could exert more strength in the position with bent knees and straight back (SQUAT or Leg Lifting) compared to the position with straight knees and bent back (STOOP or Torso lifting). This is typical of strength testing and is consistent with the results observed by Chaffin et. al (1976) and also by Daniel (1978). It was also observed that the strength exerted in any position is highly dependent upon the configuration parameters defining the position. This is in agreement with several researchers in the area of strength measurement (Chaffin and Baker, 1970; Garg and Herrin, 1978).

The second null hypothesis postulated no significant difference between the three groups with respect to "between-trial variability" in repeated exertions. The analysis conducted using SCORECV as a criterion measure did not indicate any significant difference between the three groups and thus between maximal and submaximal exertions. This confirmed the results obtained by Kroemer and Marras (1980).

The analysis based on SCORECVLN as a criterion measure indicated a significant difference between the healthy maximal group and the healthy submaximal group. It also indicated a significant difference between the healthy maximal and the injured maximal groups. However, no significant difference was indicated between the healthy submaximal and the injured maximal groups. Daniel (1978) found a significant difference between the healthy submaximal and healthy maximal, and also between healthy submaximal and injured maximal groups. He did not report any significant difference between healthy maximal and injured maximal groups.

Thus, this study did not confirm Daniel's (1978) findings.

The third null hypothesis postulated no significant difference between the three groups with respect to "within-trial variability". The analysis conducted using Range as the criterion measure indicated that the mean ranges of the three groups significantly differed from each other. Thus, this null hypothesis was rejected by the analysis when using Range as the criterion measure.

It was observed that the injured individuals exerted strength levels comparable to the healthy individuals, with a higher value for range. This disagreed with Daniel's (1978) results. However, Daniel used a small sample of only four injured subjects.

The criterion measure "Standardized Range" showed great promise for discriminating healthy and injured individuals. By dividing the RANGE by the Strength score for each trial, allowance was made for differences in the level of effort between the groups. The value of this ratio was considerably larger for the INJMAX group (0.23) compared with the two healthy groups (0.15 and 0.16).

The analysis using Standardized Range as the criterion measure indicated that the mean for the injured maximal group was significantly different from the means of the healthy maximal and healthy submaximal groups. This was the only measure which strictly distinguished the injured subjects from the healthy subjects regardless of their group assignment. It also minimized differences between the two lifting positions. Again, the third null hypothesis was rejected by the analysis using Standardized Range as the dependent variable.

The submaximal exertions seemed to exhibit the smallest range value, indicating the smallest "within-trial" variability to be associated with submaximal effort. However, after adjusting for the mean effort level, the "within-trial variabilty" as measured by the Standardized Range, was the largest for the injured maximal group compared to the healthy maximal and healthy submaximal groups.

No other systematically different patterns in the data were distinguished.

An additional observation from the results of the study was that if the Caldwell regimen is used for static strength measurement, a rest period of two minutes between trials and ten minutes between sessions of ten trials is adequate to eliminate the effects of fatigue.

It was concluded from the results of the discriminant analysis that the developed procedure showed promise as an objective diagnostic technique for assessing low back injury using strength measurement. Dependent variables such as strength score, slope, range, standardized range and other derived variables were used to develop a discriminant function (model) to ascertain whether a person had sustained a low back injury.

The model developed was used to classify the present status of subjects into one of the three groups considered in the study. Such a classification predicted if the subject was considered healthy or considered to be suffering from low back injury. It also indicated the category (maximal or submaximal) that the subject's effort fell in when maximal effort was requested.

If it is determined that an injured subject was delivering his or her safe maximal effort, the reduction in MVC compared to the pre-employment level may possibly be used as an assessment of the extent of disability due to injury. It is expected that a malingerer who presents submaximal effort when requested to produce maximal effort will be classified by the model into a healthy submaximal category. The study appeared to be a source of optimism in an attempt to establish a logical basis for the fair and judicious award of compensation payments to an employee with a low back injury.

Recommendations for Further Research

An important recommendation for further research related to this study is to confirm the results of this study using a larger data base and to develop a more reliable discriminant model.

In any such study, it is recommended that the groups be matched based on age and the ability to exert strength. One possibility would be to conduct separate studies on weak, medium and strong individuals to limit the size of the experimental design.

Both male and female subjects should be assigned to all the groups if possible. In this study, fewer female subjects were used in the injured maximal group due to the restricted availability of the female subjects at the clinic. A separate analysis for each gender is likely to improve the predictive capabilities of the model.

The "within-trial variability" seemed to play an important role in the analysis. This led to the derivation of "Standardized Range" which provided a basis for distinguishing healthy and injured subjects. This variability was measured using Range as a criterion due to difficulty in the data reduction as explained in Chapter III. Standard deviation is a more reliable measure of variabilty. It would perhaps be better to use standard deviation as a measure of "within-trial variability" and investigate the results.

Additional research is desirable using range of motion as a dependent variable and comparing the between-trial variability in repeated trials with these measurements. Then, an additional variable could be incorporated in the Discriminant Model for better discrimination.

Maximum voluntary contraction is affected by the level of motivation and the instructions to the subjects. It may be important to study the effects of different instructions and motivational levels on measurements in such a study. It is suspected that motivational or psychological factors such as those induced by possible monetary gain play an important part.

The results of the present study are not applicable to acute low back pain patients. Another recommendation for additional research in this area is to develop a discriminant model and verify present findings using acute low back pain patients.

Finally, additional research is recommended to study the slope and strength exertion patterns of injured subjects exerting submaximally and to compare the results with submaximal exertions of healthy individuals.

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APPENDIX A1

INSTRUCTIONS for HEALTHY SUBJECTS (MAXIMAL GROUP)

We intend to measure your maximal lifting strength in this experiment in two different lifting positions. These positions are commonly used in manual material handling. Particularly, you will be lifting a handle provided for the given position.

In the first lifting position, namely the LEG LIFTING POSITION, you will stand as shown in the diagram on the wall. You will maintain a 90 degree angle at the knee as shown in the diagram. In this lifting position you will exert your maximum force on the handle by trying to raise yourself into an erect position. The force will be applied through your leg muscles. Your arms are used for the sole purpose of holding the handle. Please do not jerk the handle. To begin each exertion you will hold the handle and get ready in the assigned position. You will hear a word count "Three... Two... One... Go... Stop" played from a cassette tape for each trial. When you hear the word "Go", you should bring your force (exertion) to the maximal level as soon as possible. You will maintain this attained maximum force level as steady as you can until you hear the word "Stop". The time interval between the words "Go" and "Stop" is five seconds and this period is for your strength build up and maintaining the attained maximum exertion. You may relax after the word "Stop". Each maximum strength exertion will be followed by a two-minute rest period. After completing ten such trials, you will be given a rest period of ten minutes.

In the second lifting position, namely the BACK LIFTING (TORSO LIFTING) POSITION, you will stand as shown in the diagram on the wall. You will maintain a 110 degree angle at the waist as shown in the diagram. In this position you will exert your maximum force on the handle provided for this position by trying to raise yourself in an erect position. The force will be applied through your back muscles. Your arms are used for the sole purpose of holding the handle. Once again, please do not jerk the handle. The force will be exerted following the word count as in the LEG LIFTING POSITION explained above.

You will exert maximum force, as hard as you can, WITHOUT INJURING YOURSELF. You are free to interrupt or terminate the experiment at any time. While there is no danger foreseen for the subjects, acute discomfort, pain or fatigue shall be considered as signs indicating that the experiment should be interrupted or terminated. While we encourage you to exert your maximum strength, do not strain yourself by exerting force beyond your safe judgement so that there is any danger of injuring yourself.

IMPORTANT:

1. EXERT YOUR MAXIMUM FORCE WITHOUT INJURING YOURSELF.
2. INCREASE YOUR FORCE TO THE MAXIMUM AFTER THE WORD "GO" AS SOON AS POSSIBLE BUT DO NOT JERK THE HANDLE.
3. MAINTAIN THIS MAXIMUM FORCE UNTIL YOU HEAR THE WORD "STOP".

APPENDIX A2

INSTRUCTIONS for HEALTHY SUBJECTS (SUB-MAXIMAL GROUP)

We intend to measure your performance in exerting half of your maximum lifting strength in two different lifting positions. These positions are commonly used in manual material handling. Particularly, you will be lifting a handle provided for the given lifting position.

In order to know what half of your maximum strength is, we will find out your maximum strength by the following procedure. You will hear a word count "Three... Two... One... Go... Stop" played from a cassette tape. You will hold the handle in the assigned position and pull the handle as hard as you can without injuring yourself when you hear the word "Go". You should maintain your maximum force as steady as you can till you hear the word "Stop" five seconds later. Exert only that level of maximum force which you can maintain for this five second period. Do not jerk the handle. Having found your maximum lifting strength, you will be asked to exert half of that next, during the experiment. Initially before the testing begins you will be told whether you are exerting half of the maximum strength or not. Five such training trials will be given to you so that you know what you are to do in the actual experiment. You will be provided no feedback during the actual experimental trials.

In the first lifting position, namely the LEG LIFTING POSITION you will stand as shown in the diagram on the wall. You will maintain a 90 degree angle at the knee as shown in the diagram. In this lifting position you will exert half of your maximum force on the handle by trying to raise yourself into an erect position. The force will be applied through your leg muscles. Your arms are used for the sole purpose of holding the handle. Please do not jerk the handle. To begin each exertion, you will hold the handle and get ready in the assigned position. When you hear the word "Go" in the word count you should bring your force exertion to half of the maximal level as soon as possible. You should maintain the attained force level (half of maximum force) as steady as you can until you hear the word "Stop". The time interval between the the words "Go" and "Stop" is five seconds and this period is for your strength build up and maintenance of the exerted level. You may relax after the word "Stop". Each exertion will be followed by a two-minute rest period. After completing ten such trials, you will be given a rest period of ten minutes.

In the second lifting position namely the BACK LIFTING (TORSO LIFTING) POSITION, you will stand as shown in the diagram on the wall. You will maintain a 110 degree angle at the waist as shown in the diagram. In this position you will exert half of your maximum force on the handle provided for this position by trying to raise yourself in an erect position. The force will be applied through your back muscles. Your arms are used for the sole purpose of holding the handle. Do not jerk the handle. The force will be exerted following the word count as in the leg lifting position explained earlier.

Remember, you are free to interrupt or terminate the experiment at any time. While there is no danger foreseen for the subject, acute discomfort, pain or fatigue shall be considered as signs indicating that the experiment should be interrupted or terminated. You will exert half of your maximum strength in each lifting position. You will repeat the exertions ten times for each lifting position.

IMPORTANT:

1. EXERT YOUR FORCE WITHOUT INJURING YOURSELF.
2. INCREASE YOUR FORCE TO THE DESIRED LEVEL (HALF OF MAXIMUM) AS SOON AS POSSIBLE BUT DO NOT JERK THE HANDLE.
3. MAINTAIN THIS FORCE UNTIL YOU HEAR THE WORD "STOP".

APPENDIX A3

INSTRUCTIONS for the INJURED SUBJECTS (MAXIMAL GROUP)

We intend to measure your safe maximum lifting strength in this experiment in two different lifting positions. These positions are commonly used in manual material handling. Particularly, you will be lifting a handle provided for the given position.

In the first lifting position, namely the LEG LIFTING POSITION you will stand as shown in the diagram on the wall. You will maintain a 90 degree angle at the knee as shown in the diagram. In this lifting position you will exert your safe maximal force on the handle (such as not to cause any increased pain) by trying to raise yourself into an erect position. The force will be applied through your leg muscles. Your arms are used for the sole purpose of holding the handle. Please do not jerk the handle. To begin each exertion you will hold the handle and get ready in the assigned position. You will hear a word count "Three... Two... One... Go... Stop" played from a cassette tape for each trial. When you hear the word "Go", you should bring your force exertion to the safe maximal level as soon as possible. You will maintain this attained maximum force level as steady as you can until you hear the word "Stop". You may relax after the word "Stop". The time interval between the words "Go" and "Stop" is five seconds and this period is for your strength build up and for maintaining the attained exertion. Each maximum strength exertion will be followed by a two minute rest period. After completion of ten trials, you will be provided a rest period of ten minutes.

In the second lifting position namely the BACK LIFTING (TORSO LIFTING) POSITION, you will stand as shown in the diagram on the wall. You will maintain a 110 degree angle at the waist as shown in the diagram. In this position you will exert your safe maximal force on the handle provided for this position by trying to raise yourself in an erect position. The force will be applied through your back muscles. Your arms are used for the sole purpose of holding the handle. Once again, please do not jerk the handle. The force will be exerted following the word count as in the LEG LIFTING POSITION explained earlier.

You will exert effort ONLY TO A POINT WHERE YOU BEGIN

FEELING ADDITIONAL OR INCREASED PAIN. This will be considered as 'A THRESHOLD FOR EXERTION' and you will not exceed this threshold under any circumstances. Thus, you will exert safe maximum force, as hard as you can WITHOUT RE-INJURING YOURSELF. You are free to interrupt or terminate the experiment at any time. While there is no danger foreseen for the subjects, acute discomfort, pain or fatigue shall be considered as signs indicating that the experiment should be interrupted and/or terminated. While we encourage you to exert your safe maximum strength, do not strain yourself by exerting force beyond your safe judgement so that there is no danger of re-injuring yourself.

IMPORTANT:

1. EXERT YOUR SAFE MAXIMUM FORCE WITHOUT RE-INJURING YOURSELF.
2. INCREASE YOUR FORCE TO THE MAXIMUM AS SOON AS POSSIBLE BUT DO NOT JERK THE HANDLE.
3. MAINTAIN THIS MAXIMUM FORCE UNTIL YOU HEAR THE WORD "STOP.

APPENDIX B

SUBJECT DATA

Name :	Tel.No. :
Height :	Weight :
Age :	Stature :
Lower Legs :	Upper Legs :
Lower Arms :	Upper Arms :

Medical History :

1. Have you suffered from any back problems? Yes/No.
If yes, give details below.

2. Have you ever undergone a hernia operation? Yes/No.
If yes, give details below.

3. Have you ever been treated for any heart problems and or Hypertension (High blood pressure)? Yes/No.
If yes, give details below.

4. Have you ever had any medical problems which you think might hinder your participation in the experiments to be conducted? Yes/No
If yes, give details below.

APPENDIX C

Table C.1 Strength Measures for HLTHMAX Group.

Subject Code	Strength Score	Slope	Range	Standard. Range	Coef. of Var.	Coef. of Var(CVLN)
A	109.71	24.92	23.50	0.215	0.095	2.03
B	71.20	10.95	13.00	0.182	0.105	2.38
C	126.52	21.38	16.35	0.129	0.095	1.94
D	119.98	13.05	15.10	0.126	0.110	2.32
E	128.80	14.69	21.10	0.164	0.090	1.89
F	160.32	13.44	21.00	0.129	0.085	1.68
G	131.86	18.60	13.05	0.101	0.060	1.28
H	147.66	18.42	23.40	0.157	0.115	2.30
I	183.68	23.99	21.00	0.116	0.035	0.70
J	174.67	24.41	26.95	0.154	0.055	1.06
K	164.36	22.72	16.20	0.104	0.060	1.20
L	255.15	39.76	23.15	0.092	0.060	1.14
M	175.08	14.04	26.65	0.154	0.070	1.30
N	194.95	20.74	27.15	0.135	0.085	1.56
O	228.15	10.25	65.90	0.288	0.075	1.44
P	185.27	11.26	24.75	0.131	0.060	1.56

Table C.2 Strength Measures for HLTHSUB Group.

Subject Code	Strength Score	Slope	Range	Standard. Range	Coef. of Var.	Coef. of Var (CVLN)
A	53.15	9.84	8.70	0.158	0.275	6.87
B	60.78	4.20	8.80	0.142	0.130	3.11
C	38.23	5.94	7.80	0.201	0.150	4.14
D	48.38	5.96	9.15	0.181	0.140	3.85
E	67.18	8.04	12.35	0.187	0.060	1.41
F	86.68	6.04	12.60	0.148	0.125	2.81
G	70.59	5.79	13.75	0.195	0.105	2.48
H	57.26	4.99	13.90	0.240	0.115	2.84
I	61.80	3.94	11.10	0.182	0.205	4.94
J	70.75	5.04	11.55	0.156	0.160	3.75
K	77.55	6.42	8.15	0.106	0.105	2.44
L	66.14	4.59	8.90	0.140	0.185	4.39
M	61.75	11.09	8.00	0.139	0.220	5.32
N	46.35	8.40	8.10	0.181	0.140	3.56
O	71.96	5.64	8.60	0.121	0.115	2.77
P	62.77	7.76	8.45	0.155	0.150	3.75

Table C.3 Strength Measures for INJMAX Group.

Subject Code	Strength Score	Slope	Range	Standard. Range	Coef. of Var.	Coef. of Var(CVLN)
A	198.55	23.56	88.15	0.446	0.070	1.35
B	205.56	30.25	27.65	0.135	0.090	1.72
C	163.21	23.13	31.20	0.189	0.115	2.36
D	241.52	26.02	73.90	0.299	0.130	2.33
E	161.96	16.86	24.35	0.144	0.200	3.85
F	216.13	16.84	37.55	0.170	0.135	2.56
G	230.27	14.03	23.10	0.100	0.080	1.51
H	171.11	23.77	48.60	0.287	0.105	2.09
I	68.33	8.21	28.35	0.430	0.200	4.65
J	195.30	15.87	32.10	0.166	0.035	0.71
K	80.37	9.24	19.00	0.234	0.150	3.42
L	75.89	8.81	15.85	0.201	0.170	4.00
M	194.13	11.54	66.90	0.330	0.215	4.02
N	121.35	9.01	20.05	0.161	0.110	2.31
O	101.45	12.71	20.95	0.209	0.285	6.10
P	121.62	9.865	32.20	0.250	0.180	3.81

APPENDIX D

DISCRIMINANT ANALYSIS

Discriminant analysis has been utilized in clinical problems involving questions of differences between groups of individuals and for appropriate assignment of individuals to the groups. A classical example is the classification of patients as neurotic or psychotic on the basis of the Minnesota Multiphasic Personality Inventory (MMPI) test scores.

The discussion of this statistical technique has been adapted from Overall and Klett (1972). In general, in a problem where this technique is appropriate, several different measurements are available for each individual. It is assumed that the measurements are quantitative scores having mulitivariate normal distributions within the populations. The measurements may be correlated or uncorrelated and may involve completely different scale units.

Discriminant analysis, using appropriate weighting coefficients, transforms values of several variables into a single score which has maximum potential for distinguishing between members of the groups. Thus, the assignment of individuals between the groups depends upon the value of a single variable. A critical value is determined that minimizes errors of misclassification.

The composite single score has a normal distribution with estimable mean and variance for each group. Thus, one can determine probabilities of misclassification and the likelihood with which an individual case belongs to each group.

Another alternative to discriminant analysis is to perform a series of univariate one-way ANOVAs. The advantage of the multivariate approach is that two or more groups that overlap considerably when each variable is viewed separately may be quite distinct when examined from a multivariate point of view.

Statistical Basis of Discriminant Analysis

Consider the case of two groups with p original measurements available for each individual. It is assumed that some unknown set of coefficients exists, which will define a composite score providing maximum discrimination between the two groups. Thus, the problem involves determining the weighted composite score from the p measurements, which will force the groups to be as statistically distinct as possible. The desired discriminant function is of the form

$$Y = a_1 x_1 + a_2 x_2 + \ldots\ldots\ldots + a_p x_p$$

where $a_1, a_2, \ldots, a_p$ are the weighting coefficients to be applied to the p original scores for each individual.

Therefore, the problem is to determine optimal values for the weighting coefficients such that the difference between the mean scores for the two groups is maximized relative to the variation within the groups. This is equivalent to maximizing the F-ratio of between-groups variance to within-groups variance.

Thus, the function to be maximized is

$$F(a_1, a_2, \ldots\ldots, a_p) = \frac{\text{between-groups variance}}{\text{pooled within-groups variance}}$$

Maximizing the criterion function F with respect to the weighting coefficients requires the simultaneous solution of a set of p equations in p unknowns to obtain $a_1, a_2, \ldots\ldots, a_p$. These equations are

$$\begin{aligned}
a_1 c_{11} + a_2 c_{12} + \ldots\ldots + a_p c_{1p} &= d_1 \\
a_1 c_{21} + a_2 c_{22} + \ldots\ldots + a_p c_{2p} &= d_2 \\
\vdots \qquad\qquad\qquad\qquad &\quad \vdots \\
a_1 c_{p1} + a_2 c_{p2} + \ldots\ldots + a_p c_{pp} &= d_p
\end{aligned}$$

where c_{ij} are the elements of the within-groups variance-covariance matrix among the p original measurements. The matrix can be computed using any available statistical package on the computer. The vector of mean differences $[d_1, d_2, \ldots\ldots, d_p]$ is computed by calculating the means of the two groups on the p original measurements and then taking the differences between them.

The above system of equations can be written in matrix form as

$$\begin{bmatrix} c_{11} & c_{12} & \cdots\cdots & c_{1p} \\ c_{21} & c_{22} & \cdots\cdots & c_{2p} \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ c_{p1} & c_{p2} & \cdots\cdots & c_{pp} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ \cdot \\ \cdot \\ \cdot \\ a_p \end{bmatrix} \begin{matrix} \\ \\ = \\ = \\ = \\ \\ \end{matrix} \begin{bmatrix} d_1 \\ d_2 \\ \cdot \\ \cdot \\ \cdot \\ d_p \end{bmatrix}$$

or in matrix notation

$$C\,a = d$$

which yields

$$a = C^{-1}\,d$$

where C = within-groups variance-covariance matrix

a = vector of weighting coefficients

d = vector of mean differences.

Thus, after computing the weighting coefficients a_1, a_2, ..., a_p, the discriminant score y for the ith individual can be computed from the equation

$$y_i = a_1x_1 + a_2x_2 + \ldots + a_px_p.$$

It must be noted that the weighting coefficients computed here maximize the difference between the discriminant score means of the two groups. The mean value of the discriminant function for groups I and II can be obtained by applying the weighting coefficients to the mean scores of the original variables for groups I and II respectively. Thus,

$$\bar{Y}^{(I)} = a_1\bar{X}_1^{(I)} + a_2\bar{X}_2^{(I)} + \ldots\ldots\ldots + a_p\bar{X}_p^{(I)}$$

and

$$\bar{Y}^{(II)} = a_1\bar{X}_1^{(II)} + a_2\bar{X}_2^{(II)} + \ldots\ldots\ldots + a_p\bar{X}_p^{(II)}$$

The within-groups variance associated with the distribution of each group's discriminant scores is

$$V(y) = a'Ca = a'C\,C^{-1}a = d'C^{-1}d = d'a$$

Since the original p measurements are assumed to have a multivariate normal distribution within the groups, the discriminant function variate can be considered to have a normal distribution within the groups with mean values $\bar{Y}^{(I)}$ and $\bar{Y}^{(II)}$ and standard deviation $s = \sqrt{d'a}$. Thus, the deviation of an individual discriminant function score from each of the group means can be regarded as a unit-normal deviate or a Z-score

$$Z(Y) = \frac{y - \bar{Y}^{(I)}}{\sqrt{V(y)}}$$

Thus, for any particular discriminant function score y_i, the Z-score deviation from each group mean can be computed. This quantity is used to compute the generalized squared distance of a given observation from the group means in order to classify individuals into groups.

By using the normal tables, it is also possible to compute probabilities of correct classification and of misclassification of individuals, once a criterion for classification (y_c) is chosen.

The relative probabilities of an observation belonging to groups I or II are a function of the ordinate values (relative heights of the probability density functions) of the two normal curves at the point corresponding to the discriminant function score for the individual observation in question. This is shown in Figure D.1 below.

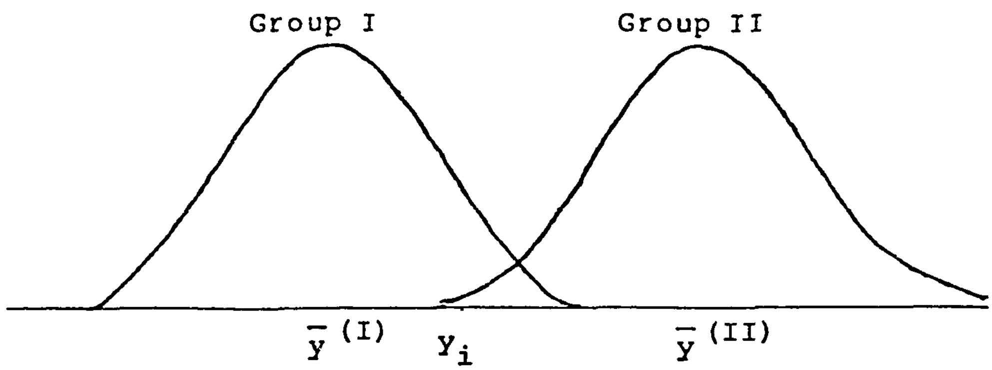

Figure D.1 Distributions of the Discriminant Function Scores for Two Classification Groups

The process of determining the "relative heights" in

Figure C.1 first involves transforming each y_i to the Z-score deviation about each group mean:

$$z_i^{(I)} = \frac{y_i - \bar{y}^{(I)}}{\sqrt{V(y)}}$$

$$z_i^{(II)} = \frac{y_i - \bar{y}^{(II)}}{\sqrt{V(y)}}$$

Let $f[y_i(I)]$ represent the probability density or the ordinate of the normal curve for group I corresponding to $Z_i(I)$ for a particular discriminant function score value y_i. Similarly, let $f[y_i(II)]$ represent the probability for group II.

Then, if Π_1 and Π_2 are the proportion of individuals in the populations from which groups I and II were drawn, the relative probabilities of an individual belonging to a particular group is estimated by

$$p_i(I) = \frac{\Pi_1 \; f[y_i(I)]}{\Pi_1 \; f[y_i(I)] + \Pi_2 \; f[y_i(II)]}$$

and

$$p_i(II) = \frac{\Pi_2 \; f[y_i(II)]}{\Pi_1 \; f[y_i(I)] + \Pi_2 \; f[y_i(II)]}$$

where $\Pi_1 + \Pi_2 = 1$.

Multiple discriminant analysis is a generalization of the discriminant analysis appropriate for only two groups. It provides a basis for classification of individuals among several groups.

The procedure "DISCRIM" from the Statistical Analysis System (SAS) package develops a multiple discriminant model using the measure of generalized squared distance. This is based on the pooled covariance matrix. It also takes into account the prior probabilities of the individuals belonging to the different groups. Finally, DISCRIM computes the posterior probability of an observation belonging to each group.

Using the notation below,

t = subscript to distinguish the groups

S_t = covariance matrix within group t

$|S_t|$ = determinant of S_t

S = pooled covariance matrix

X = vector containing variables of an observation

m_t = vector containing the means of variables in group t

q_t = prior probability for the observation to be in group t

The generalized squared distance from X to group t is given by:

$$D_t^2(X) = g_1(x,t) + g_2(t)$$

where,

$$g_1(X,t) = (x-m_t)' S_t^{-1} (x-m_t) + \log |S_t|$$

if the within-group covariance matrices are used, or

$$g_1(X,t) = (x-m_t)' S (x-m_t)$$

if the pooled covariance matrix is used. Also,

$$g_2(t) = -2\log_e(q_t)$$

Note that $g_2(t) = 0$ if the prior probabilities are all equal.

The posterior probability of an observation X belonging to group t is:

$$P_t(X) = \frac{\exp(-.05\, D_t(x))}{\sum_u (\exp(-0.5\, D_u(x)))}$$

An observation is classified in group u if setting t=u produces the smallest value of $D_t(x)$ or the largest value of $P_t(x)$.

Often, a full set of variables may contain excess, irrelevant or confusing information about the group differences. Stepwise discriminant analysis results in the independent variables being selected for entry into the analysis on the basis of their discriminating power (usually measured by Wilk's lambda). SAS employs the STEPDISC procedure to accomplish this.

STEPDISC uses forward selection, backward elimination, or stepwise selection methods. The stepwise selection method was used in this study. Stepwise selection begins with no variables in the model. At each step, if a variable already in the model fails to meet the criterion to stay, the worst such variable is removed. Otherwise, the variable that contributes most to the discriminatory power of the model is entered. When all the variables in the model meet the criterion to stay, and none of the unselected variables meet the criterion to enter, the stepwise selection process stops.

Thus, the original set of variables is reduced to those most relevant to group differentiation and this enhances the practical applicability of the model. After selecting the most relevant subset of variables using STEP-DISC, DISCRIM (discriminant procedure) may be used to obtain a more detailed analysis.