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A STATISTICAL COMPARISON OF BIOMECHANICAL BACK PERFORMANCE MEASURES FOR PHYSICIAN-REFERRED BACK PATIENTS VERSUS NORMALS

A Thesis

Presented for the

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Degree

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Teri Cherie' Smith

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ABSTRACT

The purpose of this research was to develop descriptive measures of back performance and use these to develop a classification model for discriminating between patients and normals. This model could then be adapted to a pre-employment screening tool and a performance monitoring tool. Pre-employment screening could prevent persons with the back pathology of an injured person from being placed in jobs which place high stresses on the back.

A biomechanical model was used which provides an objective means for obtaining quantitative measures. Five tests were performed: range of motion, isometric, rotational, flexion/extension, and lateral flexion. Six variables were collected using these tests: range of motion, torque, velocity, impulse, work, and power. Normality and means tests were run on the variables. Factor analyses were run on the variables and eight factors with significant variables were identified. The highest loading variable from each factor was then analyzed with a discriminant analysis and a classification and regression trees analysis. Both of these classification procedures yielded a model which could be used for a pre-employment screening test and a performance monitoring tool.

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INTRODUCTION

Magnitude of the Back Injury Problem in Industry

Frequency, Cost and Distribution of Back Injuries in Industry

Because back injuries account for 19-32% of workers' compensation claims, they represent an important problem in our industrial society (National Safety Council 1987, Abenhaim and Suissa 1987). Table 1 presents a diagram of how injuries are distributed on the body according to workers' compensation statistics from 1987. The percentage of the total cases and total compensation awarded for all injuries are given for each body part. Trunk injuries account for 32% of the number of injury cases reported, and for 42% of workers' compensation awarded. Back injuries cost an average of 28% more per injury than injuries to all other parts of the body (National Safety Council 1987). It has been estimated that back injuries cost as much as thirty billion dollars a year in America (Morris 1985), which makes back injuries prevention a primary concern of employers.

Back injury is not the problem of a limited percentage of workers. According to statistics from the Liberty Mutual Insurance Company, 80% of working Americans will suffer from back pain during their careers, with an estimated cost of over

Table 1. Parts of Body Injured in Work Related Accidents by Cases and Compensation

Part of body injured	Percent of all cases	Percent of all compensation
Eyes	5	1
Head (except eyes)	6	6
Arms	9	7
Trunk	32	42
Hands	5	3
Fingers	14	6
Legs	13	13
Feet	4	2
Toes	2	1
General	10	19

Adapted from: National Safety Council. Accident Facts. Chicago, IL: National Safety Council. 1987.

twenty billion dollars per year, with six billion dollars of that due to annual workers's compensation (Chapel 1987). This causes back injuries to be a personal concern for workers.

The age distribution of back compensation claims is similar to that of the employment population from which it is drawn. Males file 76% of workers' compensation claims for back pain, with females filing 24%. There is no significant difference between ages for males and females filing claims (Klein, Jenson, and Sanderson 1984).

Causes of Back Injuries in Industry

Figure 1 illustrates a breakdown of the task types involved in workers' compensation cases in twenty-six states in a 1979 Department of Labor Statistics study (Klein, Jenson, and Sanderson 1984). Most injuries are the result of Manual Materials Handling (MMH). MMH is the unaided movement or carrying of objects by people in the workplace. Other major causes are falls, involuntary motions, and overexertion, all of which may or may not be caused by MMH. Because MMH accounts for such a high percentage of back injuries in industry, it will be the primary cause examined in this study.

MMH tasks are very common in industry. Industry moves an average of fifty tons of material for every ton of product produced (Asfour, Genaidy, and Mital, 1988). The Liberty Mutual Insurance Company reported that 79% of MMH injuries are lower back injuries (Snook 1978).

Table 2 – 1979 Workers' Compensation Claims in the 26 SDS States for Back Strains/Sprains According to Type of Event or Exposure		
Type	No. of Claims	% of All Back Strains/Sprains
Lifting objects	137,327	48.1
Overexertion, not elsewhere classified	25,823	9.0
Pulling or pushing objects	25,557	9.0
Voluntary bodily motions	18,909	6.6
Holding, wielding, throwing, or carrying objects	16,181	5.7
Involuntary bodily motions	13,353	4.7
Falls on working surfaces	12,150	4.3
Overexertions, not elsewhere classified	6,433	2.3
Others, individuall less than 2%	29,735	10.4
Total	**285,468**	**100.1**

Figure 1. Causes of Back Compensation Claims for Worker Strains/Sprains

Source: Klein, Jensen, and Sanderson 1984

Chaffin and Ayoub have identified four components of a task that can lead to a hazardous situation (1975). Looking at each of these task components can enhance an understanding of where injuries are likely to occur in a task.

The first task component is the worker performing the task. Factors such as age, sex, body build, previous medical history, and fitness can determine a worker's capability to perform certain tasks. Other factors which may be considered are the worker's sensory capabilities, strength, coordination, response time, and training (Chaffin and Ayoub 1975). New workers without training and conditioning are at a greater risk for injury (Ergonomics Guide to Manual Lifting 1970).

The second task component to be considered is the characteristics of the object being lifted, its size, weight, load distribution, and stability (Chaffin and Ayoub 1975). Heavy, bulky objects can significantly increase the chances of musculoskeletal injury (Chaffin 1987).

The characteristics of the task itself are a third component to be considered. The frequency and pace of the task, as well as the complexity required can affect the safety of a task. Rapid motions can double the peak stresses on the body (Chaffin and Ayoub 1975). Hot, humid, or cold environments can reduce the load a worker can handle (Ergonomic Guide 1970).

The last task factor to be considered is the work practices characteristics. Work organization and operating practices can increase the risk of injury if not adequately designed for a specific task. Improper lifting height can cause harmful stresses to the lower back (Chaffin and Ayoub 1975). A layout requiring awkward positions or poor posture can cause a task to exert excessive force on the spine for what would normally be a safe load (Ergonomic Guide 1970). Administrative practices can also add to the hazards of a task. Improper rest allowances can result in fatigue which causes a significant increase the chances of an injury occurring (Chaffin and Ayoub 1975).

Difficulty in Estimating Incidents of Back Pain

Although there is no controversy about the fact that back pain is a significant problem is our industrial society, the incidence of back pain is hard to assess. This problem is caused by several factors.

One factor which makes it difficult to assess the occurrence of back pain is that back pain is a symptom, not a disease. It has been shown to be associated with stress and tension and the pain can occur anywhere, at home or work. In up to 85% of patients, the cause of back pain cannot be determined. This makes is difficult to assess the percentage of workers who develop injuries resulting in back pain from the course of their job and those whose pain is indicative of another problem entirely (Deyo, Mayer, et. al. 1987). Many insurance carriers for workers' compensation therefore want proof that the pain or injury is job-related, which can be difficult to produce (Millus 1987).

A second important factor is that the occurrence of back pain cannot be found objectively using current medical techniques and patients with no physical evidence of a problem are regarded suspiciously (Abenhaim and Suissa 1987). There is however, a reluctance to diagnose patients who are simulating back pain as malingering, due to the lack of objective criteria to determine deception. Criteria for detecting deception are subjective and speculative, including such items as possible financial gain, unexplained pain, or conflicting results from tests. (Leavitt 1987).

The problems discussed above can be compounded when a patient actually has some degree of injury and is simulating a higher degree of pain or injury. According to a study by Dr. Frank Leavitt (1987), people with pain are 17% more likely to escape detection when simulating back pain than people with no pain to build on.

Purpose of This Study

Develop Objective Tests

As discussed in the preceding section, the subjective nature of available tests to evaluate back patients is a major limitation to controlling the high cost of back injuries. This study would like to establish an objective test for evaluating back conditions. This test would conform to the guidelines set forth by Harber and SooHoo (1984) for a medical evaluation .

These guidelines suggest that an evaluation test should lead to a quantitative description of impairment and lead to specific recommendations of the immediate limitations of the worker, applicable to his or her specific work.

Harper and SooHoo also give descriptive guidelines of the evaluation procedures. The procedures should be simple, reliable, and present no danger to the subject. The cost of the test should to inexpensive relative to the proposed savings of the test. The test should detect subjects who are simulating a degree of injury greater than is actually present and be independent of subject motivation.

Develop Legal Screening and Monitoring Tests

Several industries have implemented screening processes to predict prospective employees who are at risk to incur disabling lower back injuries (Morris 1985). Using these results as a basis for employment or placement can keep individuals with lower ability out of demanding jobs. There are legal problems, however, which can limit such screening.

Many people have claimed a constitutional right against pre-employment testing. Some have claimed that testing which eliminates them from being hired violates their Fifth Amendment right from deprivation of liberty or property without "due process of law," while others claim a violation of the Fourth Amendment which guarantees freedom from "unreasonable searches and seizures" (Cross 1987).

In spite of the claims being made, private sector employers generally can introduce a medical testing program without constitutional restrictions. However, some federal statutes can limit employment decisions made from testing. An example of this is the Civil Rights Act of 1964, which prohibits employment actions based on tests results which inherently discriminate against people of certain protected classes, such as sex or race (Cross 1987).

Clear guidelines have been set by the Equal Employment Opportunity Commission concerning testing procedures. Tests must be clearly related to the demands of the job the subject will be required to perform, and it must also make predictions of the subject's ability to perform that job (Morris 1985). Fitness tests, such as the National Back Fitness Test, are actually only measures of a person's need for a back exercise program. Use of such a test as a screening procedure could be considered discriminatory in some states (Mitchell).

It is recommended that the screening consist of not only physical ability, but also a problem oriented health history. This should be purged of questions which could be used as for ethical discrimination, such as abortion history. Decisions should be made from the information obtained by company advisors familiar with the job demands (Kurt 1985).

The Equal Employment Opportunity Commission and the Age Discrimination Employment Act have caused serious setbacks in the development of screening procedures. Employers cannot refuse a person a job on the basis of age, sex, or handicap. Management also, however, has an obligation not to place a person in a situation which could be hazardous to the employee or others (Kurt 1985). A goal of this research is to develop a pre-employment or pre-placement screening technique which can legally be used by employers, and which could be used as a performance monitoring tool to periodically evaluate workers who are in high risk jobs.

Further Research Hungerford-Johnson Study

A study was done using the Isostation B-100, an ergometer, and the Orthotron I by Dr. John C. Hungerford and Baron P. Johnson P.T. (1987). This study investigated the use of isometric and isotonic strength measures, cardiovascular information, and subject variables to determine risk potential in workers.

The study was limited in several areas. The normal population consisted only of college students, which confounded age effects with back measure differences.
Only twenty-five variables were collected on each test subject, only fifteen of which had significant differences between normals and patients. Sample size was as low as forty for some of the variables.

This study will attempt to improve on the results of the Johnson-Hungerford study by addressing those limitations. The samples for both the normal population and the patient population was drawn from a diverse age bracket. Ninety variables have been collected on each subject, with a total of one hundred and thirty-two males and sixty-five females being measured for all or part of the variables.

Research Objectives to be Investigated

Descriptive Measures

The first objective of this research is to develop descriptive measures for back performance for both normal subjects (no history of back pain in the last six months) and physician referred back patients.

Classification Model

A second objective of this research is to develop a model using descriptive measures of back performance which will accurately classify persons as normals or patients.

Worker Selection

Another objective of the research is the development of a back test which could indicate prospective workers who are likely to develop back injuries. This test could be used as the basis for a pre-employment or pre-placement screening test.

Performance Monitoring Tool Based on Objective Measures

A final objective of this research would be to develop a performance monitoring tool. Developing a good diagnostic test to identify people who have back injuries or who are at risk to develop injuries, would provide a good performance monitoring tool. Periodic use of such a tool on worker's placed in jobs which are stressful on the back could identify those who are developing back injuries before they become seriously injured.

Scope and Limitations of the Study

A limitation of this study could lie in the demographic background of the subjects. The patients are from more limited geographic localities than the normals and could not be randomly chosen from the overall patient population.
The ages of the patient group had a broader range and the patients were older on the average.

Another limitation of the study could be the testing procedures. Since the patient and normal groups were tested by different individuals the protocols used could be different between the groups. However, since standard protocols are set forth for the machine used in the study, the B-200 Isostation, by Isotechnologies, it is not believed to be a significant source of variability.

CHAPTER 2

LITERATURE REVIEW

Back Injury and Manual Materials Handling

Etiology of Back Injury

To understand how back injuries occur, one must first understand the structures of the back. The primary structures of the back consist of the bones of the spinal column, the joints, the discs, and the spinal cord. In man, the spinal cord is the portion of the central nervous system which connects the brain to the rest of the system. The bones are a series of circular structures, the vertebrae, which surround and protect the spinal cord. They are connected by joints which allow a limited degree of flexibility. The bones are separated by the discs which form a thick elastic cushion between each segment. These discs act as shock absorbers for the body (Sherrington and Noback 1961).

There are several muscle groups and ligaments which hold together the vertebrae and help support the spinal column. The muscles of the thighs, buttocks, and trunk (abdomen and back) keep the back positioned in three normal curves in a person with a healthy back. These curves identify the three primary sections of the spine: cervical, thoracic, and lumbar. The lumbar curve is the part of the back required to absorb much of the stress and weight put on the body (Lift Ability 1988). Pictured in Figure 2 is the anatomy of the back.

Ninety percent of all back problems can be traced to fairly common causes. The primary causes are sprained muscles, osteoarthritis, and disc problems. (Scanlon 1986).

Muscle sprain can result from overstretching tissues or hemorrhaging into a muscle. The most common causes of muscle sprain are lifting efforts and sudden unexpected jarring (Sherrington and Noback 1961).

Osteoarthritis occurs from wear on the joints. During the aging process, the discs lose some of their moisture and shrink. The spinal column compresses, putting an increase in stress on the joints. This leads to a quicker deterioration of the joints and they can become dislocated, pressing against the spinal column which sends pain up and down the spine as the small back muscles contract.(Scanlon 1986)

The back is very susceptible to disc injuries because the discs, which are the critical support structures of the back, have no nerve endings (Armstrong 1987). Pain occurs only when there has already been trauma or a irreversible tearing of the outer layers of the discs of the lumber spine. The gelatin-like center of the disc can exert a tremendous amount of pressure on the inner layers of the disc when under pressure and cause it to tear from the inside out, something like squeezing a grape until the center bursts through the skin (Kanner 1988). When a disc has ruptured, it can cause

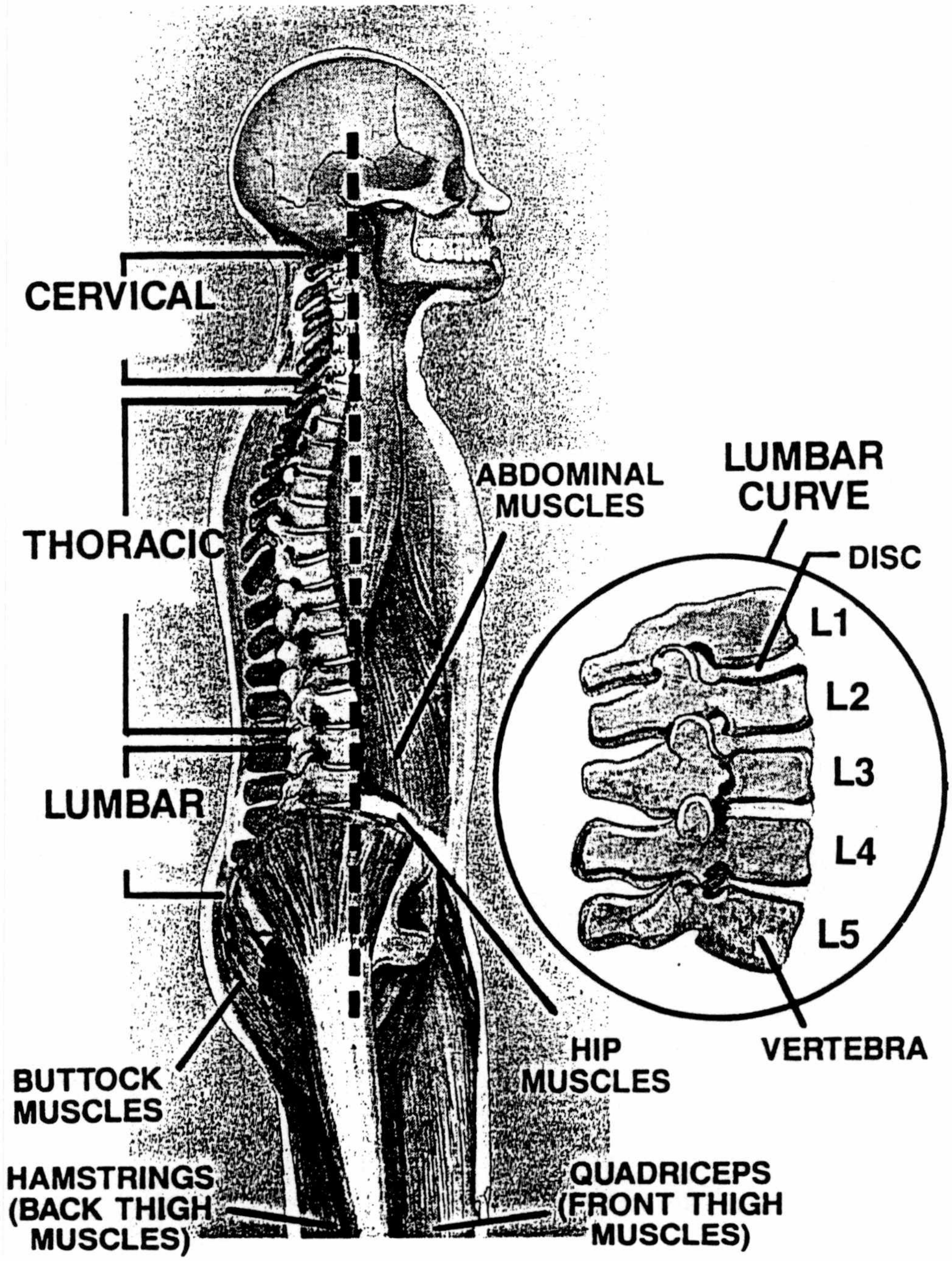


Figure 2. Anatomy of the Back

Source: Lift Ability 1988

great pain by pressing against the spinal cord or exciting nerves (Armstrong 1987).

When assessing cause of back injury, factors which should be considered are fatigue, postural stress, physical fitness, trauma, socio-economic and emotional stresses, and genetic factors. This is not by any means a comprehensive listing. The medical community is still uncertain about exact causes of many back injuries (NIOSH).

Prescriptive Models for Manual Materials Handling

Epidemiological models. An epidemiological model identifies the groups of people at risk for back injuries, the incidence of injury, and the possible preventions for injury. Risk factors can be related to the tasks people perform or to personal characteristics (NIOSH 1981).

People doing heavy lifting work have been shown to be eight times more likely to develop low-back pain. Persons exposed to excessive MMH have also been determined to be three times more likely to have compensable low-back pain.(Chaffin 1987). These results strongly suggest that MMH is a significant cause of back injuries in industry.

The NIOSH lifting Guide (1981) cites several job risk factors for manual lifting. However, it considers only three job risk factors to have been researched enough to have adequate guidelines. These are the weight of the load, the location and size of the load, and the required frequency of lift.

Studies done on these factors indicate models of the incidence of injuries. The risk of injury increases with the heaviness of the object being lifted. Objects very awkward to lift or far from the center of gravity of the body pose a possible threat of injury. High frequency of lifting also increases risk of back injury (NIOSH 1981).

Other factors which can be used to evaluate the risk of injury for a task are personal risk factors. These account for the variations in lifting ability from person to person. Gender, age, and anthropometry are the three most epidemiologically researched (NIOSH 1981).

Studies have indicated definite effects of these factors on back risk. It appears from research that a woman's lifting ability is 60% that of a man's. When lifting a load, a woman's body is placed under higher stress, and thus has a higher risk for injury.

The effect of age as a factor in back injury risk has been much studied, but few conclusions have been reached. Older people do have less physical ability, but risks are reported most frequently among people aged thirty to fifty. This could be due to fewer older people placed in high risk jobs, or more experienced older workers.

Body build has been shown to definitely affect lifting ability, but no clear conclusions have been reached. Heavier people are usually subject to quicker fatiguing, but have more strength. It has also been indicated that taller people have more back pain than shorter people. However, none of these findings have been proven conclusively (NIOSH 1981).

Biomechanical models. A biomechanical model measures the motions of the back and the forces and moments that are acting upon it when performing a task. The purpose of a biomechanical model is to be able to compare a person's physical abilities with the actual physical demands of a specific task. In addition, it should isolate the components of a task that could be a potential cause of injury. The output of such a model should be an accurate description of an individual's mechanical abilities (NIOSH 1981).

The dynamic biomechanical model of the human body assumes it is a system consisting of rigid links joined at known articulations. This is not as good a model for the back as it is for the legs and arms. To improve on this, the back/trunk region is divided into two links joined at the L_5/S_1 area for a biomechanical model involving back motions. This allows calculation of the compressive forces of the spine and moments at the L_5/S_1 area of the back which is the most commonly injured in MMH (Freivalds, Chaffin, Garg, and Lee 1982).

A biomechanical model requires three types of input. First, the mass and lengths of the links are needed. Second, the motion of each link for the task being evaluated. Last, the weight and size of the load being moved is needed (Freivalds, Chaffin, Garg, and Lee 1982).

Large torques are generated at the lumbar region of the spine when heavy loads are lifted which must be accompanied by stabilizing internal forces. Figure 3 shows a biomechanical model of the back during lifting activities. It shows two basic types of internal forces. One is the erector spinae muscles which exert a force posterior to the discs. Another internal force is the abdominal pressure acting in front of the spine. Also considered are lumbar-pelvic postures and anthropometric scaling factors (Chaffin 1987).

Application of this model shows that large forces compress the discs during lifting. Shown in Figure 4 are predicted compressive forces for different lifting postures. This indicates that loads should be lifted close to the body to decrease the bending moment on the spine and consequently the compressive force acting on the discs (Chaffin 1987). This does not necessarily mean in the "squat lift" position, squatting low and lifting the object as you stand, which recently has been taught in industry as a preferred lifting technique. When the object is too large to be placed between the knees, using the squat method results in the moment arm of the force becoming longer and the disk compression forces greatly increasing, as shown in Figure 5 (NIOSH 1981).

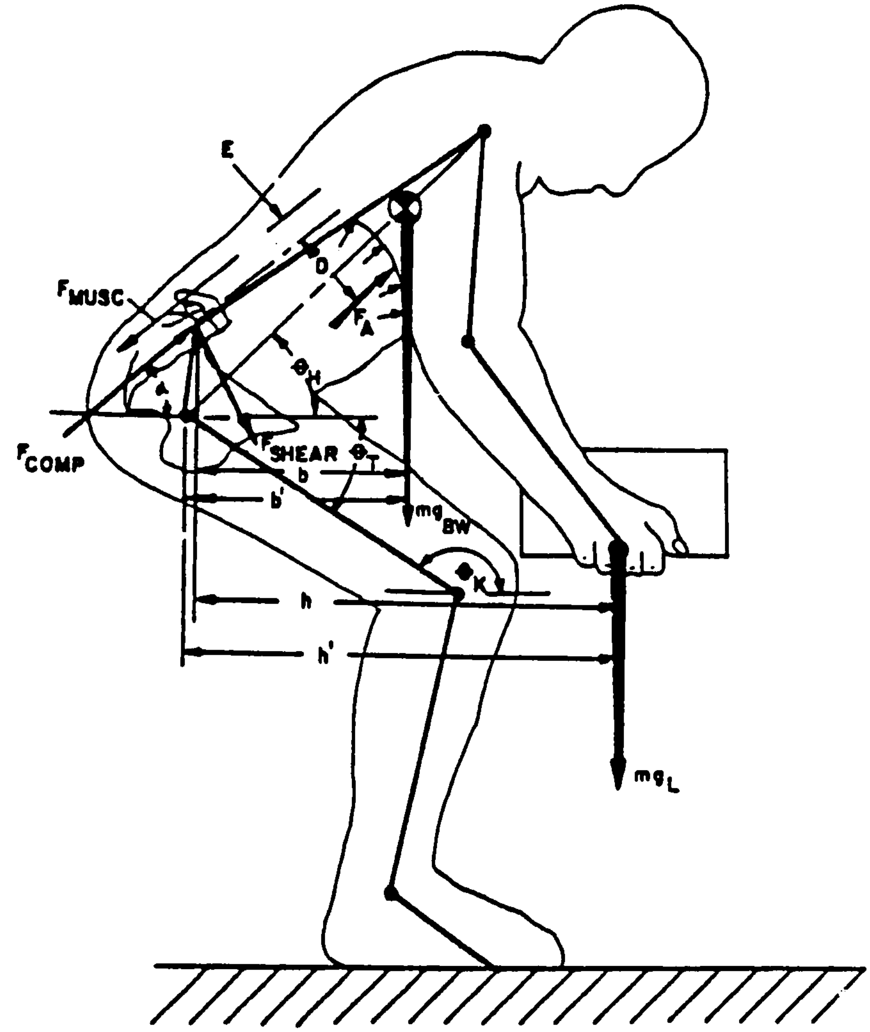


Figure 2 — Simple low-back model of lifting as adapted by Chaffin[19] for static coplanar lifting analyses (adapted from Chaffin and Andersson[1]).

Figure 3. External and Internal Forces on the Trunk While Lifting

Source: Chaffin 1987

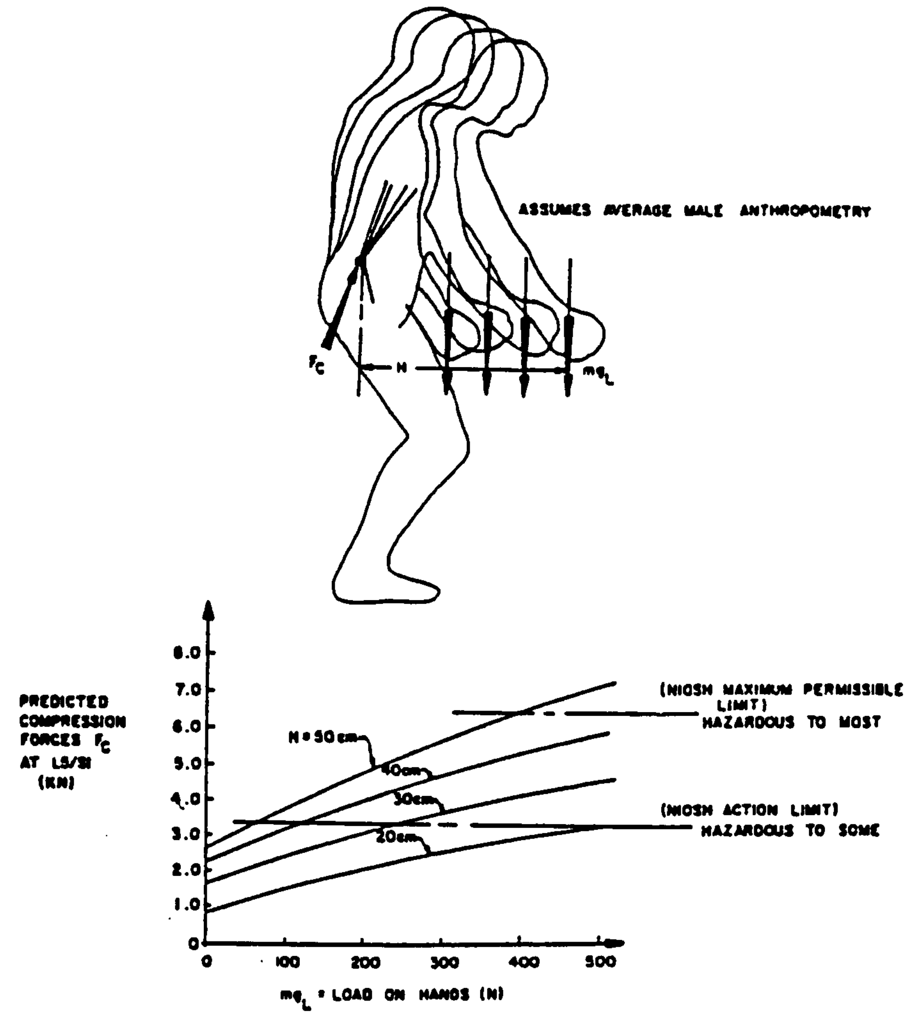


Figure 3 — Predicted L5/S1 disc compression forces for varying loads lifted in four different positions from body (adapted from Chaffin and Andersson[1]).

Figure 4. Disc Compression While Lifting for Various Load Distances From the Body

Source: Chaffin 1987

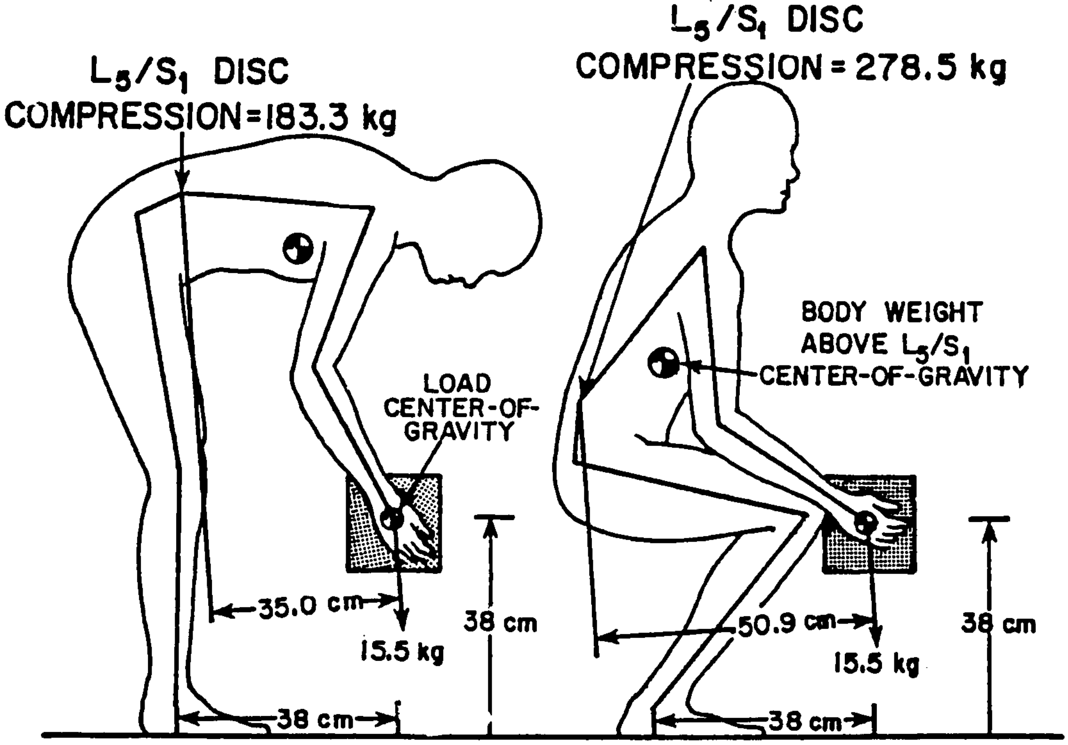


Figure 3.8: Low Back Compression Associated with Two Lifting Postures (Park and Chaffin, 1974).

Figure 5. Disc Compression While Lifting for Different Postures

Source: NIOSH 1981

Several other biomechanical factors should be considered when assessing injury risks of a task. Loads which must be lifted from the floor, especially heavy ones, can greatly increase the risk of back injuries. Loads should be lifted a little below waist high for minimum back stress (NIOSH 1981). Asymmetrical lifting can put unnecessary and harmful stresses on the lower back and also decrease the disc tolerance. Thus, asymmetrical lifting causes an increase in disc loading in positions where discs are weaker, causing a significant increase in risk of back injury (Marras, Sudhakar, and Lavender 1989). Rapid or jerky motions can increase the stresses of a load and increase the risk of injury (NIOSH 1981).

Physiological models. A physiological model attempts to determine the duration and repetition of tasks which an individual can perform without fatigue. There are two types of muscular activity which must be taken into consideration. Dynamic, or isokinetic, activity involves movement of the bones around the joints, such as walking or swimming. Static, or isometric, activity involves no movement of the bones around the joints, such as holding a heavy object. Most tasks are comprised of both types of activity (NIOSH 1981).

Dynamic activity is measured in terms of the oxygen used by the muscles, which has been shown to be linearly related to the work done. Factors which influence the oxygen intake are fitness, sex, age, body build, and the type of activity involved.

An established, relatively severe level of activity can increase an individual's maximum oxygen intake level, or their work capacity. Women have about 60% of men's maximum oxygen intake level, and age causes a decline in this level for both sexes. The higher the muscle content of the body, the higher the maximum oxygen intake level. The larger the mass of muscles used in an activity, the larger the oxygen intake (NIOSH 1981).

To measure isometric exercise, the maximum voluntary contraction (MVC) for the involved muscle group is taken. Then the time a contraction can be held before fatigue occurs is measured for submaximal levels of contraction. For an individual at 100% MVC, endurance time is only about 3-4 seconds. For an individual at 30% of MVC however, endurance time is about 250 seconds (NIOSH 1981).

Psychophysical models. There are many diagnostic techniques available to assess low back pain, such as bone scanning and electromyography. However, even using these sophisticated tests, the structural findings often conflict with the self-reported pain symptoms of the patient. Some believe that dealing with chronic low-back pain can develop a "psychologic overlay" of symptoms which can complicate treatment and therapy. There is a psychophysical pattern of behavior associated with chronic pain which cannot be separated in physical and psychological components (Gatchel, Mayer, Capra, Diamond, and Barnett 1985). This has led to a psychophysical model of identifying worker capabilities. The psychophysical approach considers the relationship between pain felt by a subject and the actual physical stimulus (Garg 1983).

The psychophysical model uses the psychological behavior of the patient to assess the injury and to help evaluate the progress and success of the treatment. According to Gatchel and colleagues (1985):

> The guiding philosophy of this approach is the restoration of physical function accomplished by the repeated noninvasive testing of back function to steer the treatment process toward attaining physical goals rather than simply pursuing changes in self-report of pain. . . . A comprehensive psychologic assessment of each patient is essential to "guide" the patient effectively through . . . treatment regimen, as well as to evaluate the patient's cognitive-psychologic resources that may affect response to treatment.

Psychophysical testing is used for both for static and dynamic testing (NIOSH 1981).

<u>Model for this study</u>. The biomechanical model will be used for this study. It has the model characteristics needed to achieve the objectives of the study. This model can evaluate static or dynamic tasks, and can develop quantitative measures of the movements and the forces generated by the back. The epidemiological model does not give easily quantifiable measures of performance and the physiological

model provides a much narrower range of variables. The psychophysical model is very subjective and has a smaller set of output variables. The rest of the literature review will concentrate on studies using the biomechanical approach.

Back Testing Literature

Range of Motion

Accurate range of motion measurements are a critical part of determining disability and deciding on therapy and rehabilitation (Keely, Mayer, Cox, Gatchel, Smith, and Mooney 1985). They can be used for diagnostic purposes, to assess rehabilitation and the effectiveness of therapy, and to determine readiness for return to work. People with low back pain seem to be limited in the range of motion of the back they can achieve. This may be an attempt to minimize the static loading on the spine (Marras and Wongsam 1986).

Several techniques have been tried for determining spinal range of motion, but many are inadequate or imprecise. These techniques include photography, planer x-rays, flexible rulers, and inclinometers (Keely, Mayer, Cox, Gatchel, Smith, and Mooney 1985).

In a study done by Keely, Mayer, Cox, Gatchel, Smith, and Mooney (1985), a technique for measuring the true lumbar movement, without the component of hip motion, was developed. The technique, designed to have a built-in check system for patient effort, uses two inclinometers to measure range of motion. One was made up of a straight edge base with pendulum indicator suspended in a disk in the middle. The second had a two point contact base with a reinitializable zero point. The range of motions results provide a very important reference point to compare the normals and the patients.

Isometric Strength Testing

Isometric strength testing involves a static simulation of the high stress tasks associated with a task (Stobble, Plummer, and Shreeves 1983). The exertion of a force against a fixed resistance in certain postures is measured (Morris 1985). The performance of the subject is compared to the requirements of the job and those who meet the requirements are considered to be less likely to develop injuries performing that task (Stobble, Plummer, and Shreeves 1983).

There has, in the past, been a risk of injury associated with isometric strength testing. To reduce this risk, it is recommended that the number of separate exertions should be kept to a minimum. If possible, lifts should be limited to one lift in the position(s) most related to the task the worker would be required to do. The probability of misjudging a person's ability must be weighed against the risk of injury during testing. As more exertions are measured, the probability of misclassifying a worker's capabilities lowers while the possibility of injury during testing increases (Zeh, Hansson, Bigos, Spengler, Batti'e, and Wortley 1984).

Isometric strength testing is often used as a tool in screening workers. Workers who do not meet the requirements of a job are three times more likely to incur sprains or strains that workers who met the strength requirements of a job (Morris 1985). A study done by Stobbe and associates (1983) showed isometric strength testing to be repeatable and reliable for human capability assessment.

Criticism of isometric strength testing has been made on several issues. One is that it usually only tests in one plane of movement, while the back usually moves in three planes. A second criticism is that it does not provide for dynamic changes in the placement of the back, loading of the joints, or acceleration/deceleration of the body (Morris 1985). Isometric testing in one study was shown to be insignificant in identifying workers with potential risk for back injury (Batti'e, Bigos, Fisher, Hansson, Jones, and Wortley 1989).

Isokinetic Testing

Isokinetic testing is a dynamic testing which allows forces acting on the body to be measured during a range of movements. This allows factors such as load height, reach distance, and lifting speed to be considered in an analysis (Morris 1985). Being a dynamic test, it includes the stress increase as the body goes through the motions of lifting (Khalil, Waly, Genaidy, and Asfour 1987).

In isokinetic testing, velocity is set at a constant rate and the resistance adjusts to meet the force applied. This yields capability measurements at each point in the lift. This is not an exact simulation of the task usually, because normally velocity changes during a task (Morris 1985).

Recent study has shown that it is possible to quantitatively describe the motion of the back in the three axes of movement during work. The relationship between the parameters of motion and risk of low back injury can be determined. The use of three dimensional measurements could be very significant in minimizing injury risk for a task (Marras, Sudhaker, and Lavender 1989).

Isokinetic measurements are considered reliable and safe, but the cost may not be justified by benefits of testing in some industrial settings. This test usually only measures in the sagittal plane and is not good for evaluation of capabilities for push/pull tasks (Morris 1985).

Velocity Testing

Velocity testing is a type of dynamic testing where the velocity is not held constant. It measures the rate of displacement of the spine. In a study done by Marras and Wongsam (1986), the flexion velocity of patients was shown to be 50% of that of normals. Velocity was shown to have good potential for differentiating between performance conditions of the trunk. This study indicates that velocity testing, combined with range of motion testing, can be used successfully as a tool for discriminating quantitatively between patients and normals.

There was also an indication in Marras and Wongsam's study that flexion and velocity data might be used to quantify measures of impairment. Thus, such testing might be used with a physical capacities evaluation and used to indicate ability to return to work.

Isostation B-200 Testing

Isostation B-200 Validation and Reliability

A study has been done (Parnianpour, Nordin, Cartas, and Kahanovitz 1987) to establish the validity and reliability of the Isostation B-200. The system was loaded with calibrated weights and the R-square value for regression analysis between the actual load and what was measured by the Isostation B-200 was calculated. The R-square value indicates the percent of variability accounted for by the model. Also calculated were the R-square values for the regression analysis of actual manually measured angles and angles measured by the machine.

Equations were produced using the regression analysis results to predict torque and angle. These equations proved to have strong predictability. The R-square coefficient had values between .985 and 1.000 giving a p value of less than .001, showing a high validity for isometric and range of motion measurements.

Correlation coefficients were calculated using the results of three separate trials. Correlation coefficients indicate the strength of the linear relationship between variables, going from a low of zero to a high of one or negative one. This yielded values from .88 to .97, using Pearson correlations. These high correlations demonstrate that there is a good reliability for measures of isometric strength and range of motion using the Isostation B-200. Similar testing on reliability by Seeds, Levene, Goldberg, and Shirke (1987) have also yielded favorable results.

Effect of Fatigue on Motor Output and Movement

A study by Parnianpour, Nordin, Kahanovitz, and Frankel (1988) using the Isostation B-200 won the prestigious Volvo Award in Biomechanics for 1988. The study had two goals: 1) The quantification of functional overlap of the muscles of the trunk; and 2) study the effects of isodynamic fatigue occurring in the flexion and extension on movements of the trunk and motor output.

The torque, angular position, and the velocity were measured for each axis of movement of the back. Trunk flexion/extension movement was in the sagittal plane. Subjects were instructed to move quickly and accurately until they were exhausted.

The study indicated that average torque can decrease by 4% from beginning of testing until the end of the testing (twenty repetitions) in the sagittal plane. Maximum torques were far greater in the sagittal plane than in the transverse or coronal planes. Significant differences due to the fatiguing were only found in the sagittal plane.

Range of motion changed significantly in all three planes due to fatigue. Range of motion was found to decrease 10% from a start of 67 degrees during the course of the testing in the sagittal plane. Range of motion in the coronal and transverse planes increased 200%.

The maximum velocity in the sagittal plane decreased 21% in the last three cycles of the test. The maximum velocity in the transverse plane decreased 27%, and decreased 50% in the coronal plane. The changes were significant ($p<.01$) in the sagittal and coronal planes.

Database of Trunk Strength in Normal Males

Parnianpour, Li, Nordin, and Kahanovitz (1988) set up database of isoinertial trunk strength using the Isostation B-200. They used three resistance levels in the sagittal, coronal, and transverse planes. These levels were set equal to 30%, 50%, and 70% of the maximal strength for each plane.

The maximum voluntary contraction used was 160 Newton-meters (Nm) in the sagittal plane, 126 Nm in the coronal plane, and 107 Nm in the transverse plane. The results of torque, velocity, and range of motion testing are shown in Figures 6-8. The measures in the sagittal plane are superior

Table 1. Maximum Torque Measured Against Resistances Equal to 30%, 50%, and 70% of MVC in the Sagittal, Coronal, and Transverse Planes

	Maximum torque (Nm)		
Resistance level (% of MVC)	*Sagittal plane*	*Coronal plane*	*Transverse plane*
30	83 (20)	61 (19)	45 (32)
50	121 (27)	87 (20)	106 (46)
70	148 (29)	102 (14)	135 (45)

MVC = maximum voluntary contraction.

Figure 6. Maximum Torque Measured Against Various Percentages of MVC for All Three Planes

Source: Parnainpour, Li, Nordin, and Kahanovitz 1988

Table 2. Maximum Velocity Measured Against Resistances Equal to 30%, 50%, and 70% of MVC in the Sagittal, Coronal, and Transverse Planes

	Maximum velocity (°/sec)		
Resistance level (% of MVC)	*Sagittal plane*	*Coronal plane*	*Transverse plane*
30	130 (28)	94 (44)	101 (20)
50	117 (23)	90 (54)	85 (12)
70	103 (23)	86 (53)	64 (24)

MVC = maximum voluntary contraction.

Figure 7. Maximum Velocity Measured Against Various Percentages of MVC for All Three Planes

Source: Parnainpour, Li, Nordin, and Kahanovitz 1988

Table 3. Range of Motion Measured Against Resistances Equal to 30%, 50%, and 70% of MVC in the Sagittal, Coronal, and Transverse Planes

	Range of motion (degrees)		
Resistance level (% of MVC)	*Sagittal plane*	*Coronal plane*	*Transverse plane*
30	88 (12)	62 (13)	81 (8)
50	87 (13)	53 (12)	77 (12)
70	74 (12)	57 (15)	61 (19)

MVC = maximum voluntary contraction.

Figure 8. Maximum Range of Motion Measured Against Various Percentages of MVC for All Three Planes

Source: Parnainpour, Li, Nordin, and Kahanovitz 1988

to those in the coronal and transverse for torque, velocity, and range of motion.

The resistance level selected has significance when used in the clinical setting. The advantage of using a level of resistance that is relative to a person's capabilities is that differences in individuals can be determined with not only velocity and power, but also that of torque. A second advantage is that the base measure is not based on the performance of a population, but adjusts for each person, so the database averages can be compared more accurately with an individuals abilities. Because of the great differences which exist among the working population, employment decisions resulting from a test based on population averages is less defendable in a court than one based on a test which will allow for individual differences.

Using the B-200 for Assessment of Disabilities

According to Berryhill (1988) the Isostation B-200 can be used to overcome a serious drawback in preparing a disability report for a functional capacities evaluation. Reports of this nature should include information such as the degree of impairment and the safe return to work level. This can be difficult because a doctor cannot rely solely on medical information to assess an individual's ability to meet certain task demands.

The functional capacity evaluation uses standardized, non-medical procedures for rehabilitation or injury evaluation. Evaluations of this type attempt to predict a person's ability to perform a task, based upon medical, psychological, and physical findings.

The problem with developing a valid functional capacities report is the fact that much of the decisions are based on the subjective responses of the patient that is involved. It is very difficult to determine how much of what a patient is reporting is factual and how much is not. The therapist must also make subjective decisions regarding the effort of the patient. Most current methods of functional capacities evaluation focus on maximum voluntary effort to determine if there is consistency between the self-reported abilities and actual abilities of a patient.

The usefulness of the Isostation B-200 lies in its computerized testing. The results collected from a patient's test can be statistically evaluated for consistency. Testing of variations and statistical significance can be made and all data stored to compare with future tests.

Testing done by Berryhill yielded variation statistics which can be useful for comparisons. The coefficient of variation (CV), the division of the standard deviation by the mean, was calculated for several measures. These statistics have been already been used by several researchers, such as Don Chaffin, in the field of back injuries.

Testing was done statically for range of motion and isometric testing. The CV for range of motion was calculated for all three planes of the back. They are 0.1, 2.7, and 2.4% for the sagittal (flexion-extension test), coronal (lateral flexion), and the transverse (rotational) respectively. The CV for isometric extension strength is 6.6%. These figures are for normal males 18-45 years of age. Dynamic testing was done for velocity and torque. For velocity, the CV is the highest of his tests with 13.3%. The CV for extension torque is 1.7%.

These results can be incorporated into a disability assessment to use objectively to determine maximum voluntary effort using consistency as a guideline. They can also be used for research as a general database of comparison for males without current history of pain.

Isometric Trunk Flexion Measurements

In a study done by McIntyre (1989), the Isostation B-200 was used to explore the stability of isometric trunk measurements. The study explored the effect of number of repetitions and time intervals on stability, and the reliability of the variables measured. The subjects for this study were ten males, ages 21-46, who had no history of back pain for at least one year.

The study also recommended a five second time interval for both types of measures. The following conclusions of this study are based on measures taken over a five second interval. The first second of a five second test should not be used alone. Instead, the latter part of the test or the whole of the test should be used for measurements.

The study shows that the maximum torque measure proved more stable than the average torque for all the intervals and repetitions considered. In addition, it is suggested by the results of this study that using maximum torque rather than average torque measures reduces the number of tests which must be performed, thereby reducing the time and cost of the tests. This is due to the results which indicate only one repetition is needed if the maximum torque measure is used, whereas for average torque, more than one repetition is needed, and the results from the first repetition should be disregarded.

Summary of Literature Review

Most back problems are caused by sprained muscles, osteoarthritis, and disc problems. As stated in chapter 1, MMH tasks are the primary cause of back injury in industry. There are four major models for evaluating MMH tasks, epidemiological, biomechanical, physiological, and psychophysical (Sherrington and Noback 1961; NIOSH 1981).

An epidemiological model identifies people at risk for injury based on the tasks they perform, the loads they are required to move, and personal risk factors. Persons doing heavy lifting work or long, sustained amounts of lifting are more likely to develop back injury. The load itself can contribute to back injury if it is heavy, awkward to lift, or must be frequently lifted. Males have more lifting ability than females, heavier people are stronger than lighter people, but more subject to fatigue, and taller people tend to have more back pain than shorter people (NIOSH 1981; Chaffin 1987).

A biomechanical model determines the stresses placed on the body during tasks. Movements of the back are centered around the L_5/S_1 area of the back. Large forces compress the discs in the back during lifting which are counteracted by internal forces. Loads should be lifted close to the body, ideally from a height just below waist level of the worker. Loads should be lifted symmetrically if possible (NIOSH 1981; Freivalds, Chaffin, Garg, and Lee 1982; Chaffin 1987).

The physiological model determines the physical capabilities of an individual, the work that can be safely performed without fatigue. Most tasks are comprised of two types of activity, static and dynamic. A person's static capability is measured by the percent of the MVC of the individual used, while dynamic ability is measured by the oxygen intake of the person (NIOSH 1981).

A psychophysical model uses the psychological behavior of the person to determine physical capabilities. This model is used mostly for persons who have been injured, to assess the extent of the injury and the success of treatment. It is used to try to decrease the dependence on the subjective responses from the patient which are often used (Gatchel, Mayer, Capra, Diamond, and Barnett 1985; NIOSH 1981).

Of the types of models available for simulating back movement, the biomechanical model was best suited for this purposes of this study. It yields objective, quantitative measures for evaluating the performance of the back.

There are several types of tests for measuring back performance that have been studied. These include range of motion, isometric, isokinetic, velocity and psychophysical.

Range of motion testing are used for diagnostic and rehabilitative purposes. Persons with low back injuries have a limited range of motion, which may be an attempt by the body to minimize loading on the spine (Marras and Wongsam 1986).

Isometric testing is statically simulating the stresses associated with a task. Subjects exert a force against a fixed resistance, and their effort is compared to the requirements of the job. When administering strength testing, repetitions should be minimized to decrease the risk of injury during testing. A drawback of isometric testing is that generally it is performed only in one plane of movement and it cannot realistically simulate most tasks since no movement is involved (Stobble, Plummer, and Shreeves 1983; Zeh, Hansson, Bigos, Spengler, Batti'e, and Wortley 1984).

Isokinetic testing measures the forces acting on the body during movement. Velocity is constant and the resistance adjusts to meet applied forces. Isokinetic measurements in three dimensions has been successfully taken and a relationship between the parameters of measurement and risk of injury has been established (Morris 1985; Marras, Sudhaker, and Lavender 1989).

Velocity testing involves measuring the rate of displacement of the back. A significant difference in flexion velocity between injured persons and persons with no injuries has been shown. Velocity testing has been successfully incorporated with other types of testing, such as range of motion, as a tool for identifying persons with other types of testing such as (Marras and Wongsam 1986)

The Isostation B-200 has been used by several researchers for measuring back performance. The validity and reliability of the B-200 was established by Parnianpour et. al. (1987) for isometric and range of motion measures. Regression analysis using measures taken by the B-200 was shown to have strong predictive ability for torque and angle.

A study was done of the effects of fatigue using the Isostation B-200. The results showed that the average torque in the sagittal plane decreases due to fatigue (there is no significant difference in the transverse and coronal planes, in which the torques were much smaller than in the sagittal plane). Range of motion decreased 10% in the sagittal plane due to fatigue, but increased 200% in the transverse and coronal planes. The maximum velocity decreased significantly due to fatigue in the sagittal and coronal planes (Parnianpour, Nordin, Kahanovitz, and Frankel 1988).

A database for normal males was established by Parnianpour, Li, Nordin, and Kahanovitz (1988). Resistance levels were used which were in various percentages of the subjects MVC. The torque, velocity, and range of motion were measured for each subject.

A normal male database was also developed and used by Berryhill (1988) for use in clinical assessment. Range of motion, isometric, velocity, and torque measures were taken. Berryhill suggests that these results should be used as a comparison and incorporated into a disability evaluation.

The Isostation B-200 has also been used to test the stability of isometric trunk measurements. Maximum torque measures are more stable than average torque measures. It was suggested that tests be taken over a five second interval, disregarding the first second.

The objective of this study is develop back performance measures using the information from the Isostation B-200 back testing machine: position, torque, velocity, impulse, work, and power in the three axes of movement of the back. This will include a range of motion test, an isometric test in three planes and dynamic tests in three planes. Once these measures are developed, they will be used to develop a model to identify persons with the back pathology of an injured back, which would suggest either an actual injury or a potential for injury. This model could be used as a pre-employment screening tool and a performance monitoring tool. The literature available suggests that the objectives of this study have not been researched as proposed here.

CHAPTER 3

METHODOLOGY

Data Collection

Population Demographics

There were forty-two men in the normal population. The ages of the men were between 24-45 years of age, with an average of 32. The average height of the normal men was 70 inches, with a range of 60-76 inches. The weight varied from 120-280 pounds, with an average of 185 pounds.

There were thirty-three women in the normal group. The ages for the women were also 24-45 years, with 32 as the average. The heights of the normal women ranged from 59-69 inches, averaging 65. The average weight was 145 pounds, with a range of 107-240 pounds.

Male patients comprised the largest sub-group with ninety subjects. The ages ranged from 18-59 years old, with an average of 40 years. The average height of this group was 71 inches, ranging from 60-76 inches. The range of the weights was 126-323 pounds, averaging 191 pounds.

The number of female patients in the study was thirty-two. The ages had a range of 31 years, going from 22-53 years, with an average of 38 years. The average height of the female patients was 65 inches, varying from 60-70 inches. The weights of the female patients went from 93-250 pounds, averaging 149 pounds.

The demographic data is summarized in Table 2. The patient group has a broader range of values for all three variables. The average for patients and normals is similar for height and weight, but the patients are older on the average.

Equipment

The data was collected using the Isostation B-200, created by Isotechnologies, Incorporated. The B-200 is designed to allow simultaneous movement along the three axes of the back. It makes use of an electric elevator to adjust for varying heights and the physical restraints are adjustable for different girths. This allows the intersection of the three axes to be set for the size of each individual. This intersection is set at the L_1/S_5 area of the spine. The restraints allow the subject to be standing or seated during testing. Isometric locks can be used to restrict movement for isometric testing.

The B-200 is connected to an IBM compatible personal computer. Measurements of velocity, angular position, and torque can be collected in each plane. Resistances are set using a dynamometer which produces a torque against which the subject must move. These resistances can be set manually or from the computer. The resistances for the tests (see below)

Table 2. Demographic Data for Subjects in Study

	NORMAL MALES	NORMAL FEMALES	PATIENT MALES	PATIENT FEMALES
N	42	33	90	32
AGE AVERAGE (YEARS)	24-45 32	24-45 32	18-59 40	22-53 38
HEIGHT AVERAGE (INCHES)	64-76 70	59-69 65	60-76 71	60-70 65
WEIGHT AVERAGE (POUNDS)	120-280 185	107-240 145	126-323 191	93-250 149

were set as shown in Table 3. The measurements are then stored on the computer, either in the hard drive or on a floppy disk. This allows for later retrieval of tests for review or comparison.

Types of Tests

There were three types of tests which were performed on both normals and patients. These include range of motion, isometric, and isokinetic tests. These are broken down into five separate tests for ease of explanation. These are range of motion, isometric, rotational, flexion/extension, and lateral flexion.

The tests are measured in the three planes of movement of the back, the sagittal, frontal, and coronal. These planes are shown in relationship to the human body in Figure 9. Rotating refers to movement created by twisting at the waist (movement in the transverse plane). This is shown in Figure 10a. Flexion/extension is bending from the waist (movement in the sagittal plane), as shown in Figures 10b. Lateral flexion is bending side to side from the waist as seen in Figure 10c (movement in the coronal plane).

The range of motion test allows the subject virtually unrestrained movement in all directions and the subject is asked to move as far as possible in each plane. The range of motion measures the displacement of the back from the upright position. This is done in all three planes of back movement.

Table 3. Resistances by Type of Test (ft-lbs)

	PLANE		
TEST	ROTATIONAL	FLEXION/ EXTENSION	LATERAL FLEXTION
RANGE OF MOTION	1	1	1
ISOMETRIC	63	118	63
ROTATIONAL	20	118	63
FLEXION/ EXTENSION	63	30	63
LATERAL FLEXION	63	118	30

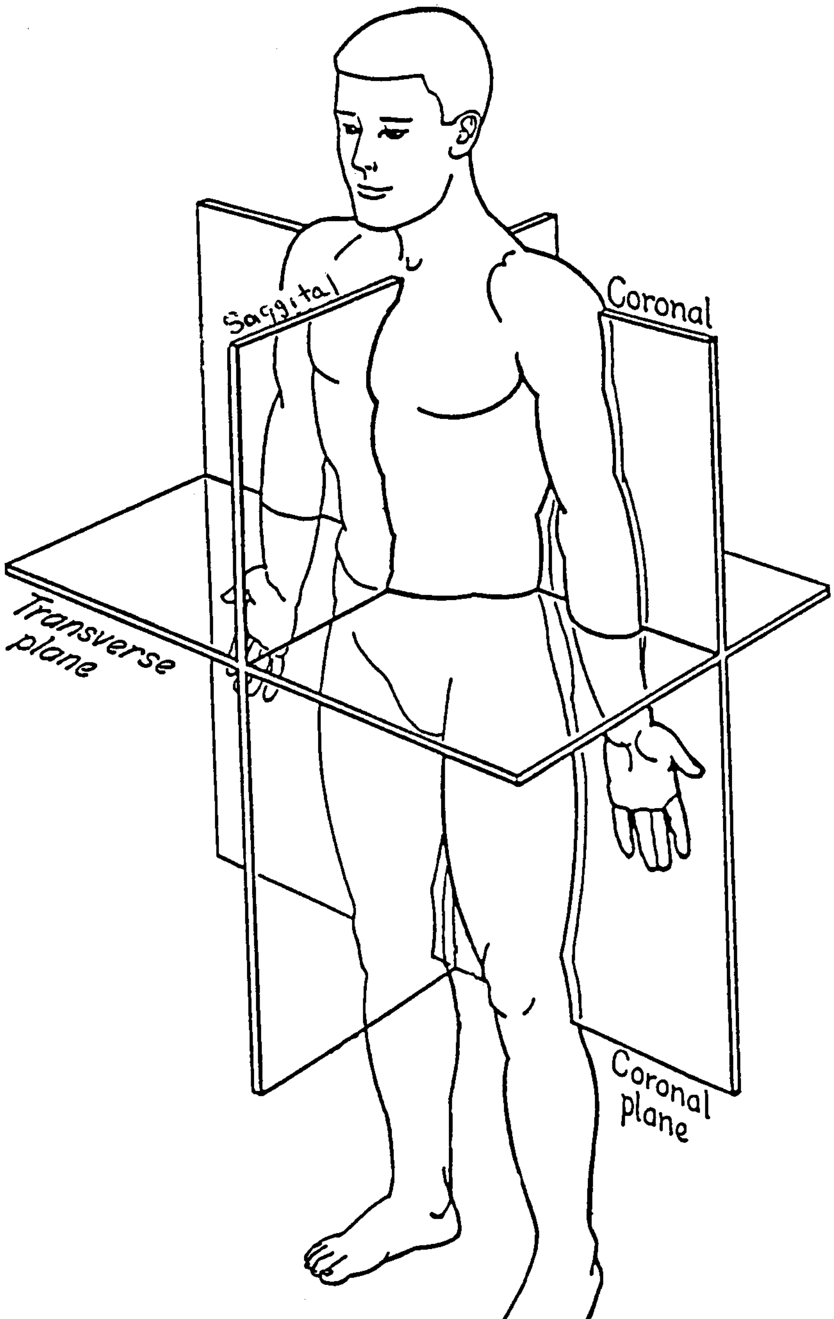


Figure 9. Three Planes of Movement of the Back

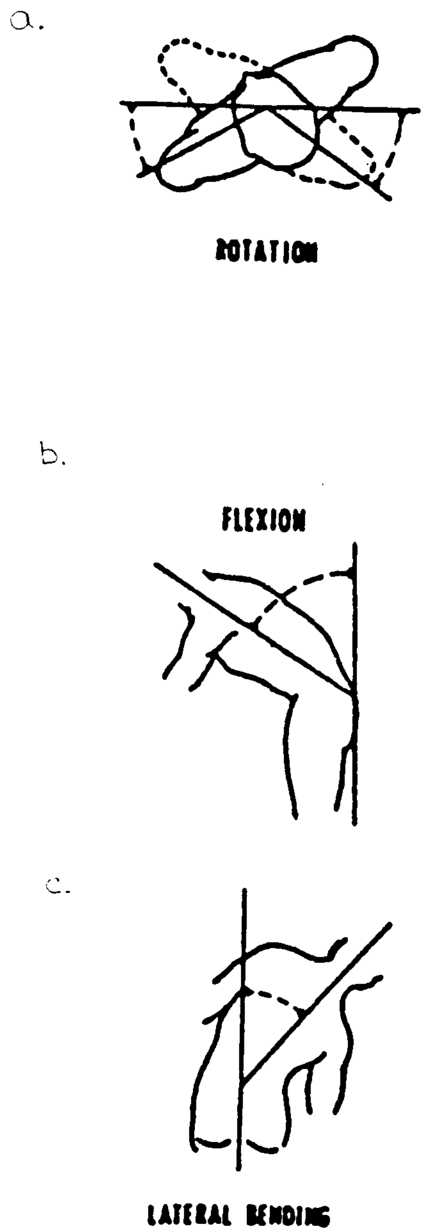


Figure 10. Types of Bending or Twisting Involved in Study

Isometric testing measures the static strength of an individual. Locks are used to prevent movement of the machine in all three planes. These locks are set at a certain resistances and the subject attempts to move against the resistance. The forces produced by the subject are measured. The three of interest for this study are maximum and average torque, and impulse.

In the rotational, flexion/extension, and lateral flexion tests, the subject is asked to move rapidly as far as possible back and forth in the test plane, transverse, sagittal, and frontal respectively. The efforts of the subject in the plane of study are recorded, maximum and average torque, impulse, maximum and average velocity, work, and power. The maximum torques produced in the secondary planes are also recorded.

Seventy-four of the normal subjects have all five tests, and one subject is missing two tests. Fifty of the patient subjects have all five tests, while seventy-two are missing one or more of the tests. This leaves a minimum number of observations of 124 for any variable, including both males and females.

Measurements

The angular position, torque, and velocity measurements are used by the B-200 software to compute other performance measures. All measures computed are derived from the basic units of time, mass, and length. The units used are seconds, pound, and feet, respectively, for this study.

Using the angular displacement measurements, the movement from an initial zero position to the extreme point of movement (position endpoint) is recorded. From this, the range of motion is calculated. The units for angular displacement are degrees. See Figure 11 for a diagram of lateral flexion range of motion.

The torque values recorded by the B-200 measure the turning effect produced by a force. This turning effect is affected by both the force and its distance from the axis of rotation, as shown in Figure 12. This causes torque to be a vector, thus having both magnitude and direction. Positive torque is denoted for flexion, right lateral flexion, and right rotation. Torque is measured in pound-feet. Both the average torque and the maximum torque can be calculated.

The rate of change of the angular position is measured as the angular velocity. This measurement is also a vector. The magnitude is the speed of travel. The positive direction indicates flexion, right rotation, and lateral bending to the right. Measurements are given in degree per second. The maximum and average velocity are calculated.

The angular impulse is found by measuring the area under the torque versus time curve. It is the product of the torques and the length of time effort is sustained. Angular impulse is a vector, with magnitude and direction. In the

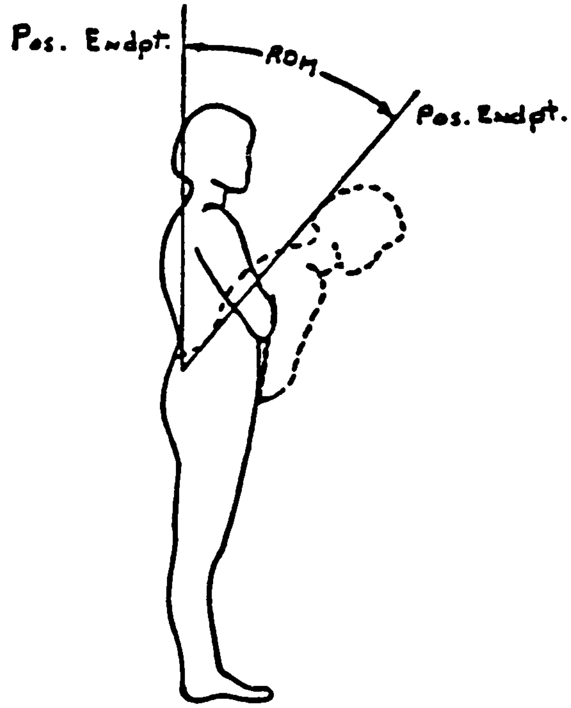


Figure 11. Range of Motion Measurement

Source: Isostation B-200 User's Manual

Figure 2-3. Torque

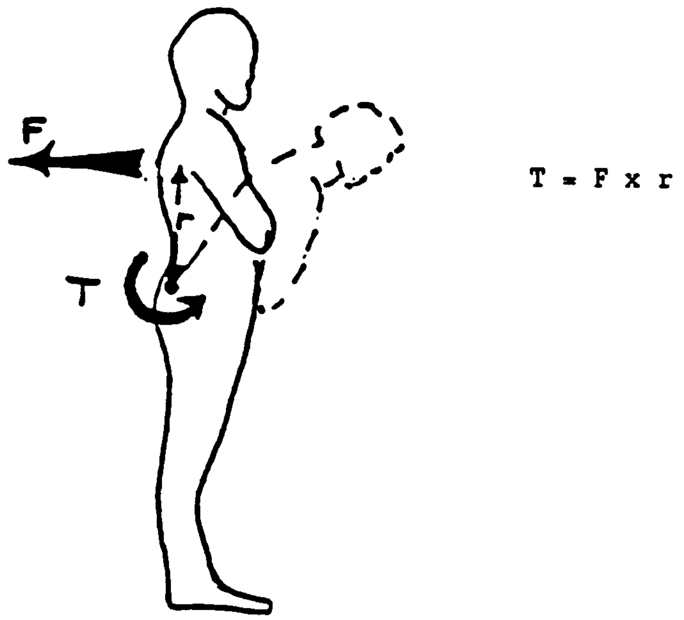


Figure 12. Torque Generation

Source: Isostation B-200 User's Manual

B-200 software, a positive sign signifies impluse in flexion, right lateral flexion, and right rotation. The units used in this study are pounds force feet seconds (lbs-ft. sec.).

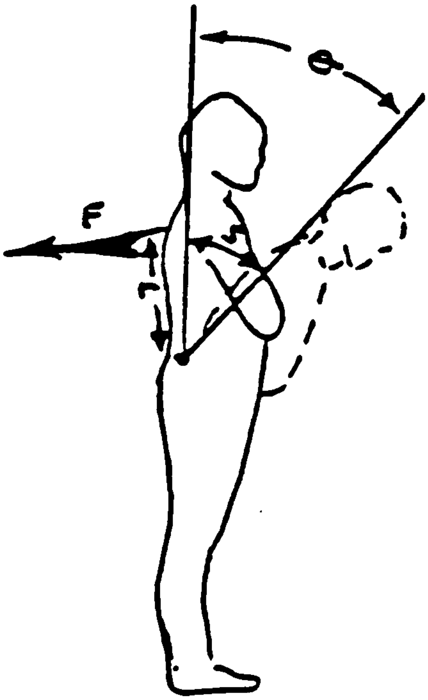
Also calculated is the work done. Work is the product of the magnitude of the force acting on the body and the distance the body moves in the direction of the force. The sign of the work indicates work done during flexion or extension, for positive and negative respectively. The units of work used for this study are foot pounds force (ft-lbs). Figure 13 shows the relationships used to calculate power and work.

The power exerted by the subject is can be calculated with the B-200. The power is the rate of work (see Figure 13). It is produced by the angular velocity and the average torque, with units of foot-pounds per second (ft-lbs/sec.). Positive power indicates power produced in flexion, right lateral flexion, and right rotation.

A total of ninety variables were obtained with these five tests. The range of motion test yielded 6 variables. The isometric test yielded thirty variables. The rotational, flexion/extension, and the lateral flexion tests yielded eighteen variables each. These variables are shown by test with the variable names used in the analysis in Figure 14. The variables will be referred to by the abbreviated form for the rest of the study.

Figure 2-6. Work and Power

F = force
r = radius
T = torque
θ = angular displacement
t = time



$$T = F \times r \qquad (1)$$

$$\therefore F = \frac{T}{r}$$

$$S = \theta_{rad} \times r \qquad (2)$$

$$Work = F \times s$$

$$= \frac{T}{r} \times \theta_{rad} \times r \qquad (1)(2)$$

$$\therefore Work = T \times \theta_{rad} \qquad (3)$$

$$Power = \frac{Work}{t} \qquad (4)$$

$$= T \times \frac{\theta rad}{t} \qquad (5)$$

$$\omega = \frac{\theta rad}{t} \qquad (6)$$

$$\therefore Power = T \times \omega \qquad (5)\ (6)$$

Figure 13. Relationship of Work and Power to Torque and Angular Displacement

Source: Isostation B-200 User's Manual

RANGE OF MOTION TEST	
RM_LR	ROM - LEFT ROTATION
RM_RR	ROM - RIGHT ROTATION
RM_F	ROM - FLEXION
RM_E	ROM - EXTENSION
RM_LLF	ROM - LEFT LATERAL FLEXION
RM_RFL	ROM - RIGHT LATERAL FLEXION
ABBREVIATIONS	
ROT	ROTATIONAL PLANE
F/E	FLEXION/EXTENSTION PLANE
LF	LATERAL FLEXION PLANE
POS	POSITIVE
NEG	NEGATIVE
ISOMETRIC TEST - ROTATION	
IR_MT_P (IR_MT_N)	ROT MAXIMUM TORQUE POS (NEG)
IR_AT_P (IR_MT_N)	ROT AVERAGE TORQUE POS (NEG)
IR_I_P (IR_I_N)	ROT IMPULSE POS (NEG)
IR_FMT_P (IR_FMT_N)	F/E MAX TORQUE POS (NEG)
IR_LMT_P (IR_LMT_N)	LF MAX TORQUE POS (NEG)
ISOMETRIC TEST - FLEXION/EXTENSION	
IF_MT_P (IF_MT_N)	F/E MAXIMUM TORQUE POS (NEG)
IF_AT_P (IF_AT_N)	F/E AVERAGE TORQUE POS (NEG)
IF_I_P (IF_I_N)	F/E IMPULSE POS (NEG)
IF_RMT_P (IF_RMT_N)	ROT MAXIMUM TORQUE POS (NEG)
IF_LMT_P (IF_LMT_N)	LF MAXIMUM TORQUE POS (NEG)
ISOMETRIC LATERAL FLEXION TEST	
IL_MT_P (IL_MT_N)	LF MAXIMUM TORQUE POS (NEG)
IL_AT_P (IL_AT_N)	LF AVERAGE TORQUE POS (NEG)
IL_I_P (IL_I_N)	LF IMPULSE POS (NEG)
IL_RMT_P (IL_RMT_N)	ROT MAXIMUM TORQUE POS (NEG)
IL_FMT_P (IL_FMT_N)	F/E MAXIMUM TORQUE POS (NEG)
ROTATIONAL TEST	
RR_MT_P (RR_MT_N)	ROT MAXIMUM TORQUE POS (NEG)
RR_AT_P (RR_AT_N)	ROT AVERAGE TORQUE POS (NEG)
RR_I_P (RR_I_N)	ROT IMPULSE POS (NEGATTIVE)
RR_MV_P (RR_MV_N)	ROT MAXIMUM VELOCITY POS (NEG)
RR_AV_P (RR_AV_N)	ROT AVERAGE VELOCITY POS (NEG)
RR_W_P (RR_W_N)	ROT WORK POS (NEG)
RR_P_P (RR_P_P)	ROT POWER POS (NEG)
RF_MT_P (RF_MT_N)	F/E MAXIMUM TORQUE POS (NEG)
RL_MT_P (RL_MT_N)	LF MAXIMUM TORQUE POS (NEG)
FLEXION/EXTENSION TEST	
FR_MT_P (FR_MT_N)	ROT MAXIMUM TORQUE POS (NEG)
FF_MT_p (FF_MT_N)	F/E MAXIMUM TORQUE POS (NEG)
FF_AT_P (FF_AT_N)	F/E AVERAGE TORQUE POS (NEG)
FF_I_P (FF_I_N)	F/E IMPULSE POS (NEGATTIVE)
FF_MV_P (FF_MV_N)	F/E MAXIMUM VELOCITY POS (NEG)
FF_AV_P (FF_AV_N)	F/E AVERAGE VELOCITY POS (NEG)
FF_W_P (FF_W_N)	F/E WORK POS (NEG)
FF_P_P (FF_P_P)	F/E POWER POS (NEG)
FL_MT_P (FL_MT_N)	LF MAXIMUM TORQUE POS (NEG)
LATERAL FLEXION TEST	
LR_MT_P (LR_MT_N)	ROT MAXIMUM TORQUE POS (NEG)
LF_MT_P (LF_MT_N)	F/E MAXIMUM TORQUE POS (NEG)
LL_MT_p (LL_MT_N)	LF MAXIMUM TORQUE POS (NEG)
LL_AT_P (LL_AT_N)	LF AVERAGE TORQUE POS (NEG)
LL_I_P (LL_I_N)	LF IMPULSE POS (NEGATTIVE)
LL_MV_P (LL_MV_N)	LF MAXIMUM VELOCITY POS (NEG)
LL_AV_P (LL_AV_N)	LF AVERAGE VELOCITY POS (NEG)
LL_W_P (LL_W_N)	LF WORK POS (NEG)
LL_P_P (LL_P_P)	LF POWER POS (NEG)

Figure 14. Variables Used in Study

Origin of Collection

The data used in this study was received from two different sources. The normal study group was received from Isotechnologies, Incorporated. The patient study group was received from the Industrial Disability Management Center (IDMC).

Isotechnologies received information on normal subjects from several test centers around the nation. These test centers were trying to establish a database of information for the measures available with the new Isostation B-200. The seventy-five normal files were consolidated and sent by Isotechnologies.

Baron Johnson P.T., a licensed physical therapist at IDMC, and a test researcher for the Isostation B-200, collected the patient data used for this study. Patients were physician-referred to Mr. Johnson for diagnosis, therapy, and rehabilitation. Isostation B-200 tests were taken at several stages in the course of rehabilitation for most patients. However, only the one closest to the injury date was used for this study.

Format of Data

The data collected by the researchers was received on floppy disks, both 3 1/2 inch and 5 1/4 inch disks. The data was retrieved from the disks using the B-200 software program on an IBM Personal System 2 (PS2) computer. For each test, a graph giving the pertinent data was retrieved and data taken directly from the graph by hand. This data was then put into a Lotus 1-2-3 spreadsheet. For analysis using the Statistical Analysis System (SAS), the data was sent unformatted to a Lotus *.prn file, which is created as an ASCII file. This was sent directly to the UTK Vax system using Procomm. For the Classification and Regression Trees (CART) analysis, the SAS file was sent to the CART program.

Analysis of Data

Overview of Analysis

First, the sample size and variable number was considered. Then descriptive analysis were run, namely univariate normal tests. Next, inferential analysis was run with t-test and the Wilkerson non-parametric tests. A factor analysis was then run using principle components analysis with iterations. The variables isolated from this were evaluated with a discriminant analysis and also with a Classification and Regression Trees (CART) analysis. A graphical overview of this is presented in Figure 15.

Sample Size and Variable Number

The data was first evaluated in terms of sample size and number of variables. The sample size for the males was 132 and the sample size for the females was 65. There were 90 initial variables. It was decided to limit the study to males

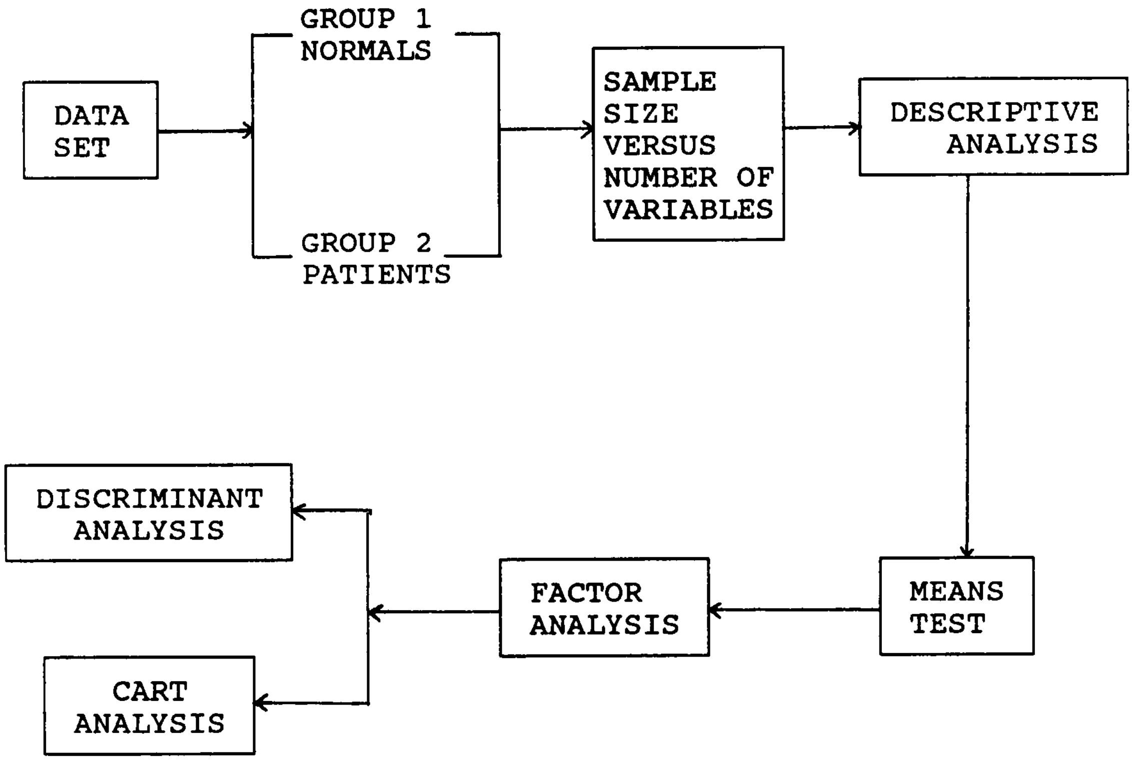


Figure 15. Overview of Analysis

only because the female sample was smaller than the number of variables which would greatly restrict the types of analysis available.

Descriptive Analysis

The next step of the analysis was to perform normality tests on the data using SAS. This procedure involves the Shapiro-Wilkes Test for data with a sample size of 50 or less, which encompasses the variables for the normal population. The Kolomogorov D statistic is used for sample sizes of 51 or greater, which includes the entire patient set of variables.

Inferential Analysis

Testing was performed on the means of the variables to determine if a difference existed between the values of the variables for the patients and the values of the variables for the normals. T-tests and non-parametric tests were run on the data. This step was used to eliminate several variables on the basis of lack of discriminatory ability.

Because the sample variance was unknown, the t-test was used on the normally distributed data. The statistic t is derived as follows:

$$t = \frac{(\bar{x}_1 - \bar{x}_2)}{\sqrt{(s^2/n_1 + s^2/n_2)}}$$

$\bar{X}$ denotes the sample mean, s is the sample standard deviation, and n is the number of observations with the subscripts denoting the sample group, with 1 being normals and 2 being observations. The null hypothesis for this test was $H_n = H_p$, the mean value of the variable is the same for both normal and patient groups. The test statistic is compared to the critical value for the t distribution using the degrees of freedom and the level of significance, which is .05 for this study. If the test statistic is greater than the absolute value of the critical value, then the null hypothesis is rejected. The data is assumed to be normally distributed for the t test (McCuen 1985).

Because normality could not be definitely proven for some variables, the Wilcoxen Matched-Pairs Signed Ranks test was also used on the variables. The Wilcoxen test also tested for differences of central tendency between the normal group and the patient group. The null hypothesis for this test was also $H_n = H_p$. The positive and negative differences between the values of the two groups are summed and the lesser of the absolute value of these amounts is taken as the test statistic T. The significance level was chosen as .05. This value is compared to the Wilcoxen critical value using the sample size and the level of significance as parameters. The null hypothesis is rejected if the critical value is greater than the test statistic (McCuen 1985).

Factor Analysis

Factor analysis was used to reduce the number of variables in the study. Factor analysis is a set of procedures which determine a set of derived variables, or factors, which represent the data. In a large data set, often many variables are measuring similar things. A group of like variables is found and called a factor, with each variable having a calculated weight in the factor. Thus, by taking the variables with the most weight in a factor, the amount of replicated information is decreased. The nine initial variables have been reduced into three factors, which can then be used for further analysis, such as regression or discriminant (Kachigan 1982).

There are three key steps in a factor analysis. First, a set of variables are measured for a set of subjects. An object by variable matrix is formed. The second step is the formation of a correlation matrix. The correlation matrix shows the correlation coefficients for pairings of all the variables. The correlation coefficient measures the relationship between two variables, or the amount of redundant information they contain. The last step is a determining a factor matrix. The factor matrix contains the loadings of each variable for each factor.

The type of factor analysis used for this study was a principle components analysis with iterations. This produces factors which explain the maximum possible amount of the variation. The first factor the analysis produces will account for all the variables that cause the highest squared correlations between the variables and the factor. Then the next factor is extracted using the same methods on the variables which are uncorrelated with the first factor. This continues until most of the variance has been explained by the produced factors. Iterating involves putting communality estimates in the diagonal of the correlation matrix (Gorsuch 1983).

Varimax rotation was used in the factor analysis. This redefines the factors extracted to more evenly distribute the loadings of the variables (Kachigan 1982). This maximizes the variance of the squared loadings across a particular factor (Gorsuch 1983).

Discriminant Analysis

Discriminant analysis was used to identify a grouping function to classify persons using the variables isolated with factor analysis. This yields a function which can be used to predict persons with back injuries using their values on the variables. The discriminant function is chosen so as to minimize classification errors made when using the function for prediction.

The discriminant function is a derived variable consisting of a weighted sum of the predictor variables. The measured variables are predictor variables, while the classification variable (normal, patient) is the criterion variable. The cutoff score is the method used to place a person in a criterion group. Persons with discriminant scores below the cutoff point are assigned to one group, while persons scoring above the cutoff point are assigned to the other group (Kachigan 1982).

Classification and Regression Trees

A Classification and Regression Trees (CART) analysis was performed on the data. CART is a relatively new procedure developed by Breiman, Friedman, Olshen, and Stone (1984). This method uses binary trees as a classification method. It is a nonparametric procedure and is very robust in its analysis.

CART takes the initial data and examines all the possible splits for each variable from its maximum value to its minimum value. It finds the one split which provides the best discrimination between the classes. This process is repeated for the left and right nodes separately. This is continued until the classification of all the cases yields five or fewer cases in each terminal node (An Introduction to CART Methodology 1985).

The tree was obtained by using 10-fold cross validation. In this method, the cases were divided into 10 roughly equal subsets. For each subset, a tree is constructed using the other nine subsets. The subset is then run down the tree and probability of misclassification is calculated using that subset. The tree is pruned by comparing each subset with the tree grown from the entire data set and choosing the one that minimizes the misclassification rate (Breiman, Friedman, Olshen, Stone 1984).

CHAPTER 4

FINDINGS AND DISCUSSION

Data Reduction

Descriptive Testing

The normal data was tested for normality using the univariate Shapiro-Wilkes test. Along with this, a stem-and-leaf diagram, a box plot, and a normal plot was generated. The criterion was a W value of greater than or equal to 0.85 with a probability of greater than or equal to 0.05

The patients were tested for normality using the univariate Kolomogorov D Test procedure. The stem-and-leaf, box plot, and normal plots were also generated for the patients. The criterion used for this was a D value of less than or equal to 0.15 with a probability less than or equal to 0.15.

The departure from the standard test of alpha equals to .05 for the Kolomogorov test was deviated from for several reasons. First, by observing the stem and leaf diagram and the normal plot, and comparing these to the variables which tested normal using the Shapiro-Wilkes test, it was believed that .05 was too restrictive and an alpha of .15 seemed to yield results which were more reasonable. Second, errors in classifying the normality of the data would not be disastrous to the rest of the analysis. Third, since this is an exploratory part of the study, there are no set restrictions that must be applied and the alpha value can be set at the discretion of the analyst.

Fifty-nine of the ninety subjects were normally distributed for both normal subjects and for patients. Four of the cases were not normal for either class. A listing of variables which did not test normal for either or both groups is given in Figure 16.

Means Testing

The means testing was done for all variables to determine if a difference existed between values for normals and values for patients. The t-test was used for variables which were normal and the Wilcoxon Signed Ranks test was used for those variables which did not prove to be normal. The results of this test are given in Figure 17.

It was decided at this point to drop the secondary plane measures, those variables which were measured in planes other than the primary plane of movement. This decision was made because the dimensionality of the variables had to be reduced to run a successful factor analysis and more than half of the secondary plane variables tested to be insignificantly different for normals and patients. The reduced variable set appears in Figure 18. The total number of variables was then reduced to sixty-six.

	NORMALITY TEST USED	
VARIABLE	SHAPIRO-WILKES (NORMAL)	KOLOMOROGOV (PATIENT)
RM_RR	*	
IF_MT_P	*	
IF_AT_N	*	
IF_RMT_P	*	
IF_RMT_N	*	*
IF_LMT_P	*	
IF_LMT_N	*	*
IL_MT_N	*	
IL_I_N	*	
IL_RMT_N	*	
IL_FMT_N	*	
RR_AT_P		*
RR_I_P	*	
RR_MT_N	*	*
RR_AT_N	*	*
RR_I_N	*	*
RF_MT_N	*	*
FR_MT_P	*	*
FR_MT_N	*	*
FF_I_P	*	*
FF_I_N	*	*
FF_MV_N	*	
FF_P_N	*	
FL_MT_P	*	*
LR_MT_P	*	
LR_MT_N	*	*
LF_MT_N	*	*
LL_MT_P	*	
LL_I_P	*	*
LL_P_P		*
LL_MT_N	*	*
LL_I_N	*	*
LL_P_N	*	

Figure 16. Variables Indicated to be Non-normal in Distribution by Test Used.

VARIABLE	SECONDARY PLANE
IR_MT_N	
IR_AT_N	
IR_I_N	
IR_FMT_P	*
IR_FMT_N	*
IR_LMT_P	*
IR_LMT_N	*
IF_LMT_P	*
IF_LMT_N	*
IL_RMT_P	*
IL_RMT_N	*
IL_FMT_P	*
RR_MT_P	
RR_AT_P	
RL_MT_P	*
FF_MT_P	
FF_W_N	
FL_MT_P	*
LR_MT_N	*
LF_MT_N	*
LL_W_P	
LL_W_N	

Figure 17. Primary and Secondary Plane Variables Whose Means Tested Insignificant Differences Between Patients and Normals.

RANGE OF MOTION TEST

RM_LR	ROM - LEFT ROTATION
RM_RR	ROM - RIGHT ROTATION
RM_F	ROM - FLEXION
RM_E	ROM - EXTENSION
RM_LLF	ROM - LEFT LATERAL FLEXION
RM_RFL	ROM - RIGHT LATERAL FLEXION

ABBREVIATIONS

ROT	ROTATIONAL PLANE
F/E	FLEXION/EXTENSTION PLANE
LF	LATERAL FLEXION PLANE
POS	POSITIVE
NEG	NEGATIVE

ISOMETRIC TEST

IR_MT_P (IR_MT_N)	ROT MAXIMUM TORQUE POS (NEG)
IR_AT_P (IR_MT_N)	ROT AVERAGE TORQUE POS (NEG)
IR_I_P (IR_I_N)	ROT IMPULSE POS (NEG)
IF_MT_P (IF_MT_N)	F/E MAXIMUM TORQUE POS (NEG)
IF_AT_P (IF_AT_N)	F/E AVERAGE TORQUE POS (NEG)
IF_I_P (IF_I_N)	F/E IMPULSE POS (NEG)
IL_MT_P (IL_MT_N)	LF MAXIMUM TORQUE POS (NEG)
IL_AT_P (IL_AT_N)	LF AVERAGE TORQUE POS (NEG)
IL_I_P (IL_I_N)	LF IMPULSE POS (NEG)

ROTATIONAL TEST

RR_MT_P (RR_MT_N)	ROT MAXIMUM TORQUE POS (NEG)
RR_AT_P (RR_AT_N)	ROT AVERAGE TORQUE POS (NEG)
RR_I_P (RR_I_N)	ROT IMPULSE POS (NEGATTIVE)
RR_MV_P (RR_MV_N)	ROT MAXIMUM VELOCITY POS (NEG)
RR_AV_P (RR_AV_N)	ROT AVERAGE VELOCITY POS (NEG)
RR_W_P (RR_W_N)	ROT WORK POS (NEG)
RR_P_P (RR_P_P)	ROT POWER POS (NEG)

FLEXION/EXTENSION TEST

FF_MT_p (FF_MT_N)	F/E MAXIMUM TORQUE POS (NEG)
FF_AT_P (FF_AT_N)	F/E AVERAGE TORQUE POS (NEG)
FF_I_P (FF_I_N)	F/E IMPULSE POS (NEGATTIVE)
FF_MV_P (FF_MV_N)	F/E MAXIMUM VELOCITY POS (NEG)
FF_AV_P (FF_AV_N)	F/E AVERAGE VELOCITY POS (NEG)
FF_W_P (FF_W_N)	F/E WORK POS (NEG)
FF_P_P (FF_P_P)	F/E POWER POS (NEG)

LATERAL FLEXION TEST

LL_MT_p (LL_MT_N)	LF MAXIMUM TORQUE POS (NEG)
LL_AT_P (LL_AT_N)	LF AVERAGE TORQUE POS (NEG)
LL_I_P (LL_I_N)	LF IMPULSE POS (NEGATTIVE)
LL_MV_P (LL_MV_N)	LF MAXIMUM VELOCITY POS (NEG)
LL_AV_P (LL_AV_N)	LF AVERAGE VELOCITY POS (NEG)
LL_W_P (LL_W_N)	LF WORK POS (NEG)
LL_P_P (LL_P_P)	LF POWER POS (NEG)

Figure 19. Variables After Removing Secondary Plane Measures.

Factor Analysis

A factor analysis run on the sixty-six variables remaining extracted nine factors with eigenvalues greater than or equal to one. The variables which loaded at 0.5 or greater are shown in Figure 19 for each factor. The first eight factors had definite contributory variables, while the ninth factor had no variables which contributed at the significance level choosen.

The first factor was loaded primarily by the isometric variables. All of the variables measuring isometric values were high loaders, with loadings ranging from 0.685 to 0.844. Due to the consistent high loadings of the isometric variables, this factor will be considered an isometric factor. The highest loading variable for this factor was IR_AT_N with a loading of 0.844.

The second factor consisted of the maximum and average velocity and the power for both the positive and negative directions for the flexion/extension plane and for the lateral flexion plane. The relationship between velocity and power is explained by the equation:

Power = torque x angular velocity

(Isostation B200 1987). This factor will be called the velocity/power factor for the bending planes. The loading strengths ranged from 0.519 to 0.869, with the highest loading variable being LL_MV_N.

FACTOR 1	LOADING	FACTOR 2	LOADING	FACTOR 3	LOADING	FACTOR 4	LOADING
IR_AT_N	0.84417	LL_MV_N	-0.88456	RR_MT_P	0.86865	RM_RR	0.63207
IL_AT_N	0.84142	LL_MV_P	0.87626	RR_AT_P	0.84905	RM_LLF	0.61141
IR_I_N	0.80603	LL_AV_N	0.86964	RR_AT_N	0.78177	RM_F	0.59493
IL_AT_P	0.80336	LL_AV_P	0.86319	RR_MT_N	-0.74344	RM_RFL	0.59034
IR_AT_P	0.79818	LL_P_P	0.85406	RR_W_P	0.52266	RM_LR	0.54165
IL_MT_N	-0.79480	FF_AV_N	0.72532	RR_W_N	0.51907	RM_E	0.51078
IL_I_P	0.79285	FF_P_P	0.72100				
IL_I_N	0.79140	FF_P_N	0.71085				
IL_MT_P	0.78994	FF_AV_P	0.70807				
IF_AT_N	0.78893	FF_MV_P	0.70400				
IR_MT_N	-0.76965	FF_MV_N	-0.59002				
IF_I_N	0.76613	LL_P_N	0.55993				
IR_MT_P	0.75573						
IF_MT_N	-0.75247						
IF_MT_P	0.73692						
IF_I_P	0.73585						
IR_I_P	0.70659						
IF_AT_P	0.68477						

FACTOR 5	LOADING	FACTOR 6	LOADING	FACTOR 7	LOADING	FACTOR 8	LOADING	FACTOR 9
LL_AT_P	0.83976	FF_AT_N	0.81859	RR_AV_N	0.61298	FF_I_N	0.80290	NONE
LL_AT_N	0.82592	FF_MT_N	-0.76420	RR_P_P	0.59218	FF_I_P	0.79915	
LL_MT_N	-0.78953	FF_W_N	0.64189	RR_MV_N	-0.59175	LL_I_P	0.74382	
LL_MT_P	0.75777	FF_AT_P	0.54053	RR_P_N	0.57689	LL_I_N	0.71939	
LL_W_P	0.71143			RR_MV_P	0.56828			
LL_W_N	0.64794			RR_I_P	-0.54736			
				RR_I_N	-0.53825			
				RR_AV_P	0.53770			

Figure 19. High Loading Variables on Factors Produced with Factor Analysis

The high loading variables on the third factor were the maximum and average torque and the work for the positive and negative directions for the rotational plane. The relationship between these two variables can be explained by the fact that work and power are related by the equation:

Work = Torque x Angular Displacement

(Isostation B200 1987). This factor will be considered the torque/work factor for the rotational plane. The highest loading variable was RR_MT_P.

The fourth factor was loaded by all of the range of motion variables. The highest loading was 0.632 by RM_RR and the loading ranged down to 0.511. This factor will be called the range of motion factor.

The fifth factor contained the same variables as the third factor, average and maximum torque and work, for the lateral flexion plane. The loadings ranged from 0.648 to 0.840, with the highest loading belonging to the variable LL_AT_N. This factor will be named the torque/work factor for the lateral flexion plane.

The sixth factor contains positive average torque, negative maximum and minimum torque, and negative work for the flexion/extension plane. The loading for these variables ranged from 0.541 and 0.819, with FF_AT_N being the highest loading variable. If the positive maximum torque and positive work had been included, then it would parallel factors three and five. These factors fell below the 0.5 cutoff with scores of 0.489 and 0.417 for maximum torque and power respectively. However, because these scores are close to the cutoff, and the loading variables included both torque and work, this factor will be called the torque/work factor for the flexion/extension plane, even though it is not as complete as the other torque/work factors.

The seventh factor includes maximum and average velocities, impulse, and power for the positive and negative directions in the rotational plane. This factor is similar to factor two, except for the inclusion of the impulse factor. As stated above, the power is the product of the torque and the angular velocity. The impulse is the product of the torque and time (Isostation B200 1987). The loadings ranged from 0.538 to 0.613 for RR_AV_N. This factor will be called the velocity/power/impulse factor for the rotational plane.

The eighth, and last significant, factor was loaded by impulse in the positive and negative directions for the flexion/extension and lateral flexion planes. The highest loading occurred for FF_I_N with a value of 0.803 and decreased to 0.719.

The factor analysis was verified using an image factor analysis procedure. This analysis yielded almost identical factors to the ones produced above. Image analysis produces factors which best simulate the relationships among variable images (Gorsuch 1983). Image analysis involves developing two dimensional representations of a three dimensional object, taking the parts of a variable which is predictive from other variables in the same distinct group and using them to project a 'two-dimensional' representation of the variable (Gorsuch 1983, Young 1974).

Classification Techniques

Discriminant Analysis

The discriminant analysis was run by using the the highest loading variable for each factor produced in the factor analysis. These variables and their means and standard deviations are shown in Table 4. The analysis yielded a distance function for normals and for patients. The coefficients for these functions are shown in Figure 20. When a person was evaluated, his scores were calculated for both functions, and he was labeled using the group associated with the highest scoring function. The discriminant function is obtained by subtracting the distance coefficients (Figure 20) of the patients from the distance coefficients of the normals (Kleinbaum, Kupper, Muller 1988). The function developed was: L = 23.98794079 + 0.0538052*IR_AT_N - 0.07946369*LL_MV_N + 0.51819799*RR_MT_P + 0.2247312*RM_RR - 0.5990395*LL_AT_P - 1.23673177*FF_AT_N + 0.00652242*RR_AV_N - 0.01548804*FF_I_N. The classification error matrix for this analysis is shown in Figure 21.

Table 4. Means and Standard Deviations of Eight Final Variables for Patients and Normals

	NORMAL		PATIENT	
VARIABLE	MEAN	STD DEV	MEAN	STD DEV
IR_AT_N	42.99	15.36	22.15	11.57
LL_MV_N	-120.48	40.98	-64.28	37.96
RR_MT_P	19.25	1.09	18.81	2.09
RM_RR	41.90	6.69	31.21	9.35
LL_AT_P	24.04	2.01	28.11	3.67
FF_AT_N	26.32	2.42	30.67	3.94
RR_AV_N	65.57	23.38	30.59	20.27
FF_I_N	23.00	5.23	59.81	49.81

DISCRIMINANT ANALYSIS LINEAR DISCRIMINANT FUNCTION

$$\text{CONSTANT} = -.5\ \bar{X}'_J\ \text{COV}^{-1}\ \bar{X}_J \qquad \text{COEFFICIENT VECTOR} = \text{COV}^{-1}\ \bar{X}_J$$

	DV 1	2
CONSTANT	-109.98079412	-133.96873491
IR_AT_N	0.10376448	0.04995928
LL_MV_N	-0.03979999	0.03966370
RR_MT_P	6.07282592	5.55462793
RM_RR	0.48717612	0.26244492
LL_AT_P	2.54434286	3.14338236
FF_AT_N	0.84753763	2.08426940
RR_AV_N	-0.22777698	-0.23429940
FF_I_N	0.21379348	0.22928152

Figure 20. Coefficients for Discriminant Analysis with Pooled Covariance Matrices

NUMBER OF OBSERVATIONS AND PERCENTS CLASSIFIED INTO DV:

FROM DV	1	2	TOTAL
1	40 97.56	1 2.44	41 100.00
2	2 4.44	43 95.56	45 100.00
TOTAL PERCENT	42 48.84	44 51.16	86 100.00
PRIORS	0.5000	0.5000	

Figure 21. Classification Matrix for Discriminant Analysis with Pooled Covariance Matrices

The covariances were tested and the results indicated unequal covariances for the normal and patient groups. The above discriminant analysis was run using pooled covariances, which assumes equal covariances. A second analysis was run using within covariance matrices for the discriminant analysis. The discriminant output using within covariance matrices does not, however, yield distance coefficients for the variables so a discriminant function for this particular analysis could not be calculated.

The accuracy of this analysis was remarkably successful. Only one observation was misclassified. The classification matrix is shown in Figure 22. All of the normals were correctly classified, and all but one patient was correctly classified.

Classification and Regression Trees

Running the CART analysis on the eight variables isolated with factor analysis, also yielded successful results. A decision tree was formed with a minimum of two and a maximum of four decisions needed. This tree is pictured in Figure 23.

At the first decision point the variable FF_I_N is evaluated. If the value is less than or equal to 30.4, then the left branch is taken, if not, then the right branch is taken. Following the left branch, the next, and final, decision involves the variable LL_AT_P. If this is less than or equal to 27.7, then the person is classified as a normal,

NUMBER OF OBSERVATIONS AND PERCENTS CLASSIFIED INTO DV:

FROM DV	1	2	TOTAL
1	41 100.00	0 0.00	41 100.00
2	1 2.22	44 97.78	45 100.00
TOTAL PERCENT	42 48.84	44 51.16	86 100.00
PRIORS	0.5000	0.5000	

Figure 22. Classification Matrix for Discriminant Analysis with Within Covariance Matrices

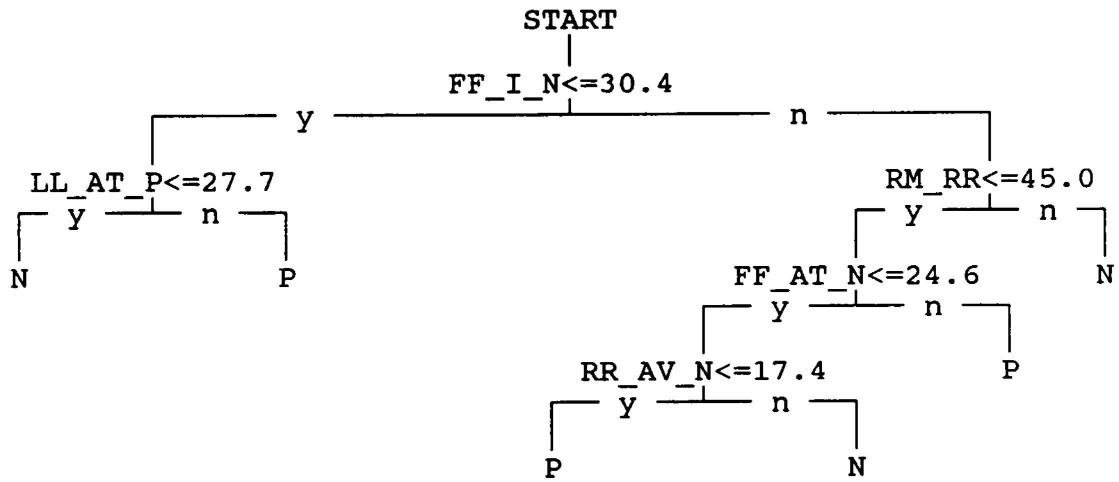


Figure 23. Decision Tree Generated by CART for Predicting Subjects With Back Injuries.

if not, the person is classified as a patient. Following the right branch, if the variable RM_RR is greater than 45.0, the person is classified as a normal. If not, the next decision involves FF_AT_N. If the value of this is greater than 24.6 the person is classified as a patient. If not, the last decision is: is RR_AV_N less than or equal to 17.4. If yes, the person is classified as a patient, if not, the patient is classified as a normal.

CHAPTER 5

SUMMARY AND RECOMMENDATIONS

Summary

Back injuries are a major problem in industry. Most Americans are at one time or another afflicted with back pain. A primary contributing factor to back injuries in industry is MMH. Back injuries are, unfortunately, hard to assess because most of the current evaluation techniques rely at least partially on the subjectiveness of the subject or the evaluator, usually both.

The purpose of this study was to develop descriptive performance measures of the back which could be used to quantitatively evaluate back injury and use these measures to develop a test to predict or identify persons with back injuries. This could be a particularly useful tool for pre-employment testing and for performance monitoring. Such a test must, however, conform to federal guidelines for avoiding discrimination against a particular group such as older people or women. Earlier research in this area was done by Hungerford and Johnson and this study was designed to broaden that research effort.

There are several prescriptive models for MMH. Epidemiological models use task characteristics and personal characteristics to determine groups at risk for injury. A biomechanical model uses the dynamic forces and movements of the back to determine a person's physical ability and compare it to a task demand. A physiological model determines a person's physical endurance for tasks. A psychophysical model uses a subject's psychological behavior to assess his or her physical injury or impairment. The model used for this study is a biomechanical because it is best suited for the objectives of the study, to be able to quantitatively measure a person's ability and to be able to compare such with the demands of a particular task.

Several types of tests have been developed to biomechanically measure a person's ability. These include range of motion, isometric, and isokinetic testing. The machine used to procure the measures, the Isostation B-2000, for this study was able to perform the above types of testing.

Several studies have been done using the Isostation B-200. Studies have been done by several researchers which indicate high validation and reliability of the machine. The machine has been used to study subjects such as the effects of fatigue on motor output and movement patterns and to explore the stability of isometric trunk measurements. A normal database has been developed for male trunk strength, and the role of the Isostation B-200 in disability assessments has been evaluated.

Five tests were used to evaluate the subjects. A range of motion test, an isometric test, and three isokinetic tests. All tests obtained measures from all three planes of movement of the back. Because of the greater amount of information obtained with the isokinetic test, it was broken down into a separate test for each plane. In the isometric tests, torque and impulse were measured. In the isokinetic tests, torque impulse, velocity, work, and power were measured.

Normality tests were run on the ninety variables measured to determine the nature of the variable distributions. Means testing was performed to determine the discriminatory ability of the data. Secondary plane measures were dropped, leaving sixty-six variables.

A factor analysis was performed on the sixty-six variables and nine factors were identified. The first factor was an isometric factor, the second factor was a velocity/power factors for the bending planes. The third, fifth and sixth factors were torque/ work factors for the rotational, lateral flexion, and flexion/extension planes, respectively. The fourth factor was a range of motion factor. The seventh factor was a velocity/power/impulse factor for the rotational plane. The eighth factor was an impulse factor for the bending planes. The ninth factor had no significant loadings.

The variable which had the highest loading for each factor was extracted for a discriminant analysis. These variables were IR_AT_N, LL_MV_N, RR_MT_P, RM_RR, LL_AT_P, FF_AT_N, RR_AV_N, and FF_I_N. The discriminant analysis produced the following discriminant function: L = 23.98794079 + 0.0538052*IR_AT_N - 0.07946369*LL_MV_P + 0.51819799*RR_MT_P + 0.2247312*RM_RR - 0.5990395*LL_AT_P - 1.23673177*FF_AT_N + 0.00652242*RR_AV_N - 0.01548804*FF_I_N. Subjects scoring less than zero are classified as patients and subjects scoring greater than zero are classified as normals. Using this function, only three of the test group were misclassified. Also run was a CART analysis which yielded a decision tree for classifying subjects. The tree produced is shown in Figure 23. Decisions are made using from two to four of the variables FF_I_N, LL_AR_P, RM_RR, FF_AT_N, RR_AV_N. The number of tests needed can be reduced using the tree. This tree could provide an easy to use procedure for use in the workplace or clinic.

Either of the two classification techniques could be used as pre-employment or pre-placement tests. Subjects who are classified as patients should not be placed in jobs which have high back risk factors. These tests could also be used to monitor job performance. Persons in jobs with high risk factors could be monitored periodically and placed in another position if the tests classified them in the patient category. Jobs in which this happens frequently should be redesigned to reduce the risk factors.

Recommendations

The results of this study would recommend that either of the classification procedures developed, the discriminant function or the classification tree would make an acceptable model to determine back injury or potential risk of back injury. Because a separate procedure would be developed for females, there would be no discrimination based on sex.

It is recommended that the use of these classification procedures as part of a pre-employment or pre-placement screening test be further researched. There are several studies which would further the results of this research.

Recommendations for further study would include using an increased database or a different population, such as females, for a similar analysis and compare the results with this study. A second research could be a double-blind study with the different subjects using the analysis techniques produced here. These studies would be a valuable tool in validating the models produced here.

This study would also recommend further research into the use of these procedures as a periodic monitoring tool for persons performing tasks which are stressful to the back. This would include the validation study mentioned above, in addition to studies on the effect on the discriminant function or classification of therapy or exercise.

Further research in the area of clinical uses of these classification techniques would be recommended. The recommended study could explore the possibilities of using these techniques to study the effect of an exercise program, the progress of rehabilitation, and the readiness for return to work.

Also recommended would be further research into the possibilities of CART as a clinical tool for back patients. This procedure has interesting potential due to the ease of use of its output.

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