DISCRIMINATION BETWEEN SINCERE AND DECEPTIVE ISOKINETIC KNEE EXTENSION RESPONSE USING SEGMENTAL CURVE ANALYSIS

by

Jo-Anne Lesley Lee Bogner

Thesis submitted to the faculty of the
Virginia Polytechnic Institute and State University in
partial fulfillment of the requirements for the degree of

MASTERS OF SCIENCE IN EDUCATION

in

Health and Physical Education

APPROVED:

Don R. Sebolt, Chairman

Jay Williams

Robert Foutz

January, 1991

Blacksburg, VA

DISCRIMINATION BETWEEN SINCERE AND DECEPTIVE ISOKINETIC KNEE EXTENSION RESPONSE USING SEGMENTAL CURVE ANALYSIS

by

Jo-Anne Lesley Lee Bogner

(ABSTRACT)

This study intended to determine if, by using coefficients of variation derived from data collected by Fisher [1989], it would be possible to develop prediction equations to discriminate between sincere and deceptive isokinetic knee extension tests, whether these equations could be applied to a new sample, and whether prediction accuracy is dependent on test speed. Fisher [1989] trained 76 college-age males subjects to either give a true maximal response or fake an injury during an isokinetic knee extension/flexion test at 60, 180, and 300 deg/sec. Data were transmitted to a computer running Segmental Curve Analysis [Wynn, 1988; Sebolt and Earles-Price, 1989], which computed six variables for each torque curve: peak torque (PT), torque at five degrees prior to and post-PT (T-5, T+5), area to five degrees prior to PT (A-5), area beyond five degrees post-PT (A+5), and area between five degrees pre- and post-PT (A55). Coefficients of variation were computed for each variable, which were used to develop prediction equations for each speed, and for all speeds combined. The prediction equations accurately predicted condition assignments ($p = 0.572 - 0.79$) when applied to Fisher's [1989] data. A second sample was solicited, trained, and tested in a manner similar to Fisher [1989], and the same prediction equations were applied. There was no significant difference ($p < 0.05$) in the prediction accuracy of these equations between their application to Fisher's [1989] data or to data collected in the current study. Furthermore, there appeared to be no significant effect of test speed on prediction accuracy. These data suggest that coefficients of variation could be used to discriminate between sincere and deceptive isokinetic performances.

ACKNOWLEDGMENTS

The author would like to give recognition to the following people for their help in making the completion of this project possible:

First, and foremost, to my husband, David, without whose patience, love, and support, I would not have been able to see what was really important, maintain my sanity, and see this through to its fruition.

To all the people who assisted me in the data collection. This was certainly a team effort. Many thanks to my brother, Stuart Lee, Susan Stolarski, and Tracy Mitchell, for being so prompt, professional, and hard-working. This truly would not have been possible without you.

To Denise Snider, who helped me keep a grip through the first year of course work.

To my committee members, Dr. Sebolt, Dr. Williams, and Dr. Foutz, for their time, suggestions, and enthusiasm in making this work a reality.

Finally, to all the other unmentioned many, who with or without knowing it, gave me the guidance, wisdom, and confidence necessary to get where I am today, wherever that may be.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

STATEMENT OF THE PROBLEM

Presently, there are three methods used to train and assess muscular strength, power and endurance. *Isometrics*, which measure muscle forces at a given fixed position, although being very specific and relatively easy to quantify, has little application to either the evaluation of or preparation for dynamic situations. *Isotonics*, perhaps the best known form of strength training and evaluation, is limited by the application of a fixed amount of weight, which may or may not challenge the subject maximally throughout his or her full range of motion (ROM). Of the three major modes of muscular training and assessment, *isokinetics* is the most recently developed mode of strength training currently in wide use as a training tool by professional athletes, a rehabilitation tool by physical therapists and trainers, as well as a research tool where precise measurement of the dynamic nature of muscular activity is essential [Davies, 1987]. Isokinetic testing involves working against a lever arm set to move at a fixed speed. Instead of lifting a set weight, the subject essentially "creates" the resistance: the harder the subject applies force, the greater the resistance. The work performed at each point in the subject's ROM is dependent on the subject's ability to perform that work, thereby allowing the subject to work maximally at every point in his ROM.

Perhaps the best known and most widely used isokinetic machines have been produced by Cybex. By the early 1970's the Cybex II isokinetic dynamometer had established itself as the gold standard of isokinetic machines [Elliott, 1978]. When a subject or patient exercises on the Cybex machine, part of the output of the exercise session is in the form of a *torque curve*, a graphical representation of the applied force throughout ROM. Recently, attempts have been made to use the Cybex output as a non-invasive diagnostic tool to identify a host of specific musculo-skeletal injuries [Davies, 1987]. To date, there is limited evidence that such an application is possible, partially due to the wide variability of individual performances [Rothstein, Lamb and Mayhew, 1987]. Another application currently under investigation is the use of the Cybex output to identify malingerers.

Malingering involves the fictitious representation of a physical or psychological malady, and has been a source of concern almost since the beginning of recorded history. Previous attempts to use isometric measurements to identify malingering behavior have shown mixed results [Gilbert and Knowlton, 1983; Niebuhr and Marion, 1987; Stokes, 1983]. It has previously been suggested that the *variability* of a given subject's performance may suggest the absence or presence of knee injury [Murray et al., 1977], or evidence a true maximal effort [Kroemer and Marras, 1980]. As a baseline for this study, previous investigations have established high levels of reliability of isokinetic knee extension response by both normal subjects giving true maximal efforts [Sebolt, Earles-Price, and Herbert, 1989a, 1989b], and for injured subjects [Snider, 1989]. Fisher [1989] also used the Cybex II to train injury-free subjects to either fake an injury or give a true maximal isokinetic knee extension response, and then compared the reliability of these two groups. As proposed, the subjects faking an injury were found to be less reliable across six variables extracted from the torque curves produced during testing.

SIGNIFICANCE OF THE STUDY

The purpose of this study was to determine if it was possible, using data collected by Fisher [1989], to develop discriminate function regression equations to predict whether a subject was faking an injury (deceptive) or giving a true maximal effort (sincere), and to cross-validate these equations by applying them to a new sample of subjects. Secondarily, this investigation also intended to discern if the ability to predict condition assignments (sincere or deceptive) was a function of exercise testing speed.

RESEARCH HYPOTHESES

The following hypotheses were examined in this investigation:

Ho1: It was not possible to discriminate between sincere and deceptive isokinetic response using coefficients of variation derived from isokinetic power and torque parameters.

Ho2: Discriminate function regression equations derived from sincere and deceptive isokinetic knee extension response from a previous sample of subjects [Fisher, 1989] did not discriminate when applied to a new sample of subjects trained in a similar fashion.

Ho3: The ability to discriminate between sincere and deceptive isokinetic knee extension response was not affected by exercise test speed.

DELIMITATIONS

The following delimitations were applied in this study:

1. Forty-one male volunteers were used as subjects. They ranged in age from 18 to 28 years.

2. Only isokinetic knee extensor torque curves were examined.

3. Measures of torque and area were recorded at the following speeds: 60, 90, 120, 150, 180, 210, 240, 270, and 300 deg/sec.

4. The six experimental variables selected for evaluation were:
   a. Peak torque *(PT)* - the highest single point on the torque curve.

b. Torque at five degrees joint angle prior to peak torque *(T-5)*.

c. Torque at five degrees joint angle beyond peak torque *(T+5)*.

d. Area from the beginning of the torque curve to five degrees joint angle prior to peak torque *(A-5)*.

e. Area from five degrees joint angle beyond peak torque to the end of the torque curve *(A+5)*.

f. Area between negative and positive five degrees joint angle around peak torque *(A55)*.

LIMITATIONS

The following limitations were recognized by the investigator as potential confounding factors which may have influenced the test results:

1. That subjects may have experienced some muscular fatigue during the course of the data collection.

2. That there may have been some effect of test sequence on the results. All tests were administered in the same order (slow, medium, fast). This is the standard order of testing used in clinical test evaluation. An attempt was made to control this effect by random selection of one test speed per subject, but this resulted in such a small sample size that it was later omitted from the previously approved test protocol.

BASIC ASSUMPTIONS

1. That subjects selected for this study have had no history of trauma, injury, or surgery to the knee, hip or associated musculature.

2. That subjects, when asked to give a true maximal effort, were indeed working to their greatest potential. This assumption is central to the success of this investigation.

3. That information on torque and joint angle was accurately transmitted from the CDRC to the computer running the SCA program.

4. That the SCA program accurately analyzed the test data for the selected parameters.

DEFINITIONS AND SYMBOLS

Degrees/second (deg/sec): the speed of limb movement, as controlled by the Cybex II dynamometer. The Cybex II limits the speed at which the limb can move to a given number of degrees of rotation around its axis per second.

Maximal voluntary contraction (MVC): The maximum amount of force development from muscular contraction of which a subject is physically and consciously capable of producing.

Peak Torque (PT): the single highest point on the torque curve, it is not dependent on joint angle of occurrence.

Power: an expression of the rate at which work is performed. Power is usually expressed as work divided by time. Therefore, work done at a faster rate requires greater power than the same work performed at a slower rate.

Range of Motion (ROM): the amount of movement of which an articulation or set of articulations is capable. Range of motion is usually measured in degrees, and is limited by the configuration of bones, tendons, and muscle tissue surrounding or composing the joint in question.

Torque: the rotational force produced when muscle acts on a bone to move it about the associated articulation's axis of rotation.

SUMMARY

Previous research on muscular testing has generally focused on the measurement of "normal" responses, i.e. behavior that is uninhibited by physical or psychological stress. It is possible to accurately measure just how much force a subject is generating at almost any joint angle or speed of contraction using a wide variety of sophisticated machines. However, very little research has been published to use these same machines to discriminate between normal and abnormal responses, such as malingering.

As a result of our increasingly litigious society, it has become necessary to develop objective methods of identifying deceptive behaviors. Most research on malingering and malingering-like behaviors has focused on isometric testing of hand-grip strength [Gilbert and Knowlton, 1983; Niebuhr and Marion, 1987; Stokes, 1983], probably since weakness of hand-grip strength has been recognized as an indicator of true injury by many states [Stokes, 1983]. Most of these researchers examined certain characteristics of a single response curve generated during isometric hand-grip tests. In contrast to this approach, previous research has suggested that *variability* in performance may be used to distinguish the absence or presence of knee injury [Murray et al., 1977], or evidence a true maximal effort [Kroemer and Marras, 1980]. Snider's [1989] investigation into the performances of injured subjects found them to be highly reliable during isokinetic testing, casting some doubt into the use of variability as an indicator of the presence of knee injury. However, this same principle may have application in the identification of those who are *faking* a knee injury, thereby proving the presence of knee injury indirectly. The present study attempts to test the concept of variability of performance as an indicator of deceptive response through the use of discriminate function analysis, and also to test the use of isokinetic testing as a tool to identify deceptive response, through application of a process called Segmental Curve Analysis (SCA) [Wynn, 1988; Sebolt and Earles-Price, 1989].

CHAPTER II

REVIEW OF LITERATURE

Isokinetic Testing

Physical performance can be measured in many ways. Over the years, numerous physical tests have been used to assess "fitness". As the definition of fitness has changed, so has the means used to measure it. Currently, fitness is generally accepted to contain the following components: cardiovascular strength and endurance, muscular strength and endurance, and flexibility. Any one person can have a high degree of proficiency in one or more of these areas, but only by possessing certain acceptable levels in all these areas can one be considered truly "fit".

Perhaps the easiest of these concepts to measure and interpret is muscular fitness. Strength and endurance are generally quantified using one of three methodologies: isometrics, isotonics, and isokinetics. *Isometrics* involves working against resistance with no change in joint angle or muscle length. The force generated is almost entirely under conscious control of the subject. Isometric work is usually assessed using *force tensiometers*, in which the object being resisted does not move as the subject exerts force on it. One of the major drawbacks of isometric training is that benefits gained are joint angle specific. Because most activities are by definition dynamic in nature, gains from this form of exercise do not translate well to most sports and athletic situations [Davies, 1987].

Perhaps the best known and most widely used form of muscular exercise and assessment is *isotonics*. In isotonic exercise, the resistance is a constant, and muscle length changes as the resistance is opposed. There are two forms of isotonic work: *concentric* and *eccentric*. In concentric exercise, the muscle shortens as it opposes the resistance, as in the upward phase of a barbell curl. In contrast, eccentric work requires the muscle to lengthen as it opposes resistance, as in the downward phase of a barbell curl. During concentric exercise, the torque generated by the muscle must be greater than the resistance it opposes. In eccentric exercise, the torque generated by the muscle is slightly less than the resistance; therefore, greater amounts of weight can be controlled during eccentric exercise. Eccentric work therefore has the advantage of producing the greatest amount of tension in the muscle. However, it also has a greater potential for producing residual muscle soreness [Davies, 1987]. Regardless, in both cases the resistance is a fixed amount, and the only thing that changes is the muscle's ability to work against the resistance as the joint angle changes.

The newest form of muscle training and assessment is *isokinetics*. Developed in the early 1960's, isokinetics have quickly become the mode of choice of researchers, physical therapists and other health care professionals [Davies, 1987]. Using isokinetic measurement, one is better able to assess the dynamic nature of muscular contraction at every point in the subject's range of motion (ROM). Isokinetic work involves generating force against a lever arm set to move at a constant speed. One of the main benefits of isokinetics is its ability to provide *accommodating resistance*, which is especially valuable in clinical situations for injured subjects. Because the subject is able to control the amount of force being generated, when he or she experiences pain, the force (and subsequently the resistance) is immediately reduced by the patient's own reflexive response to that pain. Thus the patient is able to work through full ROM even while injured. This enables the patient to avoid such adverse side effects of injury as muscular atrophy while recovering from an injury [Davies, 1987].

This ability to vary resistance as ROM changes is also of value to athletes in training, since it allows the athlete to train dynamically and maximally throughout full ROM. The reason for this lies in the *length-tension relationship* of muscular contraction. The length-tension relationship states that as the length of the muscle changes, so does its ability to generate tension. The maximal amount of tension a muscle can produce is at its resting length; as the muscle is shortened or stretched, its ability to produce tension decreases [Kreighbaum and Barthels, 1985]. As joint angle changes, so does the length of the muscle; consequently, the muscle's ability to generate force is dependent on the joint angle. During isotonic exercise, the greatest resistance that can be applied to a working muscle is dependent on the weakest joint angle in the subject's ROM, since during a single movement, the same weight must be opposed through the subject's entire ROM. That is, the subject is only able to work maximally at the weakest joint angle; all other work beyond that is submaximal because the muscle is mechanically advantaged. In isokinetics, the subject is able to produce peak force throughout his or her full ROM, since the resistance is dependent on the amount of force the subject applies to the lever arm.

By the early 1970's, the Cybex II isokinetic dynamometer had established itself as the gold standard of isokinetic training and assessment. A report on the status of isokinetics by the Journal of the American Medical Association [Elliott, 1978] described the machine as "an integral part in the functioning of most professional football clubs and sports medicine clinics in the country, but [it] also promises to assume an important role in occupational injury evaluation, athletic screening and rehabilitation, and verification of treatment results."

Of all the joints examined through the use of isokinetics, the knee is probably the most frequently tested. This in part may be due to the high incidence and severity of knee injuries [Davies, 1987], as well as the simplicity of the joint and of the test application. Unlike the shoulder, for example, there are only four bones involved in the articulation of the knee (the femur, tibia, fibula, and patella), and only one major biomechanical movement (flexion-extension), although some internal-external rotation is possible in a flexed position. The main test applied to the knee using the Cybex is the flexion-extension test.

During this test, the subject is seated in the testing apparatus, usually upright at 90-100 degrees upper torso angle. The axis of rotation of the knee joint is aligned with the axis of rotation of the dynamometer, and the length of the input shaft is adjusted so that the ankle pad rests approximately 1-2 cm. above the malleus. The subject is then secured to the testing apparatus at the pelvis, mid-thigh and ankle with Velcro straps. This arrangement is designed to isolate the muscles of the thigh [Cybex, 1983].

The Cybex II is routinely used to compare the strength of the affected (injured) limb to the unaffected limb to determine when a patient is able to resume his normal daily activities. Elliott [1978] reported that a limb-to-limb deficit of greater than 10% indicates that the injured limb is not completely rehabilitated. This determination is normally made at a speed of 60 deg/sec. An actual range for limb-to-limb deficit for normal subjects varies widely from study to study, from no significant difference between limbs [Hageman, Gillaspie and Hill, 1988; Perrin, Robertson and Ray, 1987; Sebolt, Earles-Price and Herbert, 1989a] to as much as 10-15% [Davies, 1987]. Cybex recommends that no greater than a 10% deficit between limbs should be recognized as a normal performance [Cybex, 1983]. Davies [1987] states that differences within 10-15% between limbs can usually be considered normal. However, these differences can sometimes be even greater even in an uninjured subject if he or she participates in a sport that is highly asymmetrical. Snider [1989] used the criterion of 19% or greater deficit between limbs as her criterion for injury, to differentiate her subjects from those examined by Sebolt, Earles-Price and Herbert [1989a]. However, Davies [1987] cautions that slow velocity test results alone are often not sufficient to indicate normalcy, and that functional deficiencies that are absent at slower speeds can manifest themselves at higher velocities.

Researchers in the late 1970's also claimed that training at the highest velocity of which the Cybex II is capable (300 deg/sec) could be translated into gains in quickness and power across the whole velocity spectrum for all subjects [Elliott, 1978]. The *physiological overflow principle* remains to this day a controversial concept. Some studies have found the effect to be unidirectional [Lesmes et al., 1978], and others have observed it to be bidirectional in varying degrees of magnitude [Jenkins et al., 1984; Sherman et al., 1981; Timm, 1987]. In most cases, this disagreement may be attributed in part to different durations and methods of training in observing this phenomenon. Because of the lack of agreement over this phenomenon, Davies [1987] concluded that this stressed the importance of velocity spectrum training, i.e., training at a variety of speeds, to achieve the greatest results.

As an example, Timm [1987] investigated the effect of training once a week for eight weeks at 180 deg/sec to 50% of quadriceps fatigue on PT, torque acceleration energy (TAE), and average power at 60, 120, 180, 240 and 300 deg/sec. TAE represents the total work or area under the torque curve in the first 1/8 of a second of muscular contraction [Davies, 1987]. Timm's method differed from other studies which used either a specific number of repetitions or a time limit to limit the duration of the exercise bout. Timm found a significant effect on all variables across the entire velocity spectrum. However, his research design contained some potentially confounding factors. First, only the left leg of each subject was tested and trained. In most cases, this was probably the non-dominant limb. Although most evidence suggests that there is little or no difference in strength between the dominant and non-dominant limb, it may be possible that the non-dominant limb is more receptive to training, and hence one would expect greater gains simply due to the limb involved. Secondly, there appeared to be no preliminary orientation prior to assessment to establish a pre-training baseline for comparison to post-training measures. It is almost certain that some portion of the gains between pre- and post-test were due simply to the subjects' growing familiarity with the testing apparatus. Third, there was no control group used. Timm stated that "The use of previously verified experimental methods precluded the need for a control group [Timm, 1987.]" This seems a weak excuse for the lack of a control group, and further tends to cast doubt on the validity of his results.

In contrast, Perrin, Lephart and Weltman [1989] examined the effects of training three sets of 25 repetitions each at a high velocity (270 deg/sec), three times per week for seven weeks on PT, TAE, average power, and total work at 60, 180, and 270 deg/sec. Although a trend towards gains across all variables at 60 and 180 deg/sec was observed, the gains were not statistically significant. However, the subjects in this study were intercollegiate lacrosse players (sex unspecified, but could be assumed to be male), as opposed to a group of apparently healthy college-age males and females. It is possible that less change was observed in the first population simply due to their physical status. Regardless, the disparity between the results of these two studies only serves to illustrate the fact that the question of the physiological overflow effect is far from being resolved.

Another use for the Cybex II advocated by the researchers in the late 1970's was athletic screening [Elliott, 1978]. It was believed that areas of weakness could be identified which may predispose the athlete to injury in the future. Again, there has been little evidence to support any correlation between a given measure of weakness and predisposition to injury [Grace et al., 1984]. Also, perhaps erroneously, Elliott [1978] reported that some physicians were able to assess the nature and extent of injury simply by observation of the Cybex readout. To date, there is limited evidence that it is possible to identify the exact nature of an injury through use of output from the Cybex [Rothstein, Lamb and Mayhew, 1987]. Davies [1987] contends that it may be possible to identify at least nine different pathological conditions through use of the Cybex dynamometer, and cites at least a half dozen different research studies to support this. Among the pathologies Davies claims to have a distinct torque curve pattern are chondromalacia patella, anterior cruciate ligament insufficiency, and patellar subluxation.

However, the ability to identify a particular abnormality is still largely subjective, and is dependent on the consistency of the shape of the torque curve across several trials, and may be confounded if more than one pathology is present. Currently, more traditional methods such as x-ray or arthroscopy are still required to determine the exact nature of an injury. Isokinetics is still relegated to the domains of treatment and assessment of progress. Murray et al. [1977] concluded from their own studies of isometric testing of knee extensor and flexor contractions that no one torque curve can be thought to be representative of all persons, or even of a single subject. However, they also acknowledged that *variability* may provide a baseline for evaluation of the presence of knee injury. Snider's [1989] investigation into the performances of injured subjects found them to be highly reliable during isokinetic testing, casting some doubt into the use of variability as an indicator of the presence of knee injury. However, this same principle may have application in the identification of those who are *faking* a knee injury, thereby proving the presence of knee injury indirectly.

Malingering

Malingering has been defined as a conscious act of simulating or exaggerating physical or psychological disease [Travin and Protter, 1984], and is especially troublesome in cases of workmen's compensation. It has been estimated that approximately $289 million was paid for fraudulent claims in 1982 alone [Edwards, 1983]. Since the history of malingering has been more than adequately covered by Fisher [1989], it seems unnecessary to repeat it here.

Malingering is thought to be an adaptive response to both internal and external factors with an obvious goal in mind. This assumes that the subject is consciously aware of his fictitious performance, and is therefore responsible for his actions from a medical and legal standpoint. This category of malingering is called an *other-deceiver*.

Other malingering-like behaviors have been discussed in the literature, in which varying degrees of psychoses may contribute to their manifestation [Travin and Protter, 1984].

Malingering is usually thought of as a 'higher order task' in a psychological sense. A given task, whether it be physical or psychological, is made up of interactions between demands and capabilities. Performance of that task increases as demand increases, but is ultimately limited by one's inherent capabilities. The basic capabilities we possess to meet the demands of everyday life include physical strength and endurance, the five senses, proprioception, visualization, and the ability to perform actions in series, which are essential to sensori-motor skills [Welford, 1978]. If demand exceeds capability, performance suffers. However, one can compensate for a lack of capability by developing a strategy or approach to a problem. Higher order skills require the capability to instantaneously interpret events, memory retention, and verbal communication, as well as the ability to apply knowledge acquired from one situation to a new one [Welford, 1980]. Subjects lacking the capability to perform a task based on sensory feedbacks may have to rely on higher-order mental capabilities to perform such a complex task as faking an injury. Hence, conscious attempts at malingering may require higher levels of processing than reflexive performances regulated by sensory inputs of pain, discomfort, and fatigue [Welford, 1978].

It is probably not inaccurate to say that most limitation of activity as a result of injury is due to the presence of pain. At any given moment, more than two million workers are inhibited by pain at a cost of over $2 million annually [Kandel and Schwartz, 1985]. The way a subject responds to pain will ultimately influence the pattern of behavior he exhibits. The source of most information about pain arises from free nerve endings. All muscular activity is controlled based on the contributions of sensory and motor neurons, also known as *afferent* and *efferent* neurons. Sensory neurons provide information to the central nervous system (CNS) about the external environment or internal events that may influence activity; motor neurons transmit information from the CNS to muscles to stimulate activity. In a simple two-stage system, this is all that is required. "Behavior," if it can be called that, is simply a reflexive response to internal or external stimuli. Higher order activities require higher levels of processing within the central nervous system, either through interneurons, ganglia, or the brain. This higher level of processing results in more complex behavior patterns than in a two-stage system [Darley et al., 1981]. Hence, malingering and malingering-type behavior can be considered in a physical sense as well. Kroemer and Marras [1980] theorized and demonstrated that submaximal efforts would require a longer build-up phase than a maximal effort because of the amount of mental processing required for a submaximal effort. Deceptive behavior by a subject is usually manifested as a submaximal effort. Therefore, one would expect that a true maximal effort, whether limited by pain or not, would require less processing than a deceptive effort, since the feedback loop required in processing the information that mediates the behavior would be much shorter in the case of the truly injured patient compared to the malingering subject.

The Detection of Malingering

The detection of malingering in the past has been mainly based on *subjective* findings. Subjective evidence of malingering usually involves complaint of discomfort or injury without any supporting objective findings as to the source of the complaint. In our increasingly litigious society, it has become necessary to develop *objective* means to identify malingering. Previous methods used to detect malingering have included the use of psychological tests like the Minnesota Multi-Phasic Personality Inventory (MMPI) [Grow, McVaugh, and Eno, 1980], and isometric handgrip testing.

Loss of grip strength is an objective measure deemed to be acceptable as evidence of injury to the hand by some state's compensation boards. Stokes [1983] attempted to develop an objective measure of malingering behavior by comparing curves derived from force production at five different handle positions using a sealed hydraulic hand grip dynamometer. Stokes found that a deceptive subject's curves differed significantly from those produced by a subject with true grip weakness. In the injured subject, the curves produced with the injured hand were consistently lower in terms of force development at all five handle positions compared to the uninjured hand, yet the shape of the curve paralleled that produced by the same subject's uninjured hand. In contrast, the patient whom Stokes suspected of faking an injury produced the same slightly bell-shaped curve as the injured subject with their "normal" hand but produced only minimal pressure at all five handle positions with the "injured" hand, resulting in essentially a straight line (Figure 1). It must be noted that Stokes' suspicion of malingering was based on the same subjective measure noted earlier. Also, a major flaw of this study was that only one subject per condition was examined.

Stokes' study was later re-evaluated by Niebuhr and Marion [1987]. The purpose of Niebuhr and Marion's study was to determine if Stokes' results could be replicated using injury-free subjects instructed to feign an injury. Twenty-five subjects with no upper extremity disorder or disease completed a total of 40 trials each on a Jamar hand dynamometer, consisting of combinations of: five different handle positions, dominant and non-dominant hand, sincere or deceptive effort, and two repetitions per combination of the above variables (5 x 2 x 2 x 2 = 40). These combinations were completed in randomized order. The results of the testing were analyzed using a three-way Analysis of Variance. This analysis showed that hand dominance, handle position, condition (sincere or faking), hand dominance by condition interaction, and handle position by condition interaction were all significant main effects. However, the three-way interaction of position, condition, and

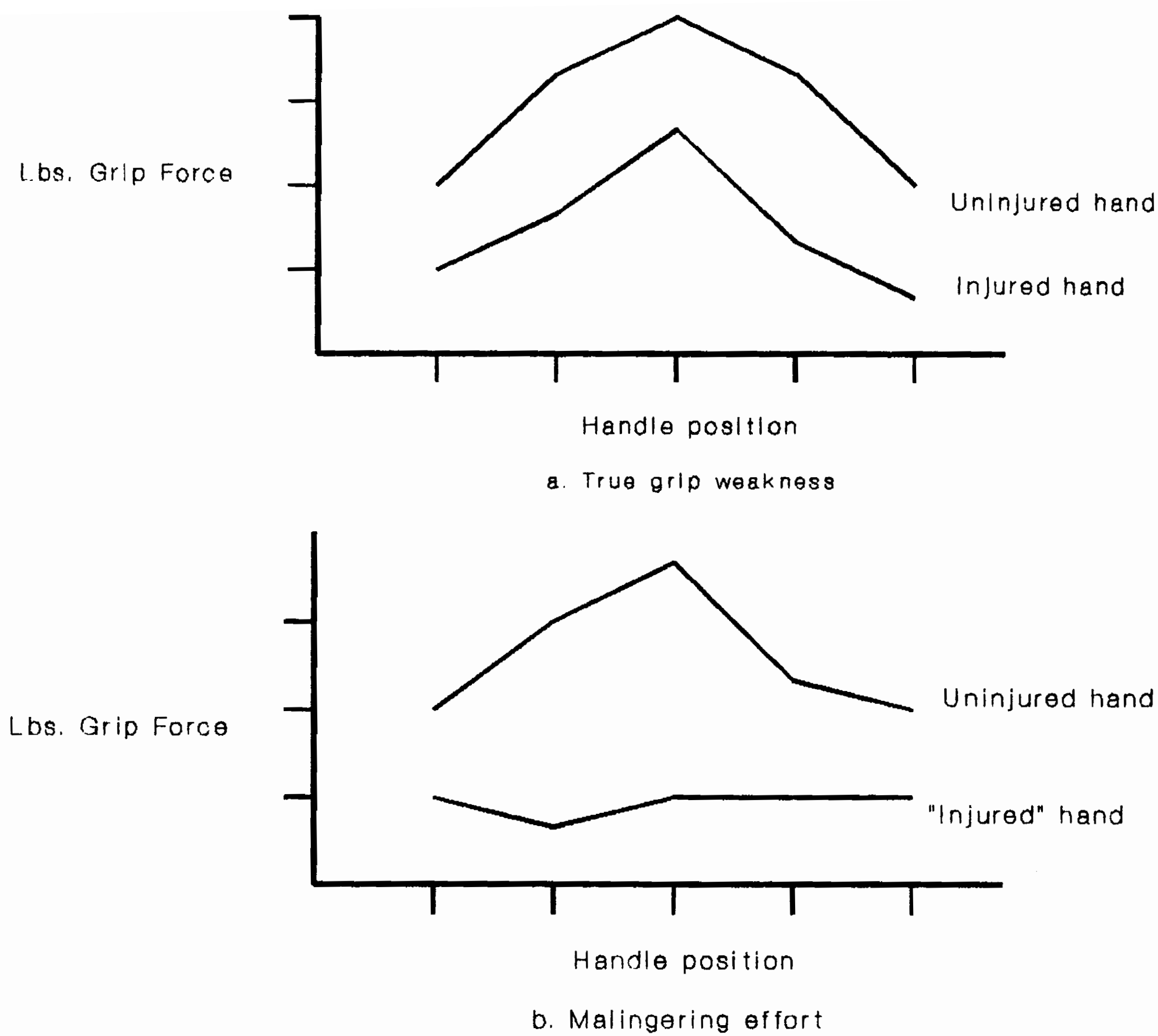


Figure 1. Comparison Between True Grip Weakness and Malingering Effort Using an Isometric Hand Grip Test (Adapted from Stokes [1983])

dominance was not significant. The Scheffe paired comparisons test showed that the middle handle position scores were significantly greater than the other handle positions for the sincere efforts, as in Stokes' study. By comparison, this same test did not demonstrate an equal effort across all five handle positions for deceptive efforts, as Stokes has contended from his results. Nonetheless, the normal curve was more curvilinear than the curve resulting from the deceptive efforts. Although the curves resulting from this study were unlike those produced by Stokes [1983], Niebuhr and Marion concurred with Gilbert and Knowlton [1983] that sincere and deceptive efforts could be discriminated. However, they also felt that further research with injured subjects needed to be done.

Gilbert and Knowlton [1983] also used grip strength effort as a method to discriminate between sincere and faking efforts in thirty-six male and female subjects. However, these investigators decided to concentrate on variables drawn from individual torque curves generated by each subject. Subjects were randomly divided into sincere (S) or faking (F) conditions, and trained to exert either a true maximal voluntary grip contraction (MVGC) or what they perceived to be 75% of their MVGC prior to testing. During testing, the investigator was not aware of the condition to which the subjects were assigned. Each subject was given two trials at the grip strength test during the experimental session. From this data, three variables were calculated for each subject: rate of force application (SLP), ratio of average force to peak force (DEV), and ratio of peak force to body weight (WTRATIO). Z scores for each of these variables were computed, and these scores were summed together [z(SLP)+ z(DEV) + z(WTRATIO)] for each subject after being sorted by sex. The top 50% of the summed z scores were predicted to belong to the S condition, and the lower 50% to the F condition. This placement resulted in correct assignment of 87.5% of the female subjects and 80% of the male subjects to their respective conditions. In addition, discriminate analysis showed DEV to be the best predictor of group membership for either sex. SLP was found to be non-significantly different between conditions. However, the combination of SLP and DEV provided the best prediction equation for males. Correlation coefficients were also calculated to measure reliability of each variable across the two trials. These reliability coefficients were *not* found to be significantly different between the S and the F conditions. This may have been due to the specification of 75% effort in the deceptive condition.

Perhaps equally as challenging is to determine whether or not a subject is giving a maximal effort. In fact, this seems to be a basic assumption upon which all other comparisons depend. Kroemer and Marras [1980] attempted to determine if it were possible to objectively determine whether a subject was giving a true maximal voluntary contraction during isometric contractions of the elbow flexor muscles.

Muscle strength scores obtained from any test are dependent on: patterns of muscle fiber recruitment, mechanical advantage, and activation and feedback between the muscles and the CNS. A maximal voluntary contraction is not actually the maximum amount of force that the muscle is capable of producing, but is limited by certain factors which may or may not allow the subject to reach his true maximal strength. Amongst these, Kroemer and Marras [1980] list "Deception by subject," which usually manifests itself as a submaximal performance.

Different methods of muscular strength assessment may produce different levels of variability in a subject's assessed muscular strength. Even within modes of assessment (isokinetic, isometric, etc.), there are many different ways to use these modes to objectively measure strength. Caldwell [1974] suggested a standardized regime for isometric strength assessment, whereby the subject would be instructed to steadily build up force for two seconds, and then hold the level of exertion for three to four seconds. Kroemer and Marras [1980] explain that the intended level of exertion is primarily regulated by the CNS, which sends efferent signals to trigger certain types and numbers of muscle fibers to fire, to produce the desired output. For a submaximal contraction, primarily slow-twitch fibers are activated; for maximal efforts, the fast-twitch fibers are also recruited, which have a characteristically higher firing rate than the slow-twitch fibers. Hence, regulation of force output is accomplished through interaction between "recruitment coding" (number and type of fibers activated) and "rate coding" (firing rate), mediated by afferent and efferent signals received and transmitted by the CNS. From these points, Kroemer and Marras developed three hypotheses: 1) a submaximal effort would require a relatively lengthy build-up phase, due to the higher level of processing involved in receiving feedback, and the rather complex recruitment and rate coding required to mediate a submaximal contraction; 2) an MVC requires little processing time, since recruitment and rate coding are fully taxed, and afferent signals simply confirm maximal effort; therefore, a maximal contraction requires less build-up time; and 3) the submaximal strength scores would exhibit more variability than the MVC scores.

Thirty subjects (15 male, 15 female) were used as subjects in the study. Subjects were asked to produce 25, 50, 75 and 100% of their MVC using isometric elbow flexion without the benefit of external feedback. The order of application was randomized to avoid the effects of order or fatigue. The subjects were instructed to build tension up to the desired tension in the first two seconds, and maintain it for at least three seconds more. Each subject performed ten contractions for each condition of the test. In addition to average maximum force produced, Kroemer and Marras also measured the onset slope of the force development, expressed as force units per second. Only the first two hypotheses were supported by the results. The onset slope was lowest at 25% of MVC, and increased steadily, with the greatest onset slope at 100% MVC. Kroemer and Marras also examined the relationship between the magnitude of the onset slope and the exerted force, which showed a high positive correlation at all levels of effort. The correlation coefficient was found to be greater when comparing the onset slope to the average of all ten repetitions as opposed to the average of the first five, indicating greater reliability with a greater number of trials. However, the results failed to support the third hypothesis. All subjects exhibited roughly the same variability in performance across all four levels of effort. The coefficients of variation were fairly constant at all levels, suggesting that variability in isometric testing may not be a good indicator of a submaximal effort. In attempting to exert a given percentage of one's MVC, subjects appeared to be most accurate in producing 50% of MVC (actual average effort was 50.3% of MVC). The actual average effort at 25% of MVC was 35.9% of MVC, and 60.3% when attempting to produce 75% of one's MVC.

From these results, Kroemer and Marras [1980] reported the following conclusions:

1) Variability, particularly as displayed during submaximal isometric efforts, is of questionable value in detecting "cheating";

2) Onset slope, or strength formation, has been overlooked as a possible predictor of level of effort; and

3) The pattern of onset slope magnitude at different levels of effort may provide a good indicator of whether or not a true MVC was given. This requires the application of the Caldwell protocol. A steeper build-up increases the likelihood that a true MVC was achieved.

Isokinetic Testing as a Means of Detecting Malingering

Recently, at least one attempt has been made to use isokinetic testing as a means of detecting muscle response deception. This is particularly practical, since isokinetics has become an increasingly popular treatment and assessment protocol [Davies, 1987].

Fisher [1989] attempted to use isokinetic testing to compare the reliability of seventy-six injury-free subjects performing knee extensions on a Cybex II isokinetic dynamometer. These seventy-six subjects were randomly divided into either sincere (S) or deceptive (D) conditions. Deceptive subjects were trained to fake an injury after being presented with a standardized injury scenario they were to follow in simulating a knee injury. Sincere subjects were trained to give true isokinetic MVCs. Both groups were tested at speeds of 60, 180, and 300 deg/sec, and performed five repetitions at each speed. During testing, the data was transmitted to a 286 computer interfaced with a DT2801 series data translation board. This computer was equipped with a program entitled Segmental Curve Analysis [Wynn, 1988; Sebolt and Earles-Price, 1989], which analyzed the torque curves generated during testing. Each curve was analyzed for the following six variables: isokinetic peak torque (PT), torque at five degrees joint angle prior to PT (TN5), torque at five degrees beyond PT (TP5), power (area under the torque curve) to five degrees prior to PT (PN5), power between negative and positive five degrees around PT (A55), and power from five degrees beyond PT to the end of the curve (PP5). Coefficients of variation and intraclass reliability were calculated for each of these variables to compare their reliability across four of the five repetitions. The first repetition was omitted from the analysis (previous studies by Sebolt, Earles-Price and Herbert [1989a] and by Snider [1989] have shown the first repetition to be unreliable and inconsistent with the other repetitions in a single test). This analysis revealed that sincere subjects produced higher measures of reliability across all three test speeds and for all six variables than did the deceptive subjects. Intraclass correlation coefficients were higher at 60 deg/sec than at 180 or 300 deg/sec in both conditions. Variables of torque were shown to be consistently more reliable than measures of power, with PT demonstrating the greatest reliability (S: R=0.98-0.99; D: R=0.94-0.97). Coefficients of variation were also found to be lower at 60 deg/sec than at 180 or 300 deg/sec across groups. Variables of torque also exhibited less variance than power variables in both groups, and sincere subjects exhibited lower coefficients of variance across all parameters than did deceptive subjects. Fisher concluded that subjects simulating an injury demonstrated lower reliability and greater variation in the isokinetic knee extension test than did subjects exerting true maximal force. She speculated that this may have been due in part to the subjects' lack of access to a reference point in terms of pain which may have provided a distinct and consistent limit to their performance.

Validity and Discriminate Function Analysis

There are two basic concepts central to most statistical evaluation: *reliability* and *validity*. Reliability, as the term implies, refers generally to the ability of an instrument to measure a given phenomenon consistently. That is, a reliable measure will give reproducible results across a number of trials. Validity, on the other hand, implies that the instrument measures what it presumes to measure. For example, measuring someone's waist size as an indication of basketball shooting ability would obviously not be valid. Both reliability and validity are important in any statistical analysis. It is possible to have a highly reliable measuring instrument that is not valid. In the example given previously, you may be able to accurately and repeatedly measure a player's waistline with a tape measure, proving that the tape measure method is very reliable, but because it has no relationship to the skill being assessed (basketball shooting ability), it is not valid. However, by the same token, a measuring instrument cannot be said to be valid if it is not reliable [Rothstein, 1985].

Validity is further subdivided into *internal* and *external validity*. Of the two, internal validity is essential to a good research design. Internal validity reflects the extent to which manipulations by the experimenter actually influence the results of the investigation. If other factors have not been controlled for, such as maturation or mortality of the subjects, which could also have yielded the same results as the intervention, then the study has little internal validity [Rothstein, 1985].

External validity refers to the generalizability of the results of the study. Essentially, a study with good external validity can apply its results to other populations, settings, or even other modes of treatment [Rothstein, 1985]. The ability to generalize to other subjects is called *population validity*, while the ability to apply results to other settings or conditions is referred to as *ecological validity* [Huck et al., 1974]. External validity can be adversely affected by factors such as testing or instrumentation effects, selection bias, and the interaction between multiple treatments [Rothstein, 1985].

Cross-validation is a means of testing external validity. Essentially, a hypothesis is developed from study of one sample, and is tested by applying it to a new sample. Cross-validation can also be conducted without the use of a new sample, by dividing the sample into two groups, developing a hypothesis from the first group and applying it to the second [Huck et al, 1974].

In this particular investigation, the hypotheses developed from the first group of subjects [Fisher, 1989] revolve around the application of *two-group discriminate function analysis*. This statistical method is used to develop a *discriminate function regression equation* using selected predictor variables (in this case, variables drawn from the torque curves of the isokinetic tests) which can be used to discriminate between dichotomous groups. In addition to the discriminate function regression equation, discriminate function analysis yields a value known as the *critical or cut-off score*. The result of substituting the appropriate values into the regression equation is compared to the critical score. If the result is greater than the critical score, then the subject is predicted to belong to group 1. If the result is less than the critical score, the subject is predicted to belong to group 2. In addition to the critical score, it is possible to apply an F-test to the regression equation derived in the analysis. The results of the F-test indicate whether or not the predictions made through use of the regression equation would be greater than those that could be achieved by chance alone [Huck et al., 1974].

Summary

Presently, there are three methods used to train and assess muscular strength. Isokinetic testing involves working against a lever arm set to move at a fixed speed. Instead of lifting a set weight, the subject essentially "creates" the resistance: the more force the subject exerts, the greater the resistance. The work performed at each point in the subject's ROM is dependent on the subject's ability to perform that work, thereby allowing the subject to work maximally at every point in his ROM. When a subject or patient exercises on an isokinetic machine, part of the output of the exercise session is in the form of a torque curve, a graphical representation of the amount of force the subject produces throughout the ROM. Recently, attempts have been made to use isokinetic output as a non-invasive diagnostic tool to identify a host of musculo-skeletal injuries. To date, there is limited evidence that such an application is possible, partially due to the wide variability of individual performances. Another application currently under investigation is the use of the isokinetic output to identify malingering.

Malingering involves the fictitious representation of a physical or psychological malady. Attempts have been made to use isometric measurements of hand-grip strength to identify malingering behavior with mixed results [Gilbert and Knowlton, 1893; Stokes, 1983; Niebuhr and Marion, 1987]. The role of variability in individual performance has been examined as an indicator of maximal or submaximal isometric effort [Kroemer and Marras, 1980], and has been suggested as possible evidence of the absence or presence of knee injury [Murray et al., 1977]. As a baseline for this study, previous investigations have established high levels of reliability in the performance of isokinetic knee flexion/extension tests by both normal subjects giving true maximal efforts [Sebolt, Earles-Price and Herbert, 1989a], and for injured subjects [Snider, 1989]. Snider's [1989] investigation into the performances of injured subjects found them to be highly reliable during isokinetic testing, casting some doubt into the use of variability as an indicator of the presence of knee injury. However, this same principle may have application in the identification of those who are *faking* a knee injury, thereby proving the presence of knee injury indirectly. Fisher [1989] also used the Cybex II isokinetic machine to train injury-free subjects to either fake an injury or give a true maximal effort to compare the reliability of these two groups. The present investigation used data collected by Fisher [1989] to develop discriminate function regression equations which could be used to predict whether a subject was giving a true maximal effort or faking an injury, and through cross-validation to test these equations on a new subject sample.

CHAPTER III

JOURNAL MANUSCRIPT

Discrimination Between Sincere and Deceptive Isokinetic Knee Extension Response Using Segmental Curve Analysis

Jo-Anne Lesley Lee Bogner

ABSTRACT

This study intended to determine if, by using coefficients of variation derived from data collected by Fisher [1989], it would be possible to develop prediction equations to discriminate between sincere and deceptive isokinetic knee extension tests, whether these equations could be applied to a new sample, and whether prediction accuracy is dependent on test speed. Fisher [1989] trained 76 college-age males subjects to either give a true maximal response or fake an injury during an isokinetic knee extension/flexion test at 60, 180, and 300 deg/sec. Data were transmitted to a computer running Segmental Curve Analysis [Wynn, 1988; Sebolt and Earles-Price, 1989], which computed six variables for each torque curve: peak torque (PT), torque at five degrees prior to and post-PT (T-5, T+5), area to five degrees prior to PT (A-5), area beyond five degrees post-PT (A+5), and area between five degrees pre- and post-PT (A55). Coefficients of variation were computed for each variable, which were used to develop prediction equations for each speed, and for all speeds combined. The prediction equations accurately predicted condition assignments ($p = 0.572 - 0.79$) when applied to Fisher's [1989] data. A second sample was solicited, trained, and tested in a manner similar to Fisher [1989], and the same prediction equations were applied. There was no significant difference ($p < 0.05$) in the prediction accuracy of these equations between their application to Fisher's [1989] data or to data collected in the current study. Furthermore, there appeared to be no significant effect of test speed on prediction accuracy. These data suggest that coefficients of variation could be used to discriminate between sincere and deceptive isokinetic performances.

Introduction

Presently, there are three methods used to train and assess muscular strength. Isokinetics is a promising mode of strength training, and is currently in wide use as a training tool by professional athletes, a rehabilitation tool by physical therapists and trainers, and as a research tool where precise measurement of the dynamic nature of muscular activity is essential. Isokinetic testing involves working against a lever arm set to move at a fixed speed. Instead of lifting a set weight, the subject essentially "creates" the resistance: the more force the subject exerts, the greater the resistance. The work performed at each point in the subject's ROM is dependent on the subject's ability to perform that work, thereby allowing the subject to work maximally at every point in his ROM. When a subject or patient exercises on an isokinetic machine, part of the output of the exercise session is in the form of a *torque curve*, a graphical representation of the amount of force the subject produces throughout the ROM. Recently, attempts have been made to use isokinetic output as a non-invasive diagnostic tool to identify a host of musculo-skeletal injuries [Davies, 1987]. To date, there is limited evidence that such an application is possible, partially due to the wide variability of individual performances [Rothstein, Lamb and Mayhew, 1987]. Another application currently under investigation is the use of the isokinetic output to identify malingering.

Malingering involves the fictitious representation of a physical or psychological malady, and has been a source of concern almost since the beginning of recorded history. Recently, attempts have been made to use isometric measurements of hand-grip strength to identify malingering behavior with mixed results [Gilbert and Knowlton, 1983; Stokes, 1983; Niebuhr and Marion, 1987]. The role of variability in individual performance has been examined as an indicator of maximal or submaximal isometric effort [Kroemer and Marras, 1980], and has been suggested as possible evidence of the absence or presence of knee injury [Murray et al., 1977]. As a baseline for this study, previous investigations have established high levels of reliability in the performance of isokinetic knee extension/flexion tests by both normal subjects giving true maximal efforts [Sebolt, Earles-Price and Herbert, 1989], and for injured subjects [Snider, 1989]. Snider's [1989] investigation into the performances of injured subjects found them to be highly reliable during isokinetic testing, casting some doubt into the use of variability as an indicator of the *presence* of knee injury. However, this same principle may have application in the identification of those who are *faking* a knee injury, thereby proving the presence of knee injury indirectly. Fisher [1989] also used the Cybex II isokinetic machine to train injury-free subjects to either fake an injury or give a true maximal effort at three test speeds, and then compared the reliability of these two groups. As proposed, the subjects faking an injury were found to be less reliable across six variables extracted from torque curves produced at all three test speeds than were the sincere subjects.

The purpose of this study was to determine if it was possible, using data collected by Fisher [1989], to develop discriminate function regression equations to predict whether a subject was faking an injury (deceptive) or giving a true maximal effort (sincere), and to cross-validate those equations by applying them to a new sample of subjects. Secondarily, this investigation also intended to discern if the ability to predict condition assignments (sincere or deceptive) was a function of exercise testing speed.

Methodology

This investigation was conducted in two phases. The first phase consisted of developing several discriminate function regression equations to be used in the second phase. The second phase was concerned with validation of the equations developed in Phase I by applying them to a different sample of subjects.

Phase I: Development of the Regression Equations

Fisher [1989] collected data from seventy-six uninjured college-age male subjects trained to either give a true maximal performance or fake an injury during a standard knee extension/flexion test on a Cybex II dynamometer. Each subject was tested on one randomly selected limb at 60, 180 and 300 deg/sec, and completed five repetitions at each speed. These data were simultaneously recorded by the Cybex Data Reduction Computer (CDRC), the Cybex dual channel recorder, and a computer running Segmental Curve Analysis (SCA) [Wynn, 1988; Sebolt and Earles-Price, 1989], a program specifically designed to support this research. The SCA program was used to quantify six parameters from the last four torque curves of a five repetition knee extension test: peak torque (PT), torque at five degrees joint angle prior to and following peak torque (T-5, T+5), area under the torque curve from the beginning of the torque curve to five degrees prior to peak torque (A-5), area from five degrees post peak torque to the end of the torque curve (A+5), and area between negative and positive five degrees around peak torque (A55) (Figure 2). The first torque curve was discarded from the analysis because it was reported in previous studies [Sebolt, Earles-Price and Herbert 1989a; Snider, 1989] to be highly unreliable. Fisher [1989] reported that sincere (S) subjects tended to be more reliable than deceptive (D) subjects across all six variables, and all three testing speeds.

In the present investigation, Fisher's data was used to develop several *discriminate function regression equations.* Since Fisher reported sincere subjects to be more reliable, it was theorized that *coefficients of variation* could serve as predictor variables. First, the best variables for prediction were identified using stepwise discriminate analysis through use of the PROC STEPDISC function of SAS [SAS, 1985].

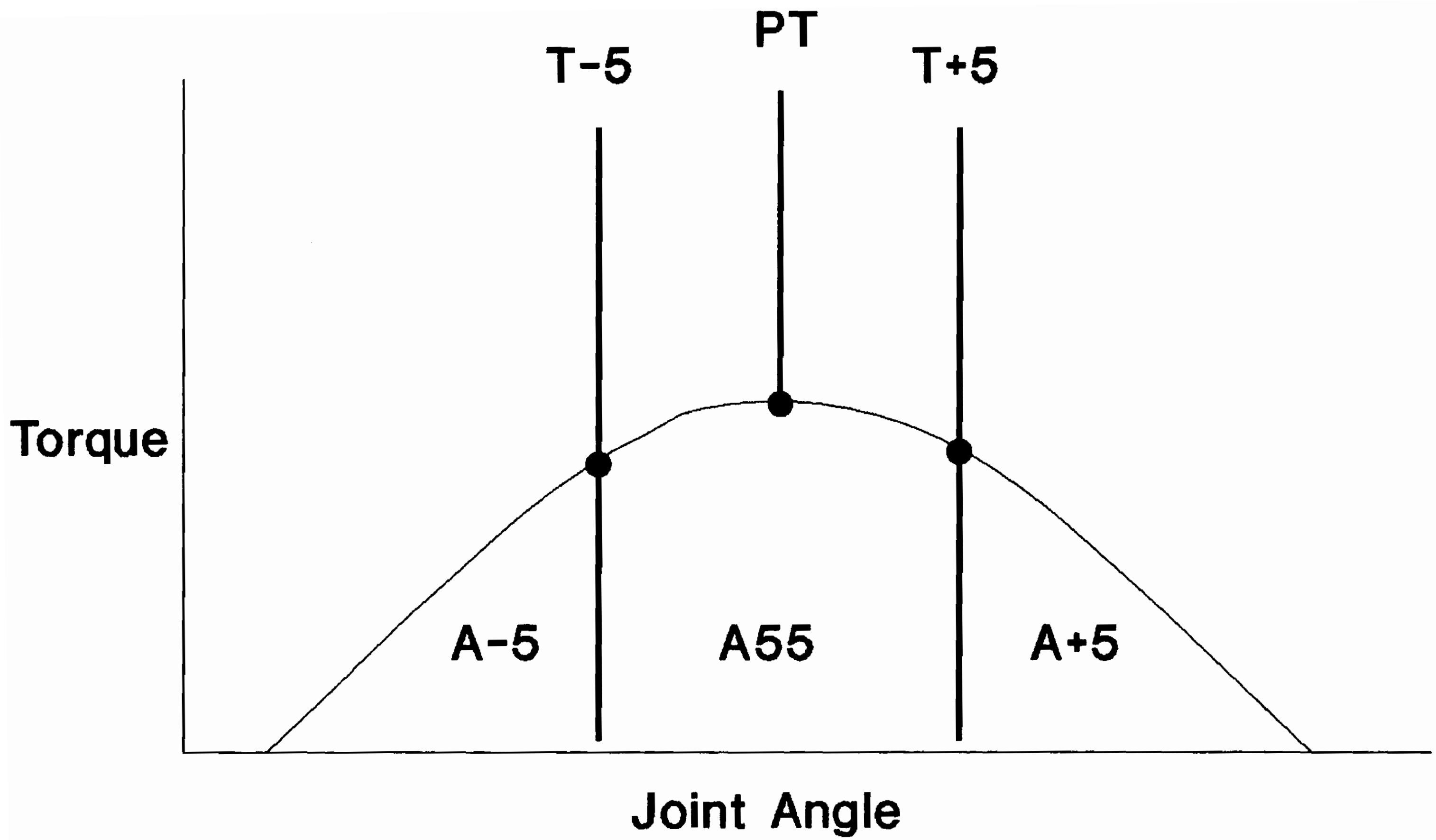


Figure 2. Parameters Selected From Torque Curve Using Segmental Curve Analysis

These variables are identified in Table 1. Discriminate function regression equations were then developed using various combinations of the coefficients of variation identified by PROC STEPDISC for each speed of testing (60, 180 and 300 deg/sec) and for all speeds combined using discriminate analysis via the PROC DISCRIM function of SAS [SAS, 1985]. The data from Fisher's [1989] study was then substituted into each of the equations, and the best predictor equations were identified as those showing the highest prediction accuracy for actual group membership (sincere or deceptive). This value was expressed as total correct predictions (correct placement to either condition - S or D) divided by the total number of subjects. The equations developed from discriminate analysis are presented in Tables 2, 3 and 4. In addition to the regression equation, discriminate analysis yielded a *critical* or *cut-off score*, to which the results of the regression equation were compared. A result greater than the cut-off score placed the subject in the sincere condition; otherwise, he was predicted to belong to the deceptive condition.

In order to test the efficiency of these equations to predict in a real population, a confidence interval representing the range of actual prediction values was computed for each equation using the following formula:

$$p - z_{a/2} * \text{sqrt}(pq/n) < P < p + z_{a/2} * \text{sqrt}(pq/n) \quad (1)$$

where:

p = the proportion of successful identifications in the sample population

q = $1 - p$

n = the number of subjects in the sample population

$z_{a/2}$ = the z value of a normal curve leaving an area of a/2 to the right.

a = the alpha level (in this case 0.05)

Table 1

Predictor Variables Identified by PROC STEPDISC [SAS, 1985]

Limb Speed	Variables Identified
60 deg/sec	VPT, VA-5, VT+5
180 deg/sec	VA-5, VT+5
300 deg/sec	VPT, VA-5
All speeds combined	VPT, VA-5

Note. VPT = coefficient of variation for peak torque; VA-5 = coefficient of variation for area prior to five degrees prior to peak torque; VT+5 = coefficient of variation for torque at five degrees joint angle beyond peak torque. Test speeds: All speeds combined = 60, 180 and 300 deg/sec.

Table 2

Prediction Equations Derived from Fisher [1989] - VPT, VT+5

Test Speed	Equation	Cut-Off
60 deg/sec	Z = -0.01797053(VPT) + 0.01329255(VT+5)	-0.23078635
180 deg/sec	Z = -0.00233832(VPT) - 0.00362565(VT+5)	-0.23655869
300 deg/sec	Z = -0.02432593(VPT) + 0.00767475(VT+5)	-0.50614769
All Speeds	Z = -0.00801363(VPT) + 0.00036028(VT+5)	-0.032190254

Note. VPT = coefficient of variation for peak torque; VT+5 = coefficient of variation for torque at five degrees joint angle beyond peak torque. Test speeds: All speeds = 60, 180 and 300 deg/sec.

Table 3

Prediction Equations Derived from Fisher [1989] -
VPT, VT+5, VA-5

Test Speed	Equation	Cut-off
60 deg/sec:	Z = -0.01903424(VPT) + 0.01274785(VT+5) + 0.00236286(VA-5)	0.19975861
180 deg/sec:	Z = -0.00495758(VPT) - 0.00359781(VT+5) + 0.00037621(VA-5)	0.08888853
300 deg/sec:	Z = -0.02858258(VPT) - 0.026196(VT+5) + 0.00373592(VA-5)	-0.14759882
All Speeds:	Z = -0.00833305(VPT) - 0.00073533(VT+5) + 0.0029788(VA-5)	-0.11341484

Note. VPT = coefficient of variation for peak torque; VA-5 = coefficient of variation for area prior to five degrees prior to peak torque; VT+5 = coefficient of variation for torque at five degrees joint angle beyond peak torque. Test speed: All speeds = 60, 180 and 300 deg/sec.

Table 4

Prediction Equations Derived from Fisher [1989] - VPT, VA-5

Test Speed	Equation	Cut-off
60 deg/sec:	Z = 0.00233764(VA-5) - 0.008261(VPT)	0.02185155
180 deg/sec:	Z = 0.00037669(VA-5) - 0.00837111(VPT)	0.12837152
300 deg/sec:	Z = 0.00043795(VA-5) - 0.03316437(VPT)	-0.14496584
All Speeds:	Z = -0.0089851(VPT) + 0.0002356(VA-5)	-0.10766866

Note. VPT = coefficient of variation for peak torque; VA-5 = coefficient of variation for area prior to five degrees prior to peak torque. Test speeds: All speeds = 60, 180 and 300 deg/sec.

P = the proportion of successful identifications in a real population.

If the lowest limits of this confidence interval were found to be greater than 0.5, this demonstrated that the ability of the prediction equation to accurately discriminate between sincere and deceptive performances was significantly ($p < 0.05$) greater than would be possible by chance alone.

Phase II: Cross-Validation of Selected Prediction Equations

41 college-age male subjects, between the ages of 18 and 28 years, were solicited from physical education classes at Virginia Polytechnic Institute and State University to participate in the current study. Criterion for participation included:

1) the absence of any history of injury, surgery or trauma to the knee, hip or associated musculature; and

2) no greater than 15% limb-to-limb deficit at 60 deg/sec.

Compliance with these criteria was determined through use of a detailed medical history questionnaire, and through isokinetic testing during orientation. All subjects also completed an Informed Consent form prior to testing. The subjects completed two sessions on a Cybex II isokinetic dynamometer.

Session I: Orientation. The first session was conducted by a lab assistant, and served to familiarize the subjects with the testing apparatus, and to train them to either give a true maximal effort, or to fake an injury. The orientation session began with a brief (3-5 minute) warm-up by slow cycling (50-60 RPM) on a stationary cycle set at a low resistance (0-25 watts). The preferred leg was determined as the limb the subject would use if asked to kick a soccer ball for distance. This was the first limb tested. The subject was seated in the testing apparatus in an upright position using standard Cybex test preparation procedures. The subject was secured to the testing apparatus by Velcro straps secured at the pelvis, mid-thigh, and ankle. During all testing, subjects were instructed to keep their arms crossed across their chest.

The same orientation protocol was applied to all subjects. First, subjects were instructed to read a standardized scenario for a true maximal effort. During all testing, subjects were instructed to work through their full ROM, with no hesitation between repetitions. Each subject was trained and tested at 60, 180 and 300 deg/sec. After the test administrator was satisfied that the subject was performing in a proper and consistent manner, the subject was instructed to give five maximal repetitions, which were recorded. The same scenario was applied to the non-preferred limb. After the second limb was tested at 60 deg/sec, the limb-to-limb deficit was determined, and if the subject exceeded the 15% cut-off, he was excused. If he qualified as a subject, maximal training was concluded at 180 and 300 deg/sec. After being trained on both limbs to give a maximal effort at all three speeds, one limb was randomly selected for training to fake an injury. The subject was then instructed to read the deceptive effort scenario. The same order of practice and testing was completed as for the maximal effort training, on the randomly assigned limb only, with the subject applying the deceptive effort scenario to his performance. At the end of the orientation, each subject was randomly assigned to either the sincere or deceptive condition, and scheduled for retesting. The subject was instructed to re-read the scenario description for the condition to which he was assigned prior to retesting, and was told not to reveal this assignment to the test administrator.

Session II: Data Collection. The second session was conducted by the principle investigator, who was unaware as to which condition the subjects had been assigned. Subjects were positioned in and secured to the testing apparatus in a manner identical to that used during the orientation session. Each subject was tested on the limb randomly assigned during the orientation at the following three speeds. Each subject was assigned one "slow", one "medium" and one "fast" speed, randomly selected from the following range of speeds: "slow": 60, 90, and 120 deg/sec; "medium": 150, 180, and 210 deg/sec; and "fast": 240, 270 and 300 deg/sec. After a brief warm-up, each subject completed a practice session at each speed. Subjects had been previously instructed to perform based upon the condition to which they had been assigned. This meant that a subject assigned to fake an injury would not actually give a true maximal effort when instructed to do so, but would perform in a manner he perceived to be appropriate for an injured subject instructed to give a maximal effort. After the subject had adequate chance to practice each speed, the actual test was administered. Starting with the slow speed, the subject was given two maximal repetitions for practice, followed by five maximal repetitions, which were recorded. Data from the five maximal repetitions were simultaneously recorded using the CDRC, the dual channel recorder, and transmitted to a microcomputer running the Segmental Curve Analysis (SCA) program [Wynn, 1988; Sebolt and Earles-Price, 1989]. The SCA program was used to compute same six variables for the last four torque curves for each test speed as in Fisher's [1989] study. From these values, coefficients of variation (V) were computed for each variable for each test speed for each subject. These coefficients were then substituted into the discriminate function regression equations derived previously, and a prediction was made as to which condition each subject had been assigned. These predictions were then compared to actual condition assignments. An expression of prediction accuracy was computed as the number of correct assignments to condition divided by the total number of subjects. These prediction values were also tested to determine if they were statistically significant using the same procedure as for Fisher's data described previously.

Secondarily, a comparison was made between the prediction accuracy of the regression equations when applied to Fisher's data and their ability to predict when applied to the second sample of subjects, using the following equation:

$$p_1-p_2-z_{a/2} * \mathrm{sqrt}(dum) < D < p_1-p_2+z_{a/2} * \mathrm{sqrt}(dum) \qquad (2)$$

where:

p_1,p_2 = the proportion of successful identifications in samples from populations 1 and 2, respectively

dum = $((p_1*q_1)/n_1)+((p_2*q_2)/n_2)$

n_1,n_2 = the number of subjects sampled in populations 1 and 2 respectively

D = the true difference between the population proportions corresponding to p_1 and p_2

If the interval arising from this equation was found to contain the value 0 (zero), then it could be said that p_1 and p_2 were not significantly different from one another. The same equation was used to compare predictions at various speeds to determine if there were any effect on the ability to predict based on testing speed.

Results

Three variable sets were used to develop prediction equations, based on the results of the step-wise discriminate analysis. Equations were derived for each speed, and for all speeds combined using each of the following three sets of predictor variables: coefficients of variation (V) for PT and T+5; VPT, VT+5 and VA-5; and VPT and VA-5. Analysis of these results were then conducted to test the three basic hypotheses of the research.

Prediction Accuracy of Equations When Applied to Fisher's [1989] Data. Prediction accuracy of equations derived from and applied to Fisher's data was found to be significantly greater than 50% at 60, 300 deg/sec and for all speeds combined, for all predictor variable combinations. Only in the case of tests conducted at 180 deg/sec was prediction accuracy of all equations found to be non-significant. Table 5 shows prediction accuracy, measured as percent correct predictions, for Fisher's data.

Prediction Accuracy of Equations When Applied to the Current Data. Using the same equations to predict group membership with data from the present study yielded somewhat less than the anticipated results. Only in the case of tests conducted at medium speeds and at all speeds combined, using VPT and VT+5 as the predictor variables were prediction accuracies significantly greater than 50% (Table 6). However, when the prediction values of Fisher's data were compared to those found when the same equations were applied to the present study, these were found to be significantly different only when applied to fast speeds for all equations and for all speeds combined using VPT and VA-5 as the predictor variables (Table 7).

Effect of Test Speed on Prediction Accuracy. Hypothesis 3 concerned the effect of test speed on prediction accuracy. When comparing predictability based on test speed, slow was different from fast when using VPT and VA-5 as the predictor variables. In all other cases, there was no significant difference based on test speed.

Similarly, equations derived from all speeds combined were compared to the equations derived from the same set of predictor variables from individual speeds to determine if one equation for all speeds could predict as well as one derived from and applied to individual speeds. There was no significant difference in the ability to predict between equations for individual speeds compared to equations derived from all speeds combined.

Table 5

Prediction Accuracy of Equations When Applied to Fisher's [1989] Data

	Test Speed (deg/sec)			
Variables	60	180	300	All Speeds
VPT,VT+5	0.630*	0.575	0.72*	0.645*
VPT,VT+5,VA-5	0.679*	0.588	0.72*	0.572*
VPT,VA-5	0.704*	0.556	0.79*	0.636*

* significant at $p < 0.05$.

Note. VPT = coefficient of variation for peak torque; VA-5 = coefficient of variation for area prior to five degrees prior to peak torque; VT+5 = coefficient of variation for torque at five degrees joint angle beyond peak torque. Test speeds: All speeds = 60, 180 and 300 deg/sec.

Table 6

Prediction Accuracy of Equations When Applied to Bogner's [1991] Data

	Test Speed			
Variables	Slow	Medium	Fast	All Speeds
VPT,VT+5	0.53	0.67*	0.49	0.60*
VPT,VT+5,VA-5	0.56	0.45	0.49	0.46
VPT,VA-5	0.65	0.49	0.38	0.52

* significant at $p < 0.05$.

Note. VPT = coefficient of variation for peak torque; VA-5 = coefficient of variation for area prior to five degrees prior to peak torque; VT+5 = coefficient of variation for torque at five degrees joint angle beyond peak torque. Test speeds: Slow = 60, 90 and 120 deg/sec; Medium = 150, 180 and 210 deg/sec; Fast = 240, 270 and 300 deg/sec; All speeds = 60, 90, 120, 150, 180, 210, 240, 270 and 300 deg/sec.

Table 7

Estimated Difference Between Accuracy of Prediction When Applied to Fisher [1989] and Bogner's [1991] Data

	Test Speed			
Variables	Slow	Medium	Fast	All speeds
VPT,VT+5	0.1	-0.09	0.23*	0.05
VPT,VT+5,VA-5	0.12	0.14	0.23*	0.11
VPT,VA-5	0.06	0.08	0.41*	0.13*

* significant at $p < 0.05$.

Note. VPT = coefficient of variation for peak torque; VA-5 = coefficient of variation for area prior to five degrees prior to peak torque; VT+5 = coefficient of variation for torque at five degrees joint angle beyond peak torque. Test speeds: Slow = 60, 90, and 120 deg/sec; Medium = 150, 180, and 210 deg/sec; Fast = 240, 270 and 300 deg/sec; All speeds = 60, 90, 120, 150, 180, 210, 240, 270 and 300 deg/sec.

Discussion

Differences between the two levels of prediction accuracy found in the two data sets could be attributed in part to the way the regression equations were developed and applied. In the case of Fisher's [1989] data, subjects were tested at 60, 180, and 300 deg/sec. The equations for "slow", "medium", and "fast" speeds were then derived from data from these test speeds. In the current study, "slow" speeds were designated as 60, 90, and 120 deg/sec; "medium" as 150, 180, and 210 deg/sec; and "fast" as 240, 270, and 300 deg/sec. One would expect that if any difference between the two data sets would occur, it would most likely be at the slow and fast speeds, since the speed from which the equations arose is at the extreme upper or lower limit of the range of speeds designated to be either "slow" or "fast." However, this was found to be the case for fast speeds only, where prediction accuracy was greater when applied to the data from which the equations were derived.

In order to examine the possible effect of these extremes in speed, the predictions based on Fisher's data were compared to the present study using only data collected at 60, 180 and 300 deg/sec. When the prediction equations derived from Fisher's data were applied to the current data set using these limited speeds, the absolute prediction values were in most cases somewhat less than using the whole range of speeds, but not significantly. However, in no instance was prediction accuracy significantly greater than 50%. When these prediction values were compared to Fisher's, the only significant differences between data sets occurred at 60 deg/sec using VPT and VT+5 as the predictor variables, and at all speeds combined using VPT and VA-5 as predictors. However, these tests increased the range of the confidence intervals because the N of the second set of data was further reduced.

The fact that the greatest prediction accuracy occurred with Fisher's data at 300 deg/sec makes sense in light of Fisher's examination of coefficients of variation for each of the three speeds. In each case, the coefficients of variation for all parameters examined (PT, T-5, T+5, A-5, A+5, A55) tended to increase with test speed for both test conditions (S or D). That is, as limb acceleration increased, subjects found it increasingly difficult to replicate their performances across several repetitions. At 300 deg/sec, the coefficients of variation for deceptive subjects were nearly twice as great as those for sincere subjects across all parameters.

This data also appears to support the use of torque parameters as the best discriminators between sincere and deceptive performances. This also makes sense in light of Fisher's findings, which showed torque parameters to be more stable than power (i.e., area under the curve) parameters at all test speeds, and for both conditions (S or D). It is likely that both experimental conditions showed such extreme levels of variability in terms of power output that power variables lent little to the ability of prediction equations to accurately discriminate between sincere and deceptive performances. The combination of VPT and VT+5 yielded the only two prediction equations that were significant when applied to data from the present study, and the only set of equations that predicted equally well for any test speed or for all speeds combined when applied to Fisher's data. In fact, the one equation from these results that showed the greatest potential for refinement and future application was the combined speed equation using VPT and VT+5 as predictor variables. This equation demonstrated the greatest prediction accuracy of the combined speed equations when applied to Fisher's [1989] data ($p = 0.65$), and was one of only two equations applied to data from the current study which achieved significance ($p = 0.60$). In addition, this equation has the advantage of being applied independent of test speed, which could be very useful in clinical settings where certain test speeds may be contraindicated.

However, step-wise discriminate analysis of Fisher's data revealed that VA-5 was the one best predictor variable in common with all test speeds. Kroemer and Marras [1980], in their investigation into objective differences between maximal and submaximal isometric elbow flexor tests, concluded that variability of average maximal force output was of questionable value in discriminating between different levels of effort (25, 50, 75 or 100% MVC). However, they also reported that onset slope, derived from the first portion of the force curve from onset of contraction to maximal force output, showed a direct relationship to level of effort. Similarly, Gilbert and Knowlton [1983], in applying this information from Kroemer and Marras [1980] to discriminate between sincere and deceptive isometric hand-grip tests, reported a much higher correlation between SLP (rate of force development) and peak force for maximal voluntary grip contractions ($r = 0.66$) compared to 75% of MVGC ($r = 0.25$). The first portion of the torque or force curve, therefore, apparently provides a significant amount of information regarding level of effort.

The reason for the difference in onset slope between levels of effort was theorized by Kroemer and Marras [1980] to be due to the relative contributions of slow and fast twitch fibers to a maximal or submaximal effort. Submaximal contractions characteristically use predominantly ST fibers, which tend to have a lower activation rate than FT fibers, and hence require more time to build up force. Maximal contractions, on the other hand, fully tax both rate and recruitment coding due to the use of both ST and FT fibers, allowing for a much faster build-up or onset phase for a maximal contraction.

These same contributions of fiber type to level of effort may also explain differences in a subject's ability to maintain that effort. Submaximal efforts require more feedback between the contracting muscle and the CNS to regulate that effort. Therefore, reduced activation rate of ST fibers should theoretically cause greater variability in a subject's ability to maintain a submaximal contraction, because of the need for continuous transmission of information concerning force of contraction to the CNS via afferent nerves, and the transmission of rate and recruitment coding information to the contracting muscle via efferent nerves. Maximal contractions, on the other hand, do not rely as heavily on this feedback to maintain a constant contraction, since both rate and recruitment coding are fully taxed [Kroemer and Marras, 1980]. One would particularly expect such variability to be more apparent in an isometric contraction, wherein a subject is required to maintain a given level of effort for three to five seconds. Kroemer and Marras [1980] were unable to observe any differences in level of effort by examining variability *across* trials, but Gilbert and Knowlton [1983] were able to demonstrate that variability *within* a given trial, measured as the ratio of maximal force to average force (DEV), provided the best indication of level of effort.

The current study is one of the first to use *coefficients of variation*, a relative indicator of effort, to discriminate between sincere and deceptive efforts. Other studies [Murray et al., 1977; Kroemer and Marras, 1980; Stokes, 1983; Gilbert and Knowlton, 1983; Niebuhr and Marion, 1987] have used absolute measures of performance (typically peak torque or force), relying on variability contained within these indices of performance to discriminate between level of effort, rather than isolating the variability score itself as a discriminator. It appears from these results that the use of coefficients of variation, particularly those derived from parameters of torque, has future potential for discriminating sincere and deceptive isokinetic performances.

References

Davies, G. (1987). A Compendium of Isokinetics in Clinical Usage (3rd ed.). La Crosse, WI: S & S Publishers.

Fisher, M. E. (1989). Intraclass Reliability Estimates of Isokinetic Response in Normal and Deceptive Subjects using Segmental Curve Analysis. Unpublished master's thesis, Virginia Polytechnic Institute and State University. Blacksburg.

Gilbert, J. C., and Knowlton, R. G. (1983). Simple method to determine sincereity (sic) of effort during a maximal isometric test of grip strength. American Journal of Physical Medicine, 62(3), 135-144.

Kroemer, K. H. E., and Marras, W. S. (1980). Towards an objective assessment of the "maximal voluntary contraction" component in routine muscle strength measurements. European Journal of Applied Physiology, 45(1), 1-9.

Murray, M. P., Baldwin, J. M., Gardner G. M., Sepic, S. B., and Downs, W. J. (1977). Maximum isometric knee flexor and extensor muscle contractions: Normal patterns of torque versus time. Physical Therapy, 57(6), 637-643.

Niebuhr, B. R., and Marion, R. (1987). Detecting sincerity of effort when measuring grip strength. American Journal of Physical Medicine, 66(1), 16-23.

Rothstein, J. M., Lamb, R. L., and Mayhew, T. P. (1987). Clinical uses of isokinetic measurements. Physical Therapy, 67(12), 1840-1844.

Sebolt, D. R., and Earles-Price, S. (1989). Isokinetic Segmental Curve Analysis [Abstract]. Proceedings of the American College of Sports Medicine, May 31-June 3, 1989, Baltimore, MD.

Sebolt, D. R., Earles-Price, S., and Herbert, W. G. (1989). Reliability estimates of isokinetic torque curves utilizing Segmental Curve Analysis [Abstract]. Proceedings of the International Isokinetic Congress, April 5-8, 1989, Lake Tahoe, NV.

Snider, D. M. (1989). Internal Consistency Reliability of Isokinetic Response Measures in Knee Injured Subjects Using Segmental Curve Analysis. Unpublished master's thesis, Virginia Polytechnic Institute and State University. Blacksburg.

Stokes, H. M. (1983). The seriously uninjured hand - weakness of grip. Journal of Occupational Medicine, 25(9), 683-684.

Travin, S., and Protter, B. (1984). Malingering and malingering-like behavior: some clinical and conceptual issues. Psychiatric Quarterly, 56(3), 189-197.

Wynn, R. (1988). Segmental Curve Analysis. Unpublished computer program, Virginia Polytechnic Institute and State University. Blacksburg.

CHAPTER IV

SUMMARY OF THE STUDY

This investigation was conducted to examine the application of discriminate analysis to the problem of differentiating between sincere and deceptive isokinetic knee extension tests. The investigation was conducted in two phases. The first phase consisted of development of the discriminate function regression equations using data collected by Fisher [1989]. The second phase served to test two basic hypotheses: First, that the equations derived from Fisher [1989] would not predict group membership as accurately when applied to a new sample of subjects, and secondly, that prediction accuracy was not dependent on exercise test speed.

Forty-one injury-free male subjects between 18 and 29 years of age were solicited from physical education activity classes to participate in this study. All subjects were screened for injury to the knee or associated joints or musculature and signed an Informed Consent form prior to all testing. All subjects completed two sessions on the Cybex II isokinetic dynamometer. The first session served to train the subjects to either give a true maximal effort or to fake an injury at three test speeds (60, 180 and 300 deg/sec). Upon completion of the orientation session, subjects were randomly assigned to either the sincere (S) or deceptive (D) condition, and scheduled for testing.

The second session was conducted by the principle investigator, who was unaware of the subjects' condition assignments. Each subject was tested on one randomly assigned limb (either preferred or non-preferred), and at three randomly selected speeds. Each subject was assigned one "slow" (60, 90 or 120 deg/sec), one "medium" (150, 180 or 210 deg/sec), and one "fast" speed (240, 270, and 300 deg/sec). After warm-up and practice, the subjects performed five maximal repetitions at each test speed. Data were simultaneously transmitted to the Cybex

Data Reduction Computer (CDRC), the Cybex dual channel recorder, and a computer running Segmental Curve Analysis (SCA) [Wynn, 1988; Sebolt, Earles-Price and Herbert, 1989a, 1989b]. The SCA program was used to derive the following variables from the last four torque curves of the five repetition test: peak torque (PT), torque at five degrees joint angle prior to and following peak torque (T-5, T+5), average area from the beginning of the torque curve to five degrees prior to peak torque (A-5), average area from five degrees post peak torque to the end of the torque curve (A+5), and average area between negative and positive five degrees around peak torque (A55). Coefficients of variation were computed for each variable across the last four repetitions. These values were then substituted into the prediction equations derived from Fisher's [1989] data. Prediction accuracy of the regression equations were expressed as the number of correct placements to condition (S or D) divided by the total number of subjects.

The first and perhaps most fundamental problem in this research was to provide evidence that sincere subjects were in fact giving a true maximal effort. As stated by Kroemer and Marras [1980], a deceptive performance usually manifests itself in the form of a submaximal performance. Relative measures of peak torque are usually expressed in terms of the ratio of peak torque to body weight percentage (PT/BW), and have been extensively studied and documented, particularly by Davies [1987]. Figure 3 shows the average PT/BW ratios for both sincere and deceptive subjects at all nine test speeds, compared to those considered normative by Davies [1987] at 60, 180, and 300 deg/sec. From 60-240 deg/sec, the absolute values and rate of decline demonstrated by sincere subjects appear to more closely parallel that described by Davies [1987] than did deceptive subjects. Only in the case of tests conducted at 270 and 300 deg/sec did there appear to be no clear-cut evidence whether one group or the other was giving an effort equal to that considered "normal".

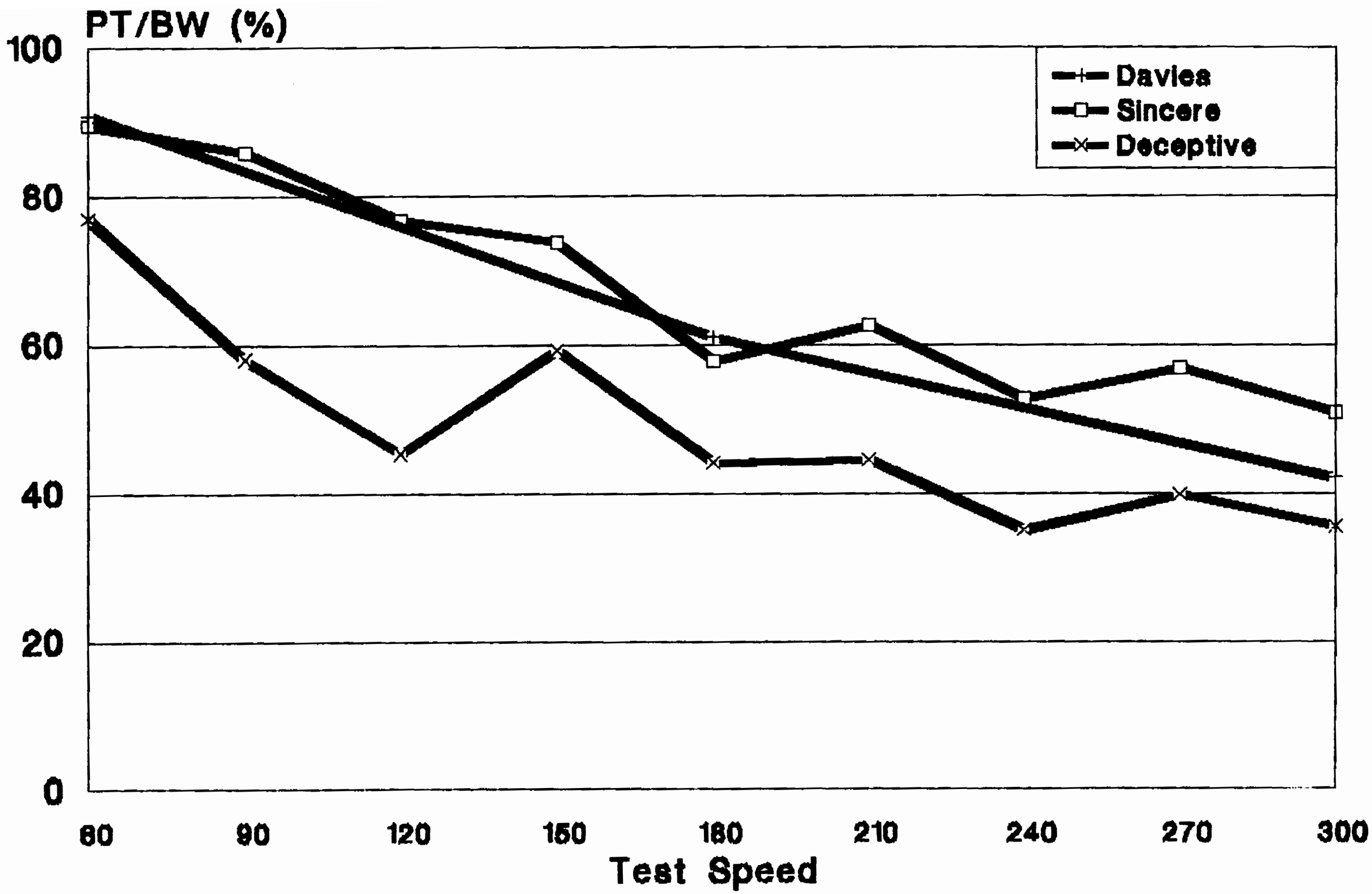


Figure 3. Mean Peak Torque to Body Weight Ratios - Sincere vs. Deceptive vs. Davies [1987]

Prediction accuracy of the regression equations when applied to Fisher's [1989] data were significantly greater than could be achieved by chance ($p > 0.5$) for all equations derived from the individual speeds of 60 and 300 deg/sec, and for all equations derived from and applied to all speeds combined. Only in the case of tests conducted at 180 deg/sec were prediction values non-significant. When these same equations were applied to data from the present study, significant prediction values were achieved only for tests at 180 deg/sec, and for all speeds combined when using VPT and VT+5 as predictor variables. However, when these two sets of data were compared, prediction values were significantly different only in the cases of fast speeds (240, 270 and 300 deg/sec), and for all speeds combined using VPT and VA-5 as predictor variables. Test speed was found to be a significant factor only when using VPT and VA-5 as predictor variables. Similarly, when equations derived from all speeds combined were compared to equations derived from the same predictor variables at individual test speeds, it was found that general speed equations predicted as well as the individual speed equations in all cases.

Research Implications

One of the primary findings of this research was the identification of three out of the six variables examined as indicators of deceptive performance. VPT, VT+5 and VA-5 were found to be the three discriminators between sincere and deceptive performances using step-wise discriminate analysis common to all three test speeds and analysis using all speeds combined. Of these three, VA-5 was found to be a significant contributor common to all four test speed conditions. This is interesting in the face of the findings of Kroemer and Marras [1980] and also of Gilbert and Knowlton [1983].

Kroemer and Marras [1980] theorized and showed that the rate of force development would be longest for submaximal efforts of 25% MVC and would grow increasingly shorter, with the shortest duration of force development occurring with maximal effort (100% MVC). Similarly, Gilbert and Knowlton [1983], in attempting to isolate variables that could best indicate deceptive isometric handgrip tests, found that DEV (ratio of average force to peak force) provided the best evidence of such behavior, regardless of the sex of the subject. However, this variable in combination with SLP (rate of force application), was the best combination used to discriminate between maximal and submaximal (75% of MVGC) efforts in males. Gilbert and Knowlton [1983] also reported a higher correlation between SLP and peak force for sincere subjects ($r = 0.66$) than for subjects attempting to produce 75% of their MVGC ($r = 0.25$). It seems likely that in spite of the apparent instability of this particular portion of the torque curve, onset of force application provides significant objective evidence of submaximal efforts.

However, Kroemer and Marras [1980] failed to show that there was any significant difference in the *variability* of peak force between submaximal (25, 50 and 75% of MVC) and maximal (100% MVC) isometric hand grip contractions. Submaximal efforts require more feedback between the contracting muscle and the CNS to regulate that effort, and particularly in the case of ST fibers, reduced activation rate should theoretically cause greater variability in a subject's ability to maintain a submaximal contraction. One would particularly expect such variability to be more apparent in an isometric contraction, where a subject is required to maintain a given level of effort for three to five seconds, as was the case in Kroemer and Marras' [1980] study. However, Kroemer and Marras [1980] were unable to any systematic differences in level of effort by examining variability *across* trials. Gilbert and Knowlton [1983], on the other hand, were able to demonstrate variability *within* a given trial, measured as the ratio of maximal force to average force (DEV), provided the best indication of level of effort. The results of this investigation appear to support the use of variability across trials to discriminate between sincere and deceptive isokinetic behavior. The different findings may be due to the difference in testing modalities.

Further investigation into the application of Segmental Curve Analysis [Wynn, 1988; Sebolt and Earles-Price, 1989a] to other modes of testing, such as isometric torque curves, may serve to answer this question.

Secondly, these results appear to support the lack of a significant affect for testing speed in the discrimination of these types of behaviors, particularly when using torque parameters as predictor variables. The one equation from this investigation that shows the greatest potential for refinement and future application is the combined speeds equation using VPT and VT+5 as predictor variables. This equation demonstrated the greatest prediction accuracy of the combined speed equations when applied to Fisher's [1989] data ($p = 0.65$), and was the one of only two equations applied to the current data which achieved significance ($p = 0.60$). In addition, this equation has the advantage of being applied independent of test speed. This fact would make this equation particularly useful in a clinical setting, where the application of certain test speeds may be contraindicated.

The specific use of coefficients of variation as discriminators of sincere and deceptive behavior is a major finding of this investigation. Other studies [Murray et al., 1977; Kroemer and Marras, 1980; Stokes, 1983; Gilbert and Knowlton, 1983; Niebuhr and Marion, 1987] have used absolute measures of performance (typically peak torque or force), and have relied on the variability contained within these indices of performance to discriminate between these types of performances, rather than isolating the variability score itself as a discriminator. It appears from these results that the method presented in this study has future potential for discriminating between sincere and deceptive isokinetic performances.

Recommendations for Future Research

In spite of the fact that this research appears to answer many questions, it also raises many more. First, it would be valuable to determine if Segmental Curve Analysis [Wynn, 1988; Sebolt and Earles-Price, 1989a] could be applied to torque curves derived from isometric testing, particularly of hand-grip strength, since this is already a widely acceptable method used to detect malingering. Application of SCA could provide a better method to specifically target *variability* in isometric testing than methods used by previous studies. A variation of this same study using isometric measures derived from a Cybex knee extension test could also be conducted to test the potential of discriminate analysis to detect deceptive performances.

This study compared variability within a single limb; another potential variation of this study could compare limb-to-limb variability. One would expect a sincere patient to exhibit equal variability of performance between limbs, whereas a malingering subject would exhibit more variability with his "injured" limb compared to the "unaffected" limb. This would provide a within-subject standard of performance which could provide a more accurate basis for comparison.

If this method could be applied to isokinetic tests applied to other parts of the body, particularly the low back, where there is an even greater incidence of malingering behavior, a significant impact could be made on the number of fraudulent insurance claims, which could substantially affect health insurance costs in the future.

Other possible refinements to this study concern methods to increase variability, since this is the measure by which conditions are differentiated. An easy way to increase variability would be to include the first torque curve in the analysis. Previous research has found that the first torque curve is very unreliable when compared to the remaining torque curves in an isokinetic test [Sebolt and Earles-Price, 1989], and was therefore excluded from the analysis in this investigation and Fisher's [1989]. It is possible that inclusion of this curve in the analysis may have increased variability to a degree where prediction accuracy would have been enhanced.

Another simple method to increase variability would be to increase the number of repetitions in the exercise test. This is obvious from a statistical standpoint, since it takes a minimum of two values to measure variation, and only four were used in this study. Increased number of repetitions may be possible for test speeds greater than 180 deg/sec, but would have obvious physiological limitations for tests approaching 60 deg/sec, where fatigue would become an increasingly confounding factor. An advantage of testing at higher limb velocities is that subjects with relative contraindications to testing are customarily tested at these higher speeds [Davies, 1987]. A possible future research study could concentrate on speeds ranging from 180 - 300 deg/sec, and increase the number of repetitions (8 - 10) in an attempt to increase variability.

It is in fact remarkable that any distinction could be made between conditions due to the effect of training subjects. During orientation, subjects were required to repeat each step of the protocol until the trainer was satisfied the subject was performing in a "proper and consistent manner." This meant that subjects were utilizing their full ROM, and by visual inspection of the dual channel recorder output appeared to produce nearly identical torque curves throughout the test. In other words, the trainers were instructed to "train out" variability. In spite of this, variability could still be used to differentiate condition assignments with a significant degree of success. In most clinical settings, a patient is not given nearly this much opportunity to practice before testing. One would expect, therefore, that even greater variability would be observed during clinical testing.

Finally, an obvious step in developing means of detecting subjects that are truly malingering is to use this same methodology to compare truly injured subjects to those who are faking an injury. Using truly injured subjects requires some medical considerations to protect them from exacerbating and existing injury, but only by passing this final test can it be said that this method holds some promise in providing significant objective evidence of malingering behavior.

REFERENCES

Caldwell, L. S., Chaffin, D. B., Dukes-Dobos, F. N., Kroemer, K. H. E., Lanbach, L. L., Snook, S. H., and Wasserman, D. E. (1974). A proposed standard procedure for static muscle strength testing. American Industrial Hygiene Association Journal, 35(4), 201-206.

Cybex. (1983). Isolated Joint Testing and Exercise. Ronkonkoma, NY: Author.

Davies, G. (1987). A Compendium of Isokinetics in Clinical Usage (3rd ed.). La Crosse, WI: S and S Publishers.

Darley, J. M., Glucksberg, S., Kamin, L. J., and Kinchla, R. A. (1981). Psychology. Englewood Cliffs, NJ: Prentice-Hall, Inc.

Edwards, L. (1988). Worker's compensation insurance. Orthopaedic Clinics of North America, 14(3), 661-668.

Elliott, J. (1978). Assessing muscle strength isokinetically. Journal of the American Medical Association, 240(22), 2408-2409.

Fisher, M. E. (1989). Intraclass Reliability Estimates of Isokinetic Response in Normal and Deceptive Subjects using Segmental Curve Analysis. Unpublished master's thesis, Virginia Polytechnic Institute and State University. Blacksburg.

Gilbert, J. C., and Knowlton, R. G. (1983). Simple method to determine sincereity (sic) of effort during a maximal isometric test of grip strength. American Journal of Physical Medicine, 62(3), 135-144.

Grace, T. G., Sweester, E. R., Nelson, M. A., Ydens, L. R., and Skipper, B. J. (1984). Isokinetic muscle imbalance and knee joint injuries. Journal of Bone and Joint Surgery, 66-A(5), 734-740.

Grow, R., McVaugh, W., and Eno, T. (1980). Faking and the MMPI. Journal of Clinical Psychology, 36(4), 910-917.

Hageman, P. A., Gillaspie, D. M., and Hill, L. D. (1988). Effects of speed and limb dominance on eccentric and concentric isokinetic testing of the knee. Journal of Orthopaedic and Sports Physical Therapy, 10(2), 59-65.

Huck, S. W., Cormier, W. H., and Bounds, W. G. (1974). Reading Statistics and Research. New York, NY: Harper and Row, Publishers.

Jenkins, W. L., Thackaberry, M., and Killian, C. (1984). Speed specific isokinetic training. Journal of Orthopaedic and Sports Physical Therapy, 6(3), 181-183.

Kandel, E. R., and Schwartz, J. H. (1985). Principles of Neural Science (2nd ed.). New York: Elsevier Science Publishing Co., Inc.

Kreighbaum, E., and Barthels, K. M. (1985). Biomechanics: A Qualitative Approach for Studying Human Movement. Minneapolis, MN: Burgess Publishing Company.

Kroemer, K. H. E., and Marras, W. S. (1980). Towards an objective assessment of the "maximal voluntary contraction" component in routine muscle strength measurements. European Journal of Applied Physiology, 45(1), 1-9.

Lesmes, G. R., Costill, D. L., Coyle, E. F., and Fink, W. J. (1978). Muscle strength and power changes during maximal isokinetic training. Medicine and Science in Sports and Exercise, 10(4), 266-269.

Murray, M. P., Baldwin, J. M., Gardner G. M., Sepic, S. B., and Downs, W. J. (1977). Maximum isometric knee flexor and extensor muscle contractions: Normal patterns of torque versus time. Physical Therapy, 57(6), 637-643.

Niebuhr, B. R., and Marion, R. (1987). Detecting sincerity of effort when measuring grip strength. American Journal of Physical Medicine, 66(1), 16-23.

Perrin, D. H., Lephart, S. M., and Weltman, A. (1989). Specificity of training on computer obtained isokinetic measures. Journal of Orthopaedic and Sports Physical Therapy, 10(12), 495-498.

Perrin, D. H., Robertson, R. J., and Ray, R. L. (1987). Bilateral isokinetic peak torque, torque acceleration energy, power, and work relationships in athletes and nonathletes. Journal of Orthopaedic and Sports Physical Therapy, 9(5), 184-189.

Rothstein, A. L. (1985). Research Design and Statistics for Physical Education. Englewood Cliffs, NJ: Prentice-Hall, Inc.

Rothstein, J. M., Lamb, R. L., and Mayhew, T. P. (1987). Clinical uses of isokinetic measurements. Physical Therapy, 67(12), 1840-1844.

Sebolt, D. R., and Earles-Price, S. (1989). Isokinetic Segmental Curve Analysis [Abstract]. Proceedings of the American College of Sports Medicine, May 31-June 3, 1989, Baltimore, MD.

Sebolt, D. R., Earles-Price, S., and Herbert, W. G. (1989a). Reliability estimates of isokinetic torque curves utilizing Segmental Curve Analysis [Abstract]. Proceedings of the International Isokinetic Congress, April 5-8, 1989, Lake Tahoe, NV.

Sebolt, D. R., Earles-Price, S., and Herbert, W. G. (1989b). Segmental Curve Analysis to detect attempts to feign a knee injury [Abstract]. Proceedings of the International Isokinetic Congress, April 5-8, 1989, Lake Tahoe, NV.

Sherman, W. M., Plyley, M. J., Vogelgesang, D., Costill, D. L., and Habansky, A. J. (1981). Isokinetic strength during rehabilitation following arthrotomy: specificity of speed. Athletic Training, 16(2), 138-141.

Snider, D. M. (1989). Internal Consistency Reliability of Isokinetic Response Measures in Knee Injured Subjects Using Segmental Curve Analysis. Unpublished master's thesis, Virginia Polytechnic Institute and State University. Blacksburg.

Stokes, H. M. (1983). The seriously uninjured hand - weakness of grip. Journal of Occupational Medicine, 25(9), 683-684.

Timm, K. E. (1987). Investigation of the physiological overflow effect from speed-specific isokinetic activity. Journal of Orthopaedic and Sports Physical Therapy, 9(3), 106-110.

Travin, S., and Protter, B. (1984). Malingering and malingering-like behavior: some clinical and conceptual issues. Psychiatric Quarterly, 56(3), 189-197.

Welford, A. T. (1978). Mental work load as a function of demand, capacity, strategy and skill. Ergonomics, 21, 151-167.

Welford, A. T. (1980). On the nature of higher order skills. Journal of Occupational Psychology, 53(3), 189-197.

Wynn, R. (1988). *Segmental Curve Analysis.* Unpublished computer program, Virginia Polytechnic Institute and State University. Blacksburg.

APPENDIX A

METHODOLOGY

Methodology

This investigation was conducted in two phases. The first phase consisted of developing several discriminate function regression equations to be used in the second, and relied heavily on use of data from Fisher's [1989] study. The second phase was concerned with validation of the equations developed in Phase I by applying them to a different group of subjects.

Phase I: Development of the Regression Equations

Fisher [1989] collected data from seventy-six uninjured college-age male subjects trained to either give a true maximal performance or fake an injury during a standard knee extension-flexion test on a Cybex II dynamometer. Each subject was tested on one randomly selected limb at 60, 180 and 300 deg/sec, and completed five repetitions at each speed. These data were simultaneously recorded by the Cybex Data Reduction Computer (CDRC), the Cybex dual channel recorder, and a microcomputer running Segmental Curve Analysis (SCA) [Wynn, 1988; Sebolt and Earles-Price, 1989a], a program specifically designed to support this research. The SCA program was used to quantify six parameters from the last four torque curves of a five repetition knee extension test: peak torque (PT), torque at five degrees joint angle prior to and following peak torque (T-5, T+5), average area from the beginning of the torque curve to five degrees prior to peak torque (A-5), average area from five degrees post peak torque to the end of the torque curve (A+5), and average area between negative and positive five degrees around peak torque (A55) (Figure 4). The first torque curve was discarded from the analysis because it was reported in previous studies [Sebolt, Earles-Price and Herbert 1989a; Snider, 1989] to be highly unreliable. Fisher [1989] reported that sincere (S) subjects tended to be more reliable than deceptive (D) subjects across all six variables, and all three testing speeds.

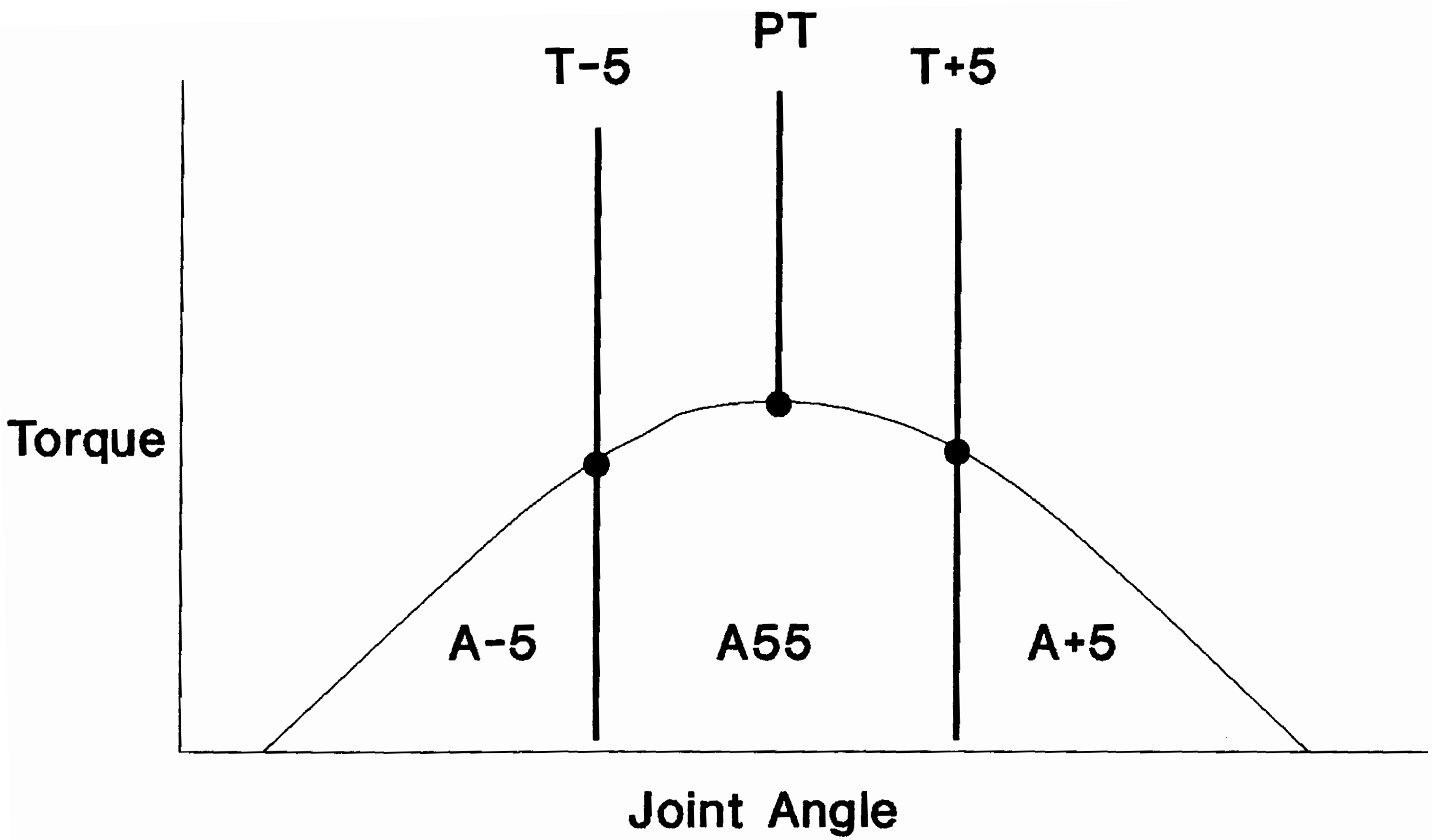


Figure 4. Parameters Selected From Torque Curve Using Segmental Curve Analysis.

In the present investigation, Fisher's data was used to develop several *discriminate function regression equations.* Since Fisher report sincere subjects to be more reliable, it was theorized that *coefficients of variation* could serve as predictor variables. First, the best variables for prediction were identified using stepwise discriminate analysis through use of the PROC STEPDISC function of SAS [SAS, 1985]. These variables are presented in Table 8 in Appendix B. Discriminate function regression equations were then developed using various combinations of the coefficients of variance identified by PROC STEPDISC for each speed of testing (60, 180 and 300 deg/sec) and for all speeds combined using discriminate analysis via the PROC DISCRIM function of SAS [SAS, 1985]. The data from Fisher's [1989] study was then substituted into each of the equations, and the best predictor equations were identified as those showing the highest prediction accuracy for actual group membership (sincere or deceptive). This value was expressed as total correct predictions (correct placement to either condition - S or D) divided by the total number of subjects. The equations developed from discriminate analysis are presented in Tables 9, 10 and 11 in Appendix B. Table 12 in Appendix B lists the prediction values obtained when these equations were applied to Fisher's [1989] data. In order to test the efficiency of these equations to predict in a real population, a confidence interval representing the range of actual prediction values was computed for each equation using the following formula:

$$p - z_{a/2} * \text{sqrt}\ (pq/n) < P < p + z_{a/2} * \text{sqrt}\ (pq/n) \tag{3}$$

where:

p = the proportion of successful identifications in the sample population

q = $1 - p$

n = the number of subjects in the sample population

$z_{a/2}$ = the z value of a normal curve leaving an area of a/2 to the right.

a = the alpha level (in this case 0.05)

P = the proportion of successful identifications in a real population.

If the lowest limits of this confidence interval were found to be greater than 0.5, this demonstrated that the ability of the prediction equation to accurately discriminate between sincere and deceptive performances was significantly ($p < 0.05$) greater than would be possible by chance alone. This in fact was found to hold true for equations derived for testing at 60 and 300 deg/sec, and for equations derived from and applied to all speeds (60, 180 or 300 deg/sec). Figure 5 in Appendix B shows the confidence intervals for each equation derived when applied to Fisher's [1989] data.

Phase II: Cross-Validation of Selected Prediction Equations

41 college-age male subjects, between the ages of 18 and 28 years, were solicited from physical education classes at Virginia Polytechnic Institute and State University to participate in the current study. Criterion for participation included:

1) the absence of any history of injury, surgery or trauma to the knee, hip or associated musculature; and

2) no greater than 15% limb-to-limb deficit at 60 deg/sec.

Compliance with these criteria was determined through use of a detailed medical history questionnaire (Appendix C), and through isokinetic testing during orientation. All subjects also completed an Informed Consent form prior to testing (Appendix D). The subjects completed two sessions on a Cybex II isokinetic dynamometer.

Session I: Orientation. The first session was conducted by a lab assistant, and served to familiarize the subjects with the testing apparatus, and to train them to either give a true maximal effort, or to fake an injury (Appendix E). The orientation session began with a brief (3-5 minute) warm-up by slow cycling (50-60 RPM) on a stationary cycle set at a low resistance (0-25 watts). The preferred leg was determined as the limb the subject would use if asked to kick a soccer ball for distance. This was the first limb tested. The subject was seated in the testing apparatus in an upright position with the knee joint positioned so that it extended just beyond the edge of the seat. Backpads were used if necessary to achieve the proper positioning. The axis of rotation of the dynamometer was then aligned to the axis of rotation of the knee to be tested, using the major prominence of the lateral femoral condyle as a landmark. The input shaft of the dynamometer was then adjusted to the length of the subject's leg so that the lower edge of the ankle pad rested approximately 1-2 cm. above the malleus. The subject was secured to the testing apparatus by Velcro straps secured at the pelvis, mid-thigh, and ankle. During all testing, subjects were instructed to keep their arms crossed across their chest.

The same orientation procedure was applied to all subjects. First, the subject was instructed to read the standardized scenario for a true maximal effort (Appendix F), and encouraged to ask questions. During all testing, subjects were instructed to start each repetition with the heel of the foot resting against the foot pad, go to full extension, and return the heel to the foot pad at the end of each repetition, with no hesitation between repetitions. Although hamstrings strength was not measured, subjects were also instructed to flex the knee as forcefully as possible. Each subject was trained and tested at 60, 180 and 300 deg/sec. At each speed, subjects performed four submaximal repetitions, followed by two maximal repetitions of practice. After the test administrator was satisfied that the subject was performing in a proper and consistent manner, the subject was instructed to give five maximal repetitions, which were recorded. The same scenario was applied to the non-preferred limb. After the second limb was tested at 60 deg/sec, the limb-to-limb deficit was determined, and if the subject exceeded the 15% cut-off, he was excused. If he qualified as a subject, maximal training was concluded at 180 and 300 deg/sec. After being trained on both limbs to give a maximal effort at all three speeds, one limb was randomly selected for training to fake an injury. The subject was then given the deceptive effort scenario (Appendix G), and encouraged to ask questions if anything were unclear. The same order of practice and testing was completed as for the maximal effort training, on the randomly assigned limb only, with the subject applying the deceptive effort scenario to his performance. At the end of the orientation, each subject was randomly assigned to either the sincere or deceptive condition, and scheduled for retesting. The subject was instructed to re-read the scenario description for the condition to which he was assigned prior to retesting, and was told not to reveal this assignment to the test administrator.

Session II: Data Collection. The second session was conducted by the principle investigator, who was unaware as to which condition the subjects had been assigned (Appendix H). Subjects were positioned in and secured to the testing apparatus in a manner identical to that used during the orientation session. Each subject was tested on the limb randomly assigned during the orientation at the following three speeds. Each subject was assigned one "slow", one "medium" and one "fast" speed, randomly selected from the following range of speeds: "slow": 60, 90, and 120 deg/sec; "medium": 150, 180, and 210 deg/sec; and "fast": 240, 270 and 300 deg/sec. After a brief warm-up, each subject completed a practice session at each speed. This consisted of four submaximal repetitions and two maximal repetitions at each speed, starting with the slowest speed. However, the subjects had been previously instructed to perform based upon the condition to which they had been assigned. This meant that a subject assigned to fake an injury would not actually give a true maximal effort when instructed to do so, but would perform in a manner he perceived to be appropriate for an injured subject instructed to give a maximal effort. After the subject had adequate chance to practice each speed, the actual test was administered. Starting with the slow speed, the subject was given two maximal repetitions for practice, followed by five maximal repetitions, which were recorded. Data from the five maximal repetitions were simultaneously recorded using the CDRC, the dual channel recorder, and transmitted to a microcomputer running the Segmental Curve Analysis (SCA) program [Wynn, 1988; Sebolt and Earles-Price, 1989a]. The SCA program was used to compute same six variables for the last four torque curves for each test speed as in Fisher's [1989] study. From these values, coefficients of variation (V) were computed for each variable for each test speed for each subject. These coefficients were then substituted into the discriminate function regression equations derived previously, and a prediction was made as to which condition each subject had been assigned. These predictions were then compared to actual condition assignments. An expression of prediction accuracy was computed as the number of correct assignments to condition divided by the total number of subjects. The prediction values for each of the equations derived when applied to the data from the present study are presented in Table 13 (Appendix I). These prediction values were also tested to determine if they were statistically significant using the same procedure as for Fisher's data described previously. Figure 6 in Appendix I shows the confidence intervals for each test speed for each set of predictor variables.

Secondarily, a comparison was made between the prediction accuracy of the regression equations when applied to Fisher's data and their ability to predict when applied to the second sample of subjects, using the following equation:

$$p_1 - p_2 - z_{a/2} * \text{sqrt(dum)} < D < p_1 - p_2 + z_{a/2} * \text{sqrt(dum)} \quad (4)$$

where:

p_1,p_2 = the proportion of successful identifications in samples from populations 1 and 2, respectively

dum = $((p_1*q_1)/n_1)+((p_2*q_2)/n_2)$

n_1,n_2 = the number of subjects sampled in populations 1 and 2 respectively

D = the true difference between the population proportions corresponding to p_1 and p_2

If the interval arising from this equation was found to contain the value 0 (zero), then it could be said that p_1 and p_2 were not significantly different from one another. The same equation was used to compare predictions at various speeds to determine if there were any effect on the ability to predict based on testing speed. The results of these analyses are also presented in Appendix I.

Finally, a comparison was made between mean peak torque values obtained by both investigators at 60, 180 and 300 deg/sec to determine if the two samples were similar. A random sample was taken from Fisher's data to equate the number of subjects in each sample. A 2 X 2 (investigator x condition) ANOVA was conducted at each test speed to compare the findings of the two studies (Appendix I).

APPENDIX B

RESULTS OF STATISTICAL ANALYSES OF FISHER'S DATA

Results of Analyses of Fisher's Data

The variables presented in Table 8 were identified via stepwise regression using the PROC STEPDISC procedure on SAS [SAS, 1985] to be significant contributors to the discrimination between sincere and deceptive performances in Fisher's [1989] study.

These variables (and various combinations thereof) were then used to develop several *discriminate function regression equations* using the PROC DISCRIM procedure on SAS [SAS, 1985]. The results of these analyses yielded the discriminate function regression or prediction equation, and the *critical or cut-off score.*

Various combinations of the three variables identified using PROC STEPDISC [SAS, 1985] were used to develop prediction equations for each speed, and for all speeds combined. The equations derived are presented in Tables 9, 10 and 11.

These equations were reapplied to Fisher's data by substitution of coefficients of variation where appropriate. The results of the regression or prediction equation were then compared to the cut-off score. Subjects whose results were greater than the cut-off score were predicted to belong to group 1 (sincere condition); subjects who scored below the cut-off score were assigned to group 2 (deceptive condition). These predictions were then compared to actual condition assignments. Prediction accuracy of each equation was expressed as the total number of correct placements (S or D) divided by the total number of subjects. The prediction accuracy for each equation when applied to Fisher's [1989] data is presented in Table 12.

Significance of each prediction equations' accuracy was computed using Equation 3 in Appendix A. Figure 5 graphically represents the confidence intervals developed for each equation using Equation 3.

Significance was shown if the lowest limits of the confidence interval exceeded 0.5 (greater than a 50/50 chance of predicting accurately).

Table 8

Predictor Variables Identified by PROC STEPDISC [SAS, 1985]

Limb Speed	Variables Identified
60 deg/sec	VPT, VA-5, VT+5
180 deg/sec	VA-5, VT+5
300 deg/sec	VPT, VA-5
All speeds combined	VPT, VA-5

Note. VPT = coefficient of variation for peak torque; VA-5 = coefficient of variation for area prior to five degrees prior to peak torque; VT+5 = coefficient of variation for torque at five degrees joint angle beyond peak torque. Test speed: All speeds = 60, 180 and 300 deg/sec.

Table 9

Prediction Equations Derived from Fisher [1989] - VPT, VT+5

Test Speed	Equation	Cut-Off
60 deg/sec	Z = -0.01797053(VPT) + 0.01329255(VT+5)	-0.23078635
180 deg/sec	Z = -0.00233832(VPT) - 0.00362565(VT+5)	-0.23655869
300 deg/sec	Z = -0.02432593(VPT) + 0.00767475(VT+5)	-0.50614769
All Speeds	Z = -0.00801363(VPT) + 0.00036028(VT+5)	-0.032190254

Note. VPT = coefficient of variation for peak torque; VT+5 = coefficient of variation for torque at five degrees joint angle beyond peak torque. Test speed: All speeds = 60, 180 and 300 deg/sec.

Table 10

Prediction Equations Derived from Fisher [1989] -
VPT, VT+5, VA-5

Test Speed	Equation	Cut-off
60 deg/sec:	Z = -0.01903424(VPT) + 0.01274785(VT+5) + 0.00236286(VA-5)	0.19975861
180 deg/sec:	Z = -0.00495758(VPT) - 0.00359781(VT+5) + 0.00037621(VA-5)	0.08888853
300 deg/sec:	Z = -0.02858258(VPT) - 0.026196(VT+5) + 0.00373592(VA-5)	-0.14759882
All Speeds:	Z = -0.00833305(VPT) - 0.00073533(VT+5) + 0.0029788(VA-5)	-0.11341484

Note. VPT = coefficient of variation for peak torque; VA-5 = coefficient of variation for area prior to five degrees prior to peak torque; VT+5 = coefficient of variation for torque at five degrees joint angle beyond peak torque. Test speeds: All speeds = 60, 180 and 300 deg/sec.

Table 11

Prediction Equations Derived from Fisher [1989] - VPT, VA-5

Test Speed	Equation	Cut-off
60 deg/sec:	Z = 0.00233764(VA-5) - 0.008261(VPT)	0.02185155
180 deg/sec:	Z = 0.00037669(VA-5) - 0.00837111(VPT)	0.12837152
300 deg/sec:	Z = 0.00043795(VA-5) - 0.03316437(VPT)	-0.14496584
All Speeds:	Z = -0.0089851(VPT) + 0.0002356(VA-5)	-0.10766866

Note. VPT = coefficient of variation for peak torque; VA-5 = coefficient of variation for area prior to five degrees prior to peak torque. Test speed: All speeds = 60, 180 and 300 deg/sec.

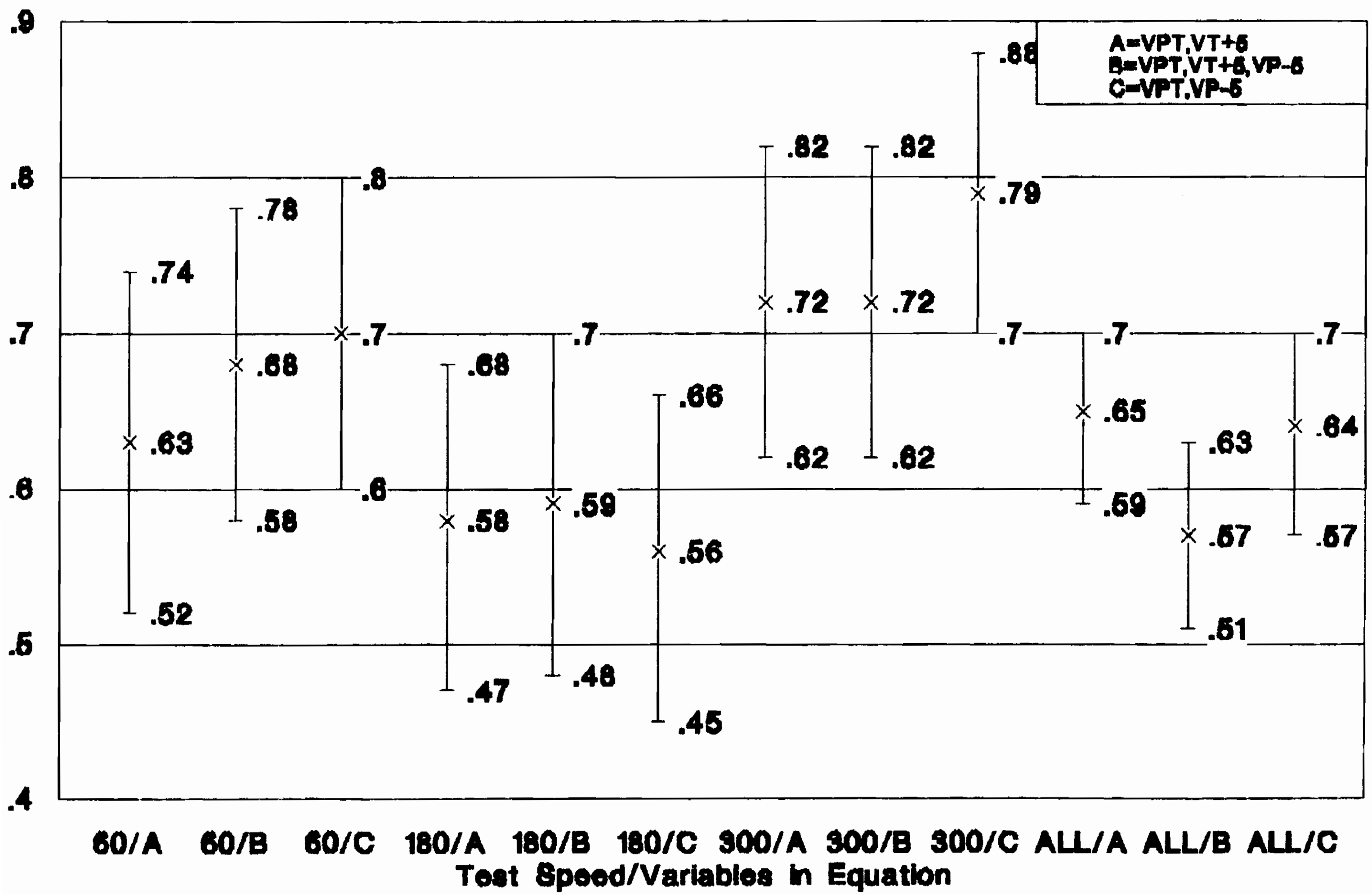
Table 12

Prediction Accuracy of Equations When Applied to Fisher's [1989] Data

	Test Speed (deg/sec)			
Variables	60	180	300	All Speeds
VPT,VT+5	0.630*	0.575	0.72*	0.645*
VPT,VT+5,VA-5	0.679*	0.588	0.72*	0.572*
VPT,VA-5	0.704*	0.556	0.79*	0.636*

* significant at $p < 0.05$.

Note. VPT = coefficient of variation for peak torque; VA-5 = coefficient of variation for area prior to five degrees prior to peak torque; VT+5 = coefficient of variation for torque at five degrees joint angle beyond peak torque. Test speed: All speeds = 60, 180 and 300 deg/sec.



($p < 0.05$)

Figure 5. Estimated Accuracy of Prediction Equations When Applied to Fisher's [1989] Data

APPENDIX C

ORTHOPAEDIC ASSESSMENT FORM

Orthopaedic Assessment Form

Name____
Date:________________________________Age:____________________
Local Address:____
Local Phone:____

1. Have you experienced any type of knee pain within the last six months? YES NO If yes, please explain:

2. Have you ever sustained an injury or trauma, or had any surgery to your knee joint, hip joint, or the muscles surrounding these joints? YES NO If yes, please explain:

3. If you have an injury, surgery, or trauma to your hip joint, knee joint, or the surrounding musculature, do you feel that you have fully recovered from it? YES NO Do you feel that the involved limb has been adequately rehabilitated? YES NO

4. Do you feel in any way that you have any orthopaedic or medical problems that may hamper your performance in this Cybex knee extension/flexion test? YES NO If yes, please explain:

Signature of participant:______________________________________
Date:________________
Witness:____

Condition assigned to:	SINCERE	DECEPTIVE
Limb to be tested:	PREFERRED	NON-PREFERRED
	(L or R)	

Lab Tech: Complete, detach here and provide to investigator

Name of subject:____
Length of input shaft (position of pin):__________________________
Forward position of dynamometer (in.):___________________________
Height of dynamometer (in.):____________________________________
# of backpads used:____
Limb to be tested: Right Left (circle one)

APPENDIX D

INFORMED CONSENT FORM

Human Performance Laboratory

Division of Health, Physical Education and Recreation
Virginia Polytechnic Institute and State University

Informed Consent

I,__________________________________, do hereby voluntarily agree and consent to participate in a testing program conducted by the personnel of the Human Performance Laboratory of the Division of Health, Physical Education and Recreation of Virginia Polytechnic Institute and State University.

Title of Study: Discrimination Between Sincere and Deceptive Isokinetic Knee Extension Tests Using Segmental Curve Analysis

The purposes of this experiment include: collection of data using isokinetic knee extension testing, and the evaluation of the data collected to determine if it is possible to predict whether a subject is faking an injury or giving a sincere effort.

Isokinetic knee extension testing involves the use of a machine called the Cybex II dynamometer, which controls the speed at which the lower limb moves, and measures the force generated by the thigh muscles during testing.

I voluntarily agree to participate in this testing program. It is my understanding that my participation will include: completion of information pertaining to my medical condition as it relates to this study. Specifically, I will inform the investigator of any history of injury, surgery or trauma to the knee, hip or associated musculature which may predispose me to injury as a result of participation in this study. In addition, I will participate in two approximately half-hour isokinetic testing sessions conducted by trained personnel to familiarize me with the apparatus and the testing procedure, and to collect data for this study. If at any time I feel that I cannot proceed with testing, I have the option to terminate the session. All medical information will be kept strictly confidential, and will only be used for this research project.

The isokinetic testing will involve several submaximal and maximal contractions of the knee extensors and flexors of both limbs.

I understand that participation in this experiment may produce certain discomforts and risks. These discomforts and risks include: latent muscle soreness and/or muscle pulls or tears due to the strenuous nature of the test, and the extremely remote possibility of death.

Certain personal benefits may be expected from participation in this experiment. These include:

At the end of the orientation session, I will be able to review the results of my test with a lab assistant who will provide me with information about my performance, and how it relates to normative data. From this information, I may be able to make adjustments in my exercise or training habits which may increase my health and/or athletic performance, and reduce the chance of injury.

I understand that any data of a personal nature will be held confidential and will be used for research purposes only. I also understand that these data may be used only when not identifiable with me.

I understand that I may abstain from participation in any part of the experiment or withdraw from the experiment should I feel that the activities might be injurious to my health. The experimenter may also terminate my participation should he feel the activities might be injurious to my health.

I understand that it is my personal responsibility to advise the researchers of any preexisting medical problems that may affect my participation or of any medical problems that might arise in the course of this experiment and that no medical treatment or compensation is available if injury is suffered as a result of this research. A telephone is available which would be used to call the local hospital for emergency service.

I have read the above statement and have had the opportunity to ask questions. I understand that the researchers will, at any time, answer my inquiries concerning the procedures used in this experiment.

Scientific inquiry is indispensable to the advancement of knowledge. Your participation in this experiment provides the investigator the opportunity to conduct meaningful scientific observations designed to make significant educational contribution.

If you would like to receive the results of this investigation, please indicate this choice by marking in the appropriate space provided below. A copy will then be distributed to you as soon as the results are made available by the investigator. Thank you for making this important contribution.

I request a copy of the results of this study.

Date:______________________________ Time:____________ am/pm
Participant Signature:____
Witness:____

HPL Personnel

Project Director: Jo-Anne Lee Bogner Telephone: 951-4333
HPER Human Subjects Chairman: Dr. C.R. Baffi Telephone: 231-8284
Dr. E.R. Stout, Chairman, Institutional Review Board for Research Involving Human Subjects. Phone 231-5283.

APPENDIX E

ORIENTATION PROCEDURES

Orientation Procedures

1. Explain isokinetic test and nature of the study.

2. Complete Cybex Test Screening Form. If subject does not meet criteria of the study, but is able to do maximal part of the test, complete this procedure only up to #7.

3. Review Informed Consent form with subject, and have them sign. Sign as witness.

4. Warm up the subject on a bicycle ergometer for 3-5 minutes at low intensity (0-25 watts) at 50-60 RPM.

5. Position subject in the isokinetic equipment. Make note of length of input shaft (position of pin from bottom), forward position and height of dynamometer, and number of backpads used. Secure the subject to the equipment at the ankle, mid-thigh, pelvis, and across the chest with the velcro straps.

6. Have subject read instructions for true maximal performance.

7. Have the subject perform the following protocol beginning with the preferred limb (the limb they would use to kick a soccer ball).

   Instruct the subject to work through full ROM, starting with the heel against the pad under the seat, through full extension. Instruct the subject to pull back as forcefully as he kicks out. The subject should also keep his arms crossed over his chest throughout the testing, and not grip the sides of the chair to assist his efforts.

   Observe torque curves after each step. If curves are not consistent, repeat that step until subject is satisfactorily consistent, but try to avoid fatiguing the subject. Do not progress to the next step until the previous step has been completed to your satisfaction.

   a) 4 submaximal repetitions at 60 deg/sec (practice).
   b) 2 maximal repetitions at 60 deg/sec (practice).
   c) 4 maximal repetitions at 60 deg/sec (record).
   d) 4 submaximal repetitions at 180 deg/sec (practice).
   e) 2 maximal repetitions at 180 deg/sec (practice).
   f) 4 maximal repetitions at 180 deg/sec (record).
   g) 4 submaximal repetitions at 300 deg/sec (practice).
   h) 2 maximal repetitions at 300 deg/sec (practice).
   i) 4 maximal repetitions at 300 deg/sec (record).

8. Repeat steps a-i for the non-preferred limb.

9. Examine data at 60 deg/sec for limb deficit. If deficit greater than 15% between limbs, review data, and dismiss subject at this time.

10. Refer to limb preference data for limb to be used for future testing.

11. Give subject standardized injury scenario to read. Answer questions if any.

12. Repeat step #7 using the assigned limb, instructing the subject to attempt to perform as he would using the injury scenario.

13. Inform subject of condition to which he has been randomly assigned. Provide copy of the appropriate scenario.

14. Schedule subject for testing session within one week of the orientation session. Instruct subjects to review the scenario they have been given prior to retesting, and not to alert the test administrator as to which condition they have been assigned.

APPENDIX F

TRUE MAXIMAL EFFORT SCENARIO

True Maximal Effort Scenario

During the isokinetic knee extension/flexion test, you will perform 5 (4 during the orientation session) maximal contractions of the quadriceps and hamstring muscles. A maximal effort implies that you are exerting the greatest amount of force of which you are physically capable. You will perform this test through your full range of motion without any hesitation between contractions.

During the second testing session, you will not reveal to the test administrator to which condition you have been assigned.

APPENDIX G

STANDARDIZED INJURY SCENARIO

Standardized Injury Scenario

You are a full time construction worker and were involved in an accident at work. You are now trying to claim workmen's compensation for your "injury". In order to collect, you have been ordered by a judge to undergo isokinetic limb testing to prove that you are truly injured. You are to convince the examining physician that you are truly injured via the knee extension/flexion test. During this test, you are to perform in such a manner which reflects the nature of your injury. You will perform the knee extension/flexion test with complete range of motion.

During the second testing session, you will not alert the test administrator as to which condition you have been assigned.

APPENDIX H

WARM-UP AND TESTING PROTOCOL

Warm-Up and Testing Protocol

1. Warm up the subject on cycle ergometer for 3-5 minutes at a low intensity (0-25 watts) at 50-60 RPM.

2. Set up procedures for the dual channel recorder and CDRC. Prepare the microcomputer for data collection.

3. Randomly select the three test speeds to be used by the subject.

4. Secure subject to the isokinetic equipment using the data from the orientation session, and secure the assigned limb. Also secure the subject at mid-thigh, across the pelvis, and across the chest.

5. Administer the following warm-up:

   Observe torque curves after each step to ensure that subject is working through his full ROM, and is consistent. Repeat each step as necessary until this is achieved. Do not progress to the next step until the previous step has been satisfactorily completed.

   a) 4 submaximal repetitions at "slow" speed.
   b) 2 maximal repetitions at "slow" speed.
   c) 4 submaximal repetitions at "medium" speed.
   d) 2 maximal repetitions at "medium" speed.
   e) 15 second rest period.
   f) 4 submaximal repetitions at "fast" speed.
   g) 2 maximal repetitions at "fast" speed.

6. Administer the test:

   a) 2 maximal repetitions at "slow" speed (practice).
   b) 5 maximal repetitions at "slow" speed (record).
   c) 30 second rest.
   d) 2 maximal repetitions at "medium" speed (practice).
   e) 5 maximal repetitions at "medium" speed (record).
   f) 30 second rest.
   g) 2 maximal repetitions at "fast" speed (practice).
   h) 5 maximal repetitions at "fast" speed (record).

APPENDIX I

RESULTS OF ANALYSES OF BOGNER'S DATA

Results of Analyses of Bogner's Data

The prediction equations derived from Fisher [1989] were applied to data collected in the present investigation. Coefficients of variation were computed for PT, T+5 and A-5, and were substituted into the regression equations where appropriate. The results of the regression equations were then compared to the cut-off score and a prediction was made for condition assignments for each subject. Prediction accuracy was computed as the number of correct placements (S or D) divided by the total number of subjects. Table 13 lists the prediction accuracy of each equation when applied to the data from the current study.

Significance was computed using Equation 3 in Appendix A. Figure 6 is a graphical representation of the confidence interval resulting from application of Equation 3 to each regression equation. Significance is indicated when the lower limit of the confidence interval exceeds 0.5.

Secondly, a comparison was made between the prediction accuracy of each equation between its application to Fisher's [1989] data and data from the current study, to determine if these predictions were significantly different. Estimated true difference between the two samples was computed using Equation 4 in Appendix A. Table 14 lists the differences between prediction accuracies between data sets. Figure 7 is a graphical representation of the confidence intervals developed using Equation 4. If this confidence interval contained 0 (zero), this demonstrated a non-significant difference in prediction accuracy of the equation when applied to the two data sets.

A comparison was then made between equations using the same predictor variables at different test speeds to determine the effect of testing speed on prediction accuracy. The methods used were similar to those used to compare Fisher's [1989] results to those of the current study. Three comparisons were made for each set of predictor

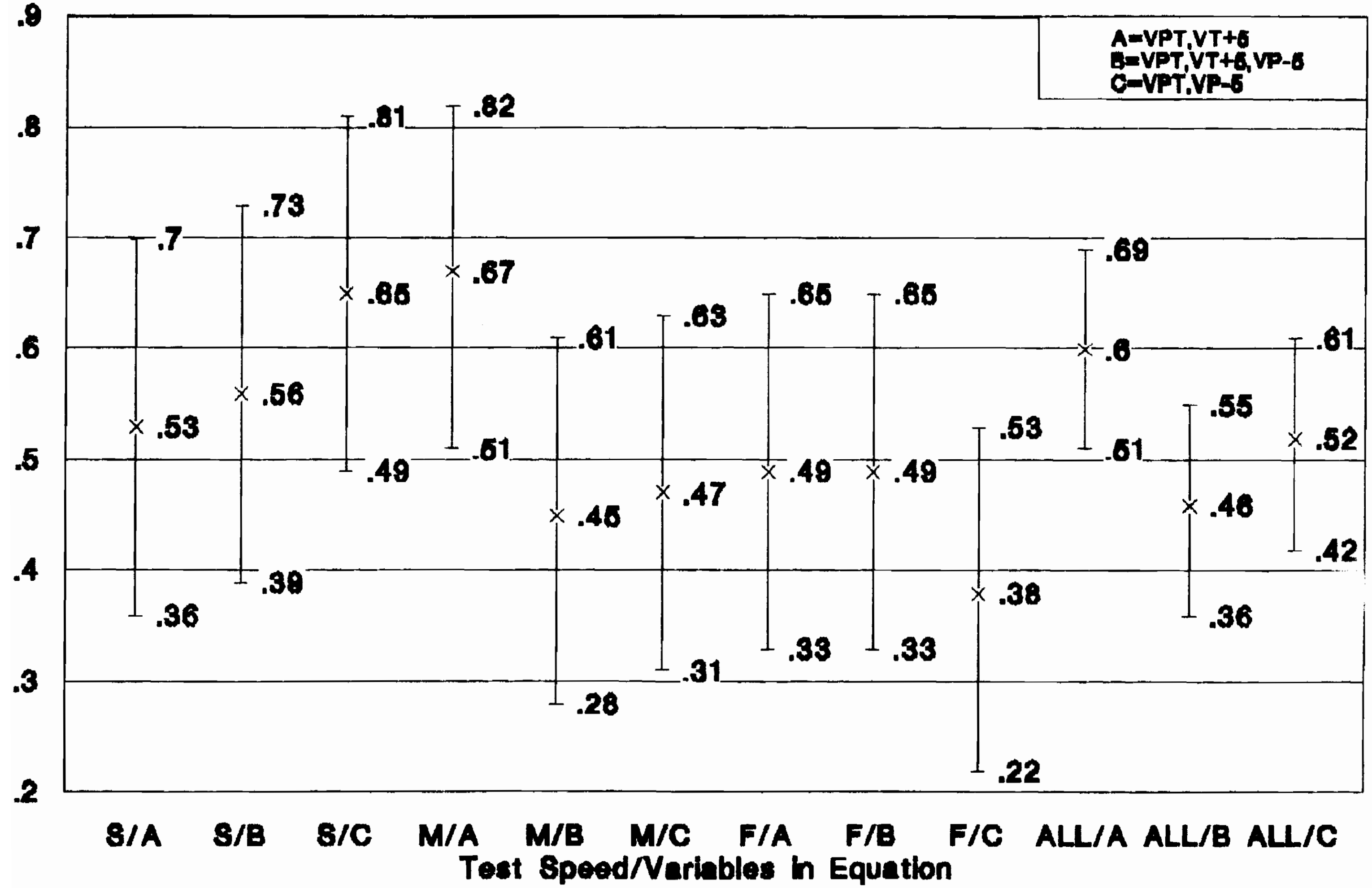
Table 13

Prediction Accuracy of Equations When Applied to Bogner's [1991] Data

	Test Speed			
Variables	Slow	Medium	Fast	All Speeds
VPT,VT+5	0.529	0.667*	0.487	0.598*
VPT,VT+5,VA-5	0.559	0.444	0.487	0.458
VPT,VA-5	0.647	0.472	0.378	0.514

* significant at $p < 0.05$.

Note. Slow speed = 60, 90 and 120 deg/sec; Medium speed = 150, 180 and 210 deg/sec; Fast speed = 240, 270 and 300 deg/sec; All speeds = 60, 90, 120, 150, 180, 210, 240, 270 and 300 deg/sec.



($p < 0.05$)

Figure 6. Estimated Accuracy of Prediction Equations When Applied to Bogner's [1991] Data

Table 14

Estimated Difference Between Accuracy of Prediction When Applied to Fisher [1989] and Bogner's [1991] Data

	Test Speed			
Variables	Slow	Medium	Fast	All Speeds
VPT,VT+5	0.10	-0.09	0.23*	0.05
VPT,VT+5,VA-5	0.12	0.14	0.23*	0.11
VPT,VA-5	0.06	0.08	0.41*	0.13*

* significant at $p < 0.05$.

Note. Slow speed = 60, 90 and 120 deg/sec; Medium speed = 150, 180 and 210 deg/sec; Fast speed = 240, 270 and 300 deg/sec; All Speeds = 60, 90, 120, 150, 180, 210, 240, 270 and 300 deg/sec.

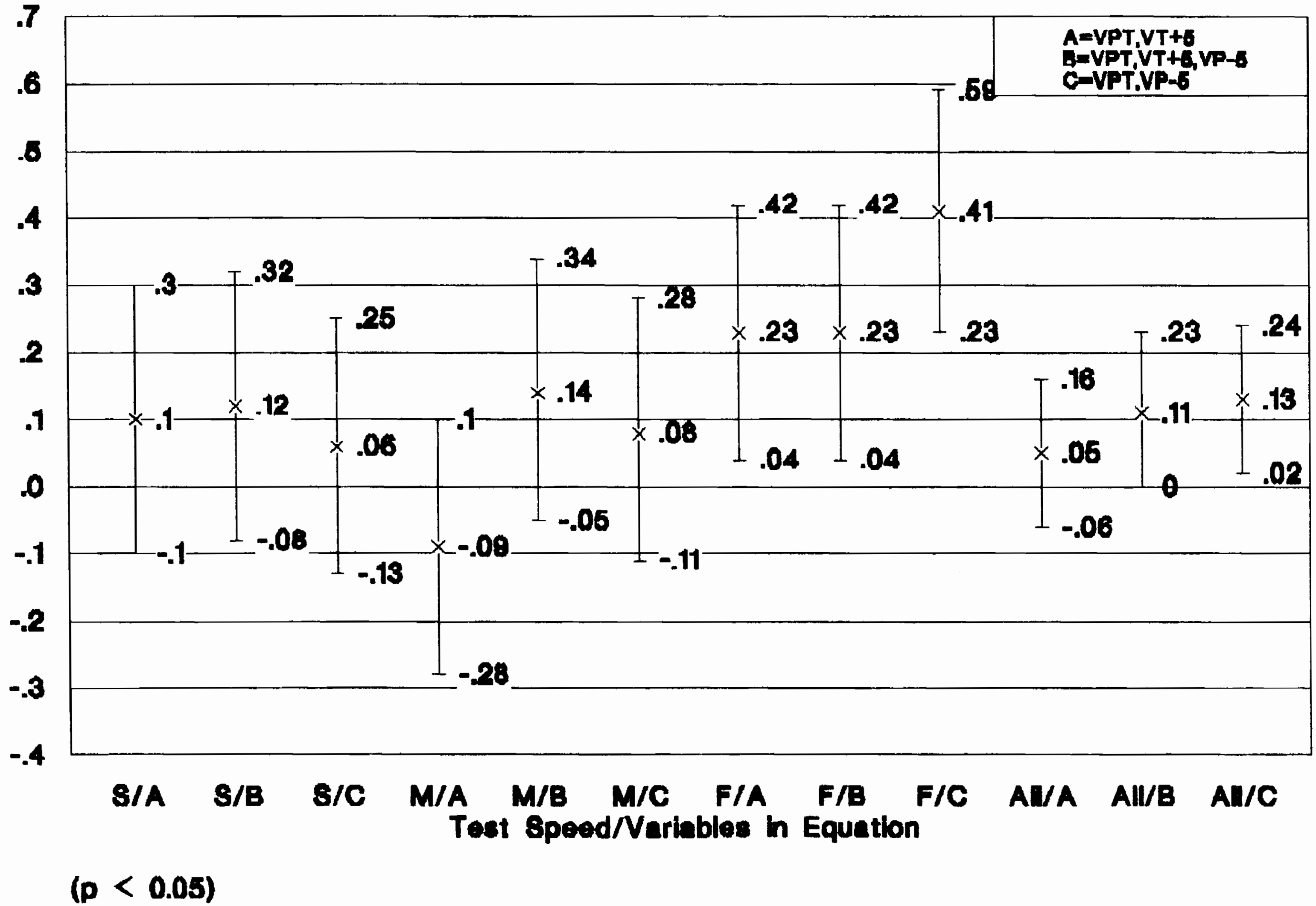


Figure 7. Estimated Difference Between Prediction Accuracy When Applied to Fisher [1989] and Bogner's [1991] Data

variables: slow vs. medium, medium vs. fast, and slow vs. fast. Table 15 lists the difference values (slow minus medium, medium minus fast, or slow minus fast) for each comparison. A positive different value, therefore, denotes that the first prediction value was greater than the second. Figure 8 graphically illustrates the confidence intervals derived from application of Equation 4. As with the previous comparison, inclusion of 0 (zero) within the confidence interval indicated a non-significant difference between test speeds.

Finally, a comparison was made between mean PT values obtained by both investigators at 60, 180 and 300 deg/sec to determine if the two samples were similar. A random sample was taken from Fisher's data to equate the number of subjects in each sample. Mean PT values for each investigator by speed are presented in Table 16. A 2 X 2 (investigator by condition) ANOVA was conducted at each test speed (Table 17).

At all three test speeds, there was a significant difference between conditions (S vs. D) for both investigators, but only in the case of PT at 60 deg/sec was there a significant difference in mean PT between investigators. This difference may have been due in part to a difference in the training protocols. Fisher's [1989] subjects were trained and tested in one session. In the current investigation, subjects had an additional opportunity to practice before testing was conducted, perhaps making them more effective in giving near-maximal performances when requested. In addition, some of the subjects in this study also participated in the study by Fisher, giving them added experience with the testing apparatus. The efficacy of this additional practice may have diminished as testing speed increased, since previous data suggest that subjects are less able to replicate performance as test speed increases. This comparison may not be as critical as it appears, since the use of coefficients of variation, a relative measure of performance, should not be dependent on the strength of the subject. In spite of this difference, these equations predicted with a high degree of accuracy when applied to the new set of data.

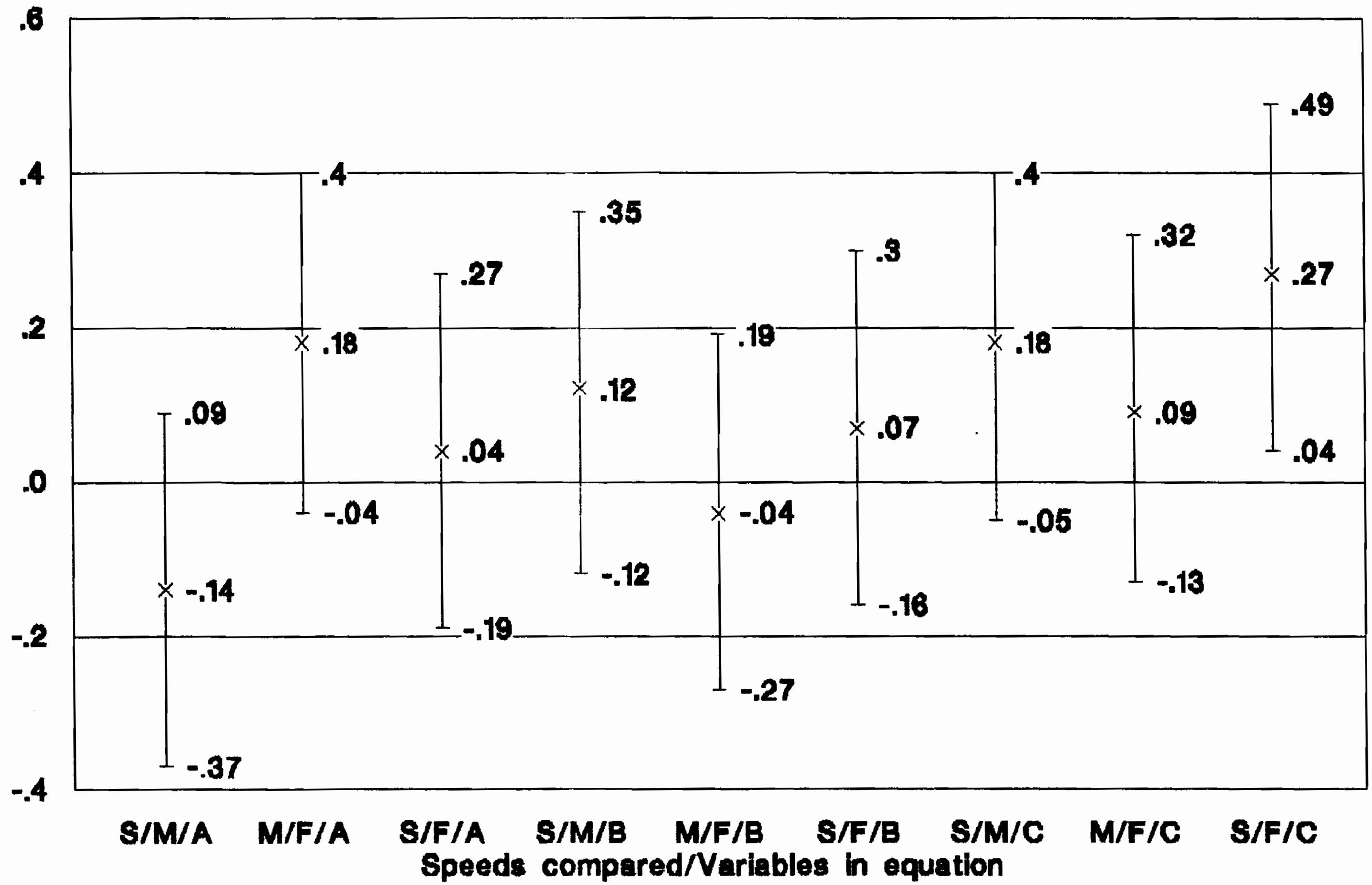
Table 15

Estimated Difference Between Prediction Equations of Different Test Speeds (Slow, Medium or Fast) Using the Same Predictor Variables

	Speeds Compared		
Variables	S vs. M	M vs. F	S vs. F
VPT,VT+5	-0.14	0.18	0.04
VPT,VT+5,VA-5	0.12	-0.04	0.07
VPT,VA-5	0.18	0.09	0.27*

* significant at $p < 0.05$.

Note. Slow speed = 60, 90 and 120 deg/sec; Medium speed = 150, 180 and 210 deg/sec; Fast speed = 240, 270 and 300 deg/sec.



($p < 0.05$)

Figure 8. Comparing Prediction Accuracy of Equations Based on Test Speed - Bogner [1991]

Table 16

Mean PT Values at 60, 180 and 300 deg/sec by Investigator

	Investigator	
Speed/Condition	Fisher	Bogner
60/S	124.32	130.49
60/D	66.32	108.13
180/S	81.87	78.22
180/D	41.40	57.53
300/S	68.87	70.29
300/D	41.29	45.23

Table 17

ANOVA Tables for Comparison of Mean PT Values by Investigator

60 deg/sec:

Source	df	Mean Square	F-ratio	Prob.
Investigator (A)	1	3700.12	5.24	0.03*
Condition (B)	1	10378.15	14.70	0.001*
A X B	1	2041.66	2.89	0.102

* $p < 0.05$

180 deg/sec:

Source	df	Mean Square	F-ratio	Prob.
Investigator (A)	1	250.04	0.60	0.447
Condition (B)	1	6011.81	14.37	0.001*
A X B	1	629.37	1.50	0.232

* $p < 0.05$

300 deg/sec:

Source	df	Mean Square	F-ratio	Prob.
Investigator (A)	1	31.94	0.13	0.72
Condition (B)	1	3077.95	12.58	0.003*
A X B	1	7.11	0.03	0.867

* $p < 0.05$

APPENDIX J

RAW DATA

LEGEND FOR RAW DATA:

ID	=	SUBJECT ID CODE: (ID #)(RIGHT OR LEFT LIMB - R OR L)(TEST SPEED)
REP	=	REPETITION # IN EXERCISE TEST
PT	=	PEAK TORQUE
T-5	=	TORQUE AT FIVE DEGREES PRIOR TO PEAK TORQUE
T+5	=	TORQUE AT FIVE DEGREES BEYOND PEAK TORQUE
A-5	=	AREA BETWEEN THE BEGINNING OF THE TORQUE CURVE TO FIVE DEGREES PRIOR TO PEAK TORQUE
A55	=	AREA BETWEEN FIVE DEGREES PRIOR TO AND FIVE DEGREES BEYOND PEAK TORQUE
A+5	=	AREA BETWEEN FIVE DEGREES BEYOND PEAK TORQUE AND THE TERMINUS OF THE TORQUE CURVE
G	=	GROUP (1=SINCERE; 2=DECEPTIVE)
L	=	LIMB (1=PREFERRED; 2=NON-PREFERRED)

ID	Rep	PT	T-5	T+5	A-5	A55	A+5	G	L
01L27	1	87.07	81.63	86.73	336.80	508.91	121.45	1	2
01L27	2	87.83	85.71	85.63	365.35	730.22	143.02	1	2
01L27	3	80.27	78.49	75.09	331.94	548.13	97.95	1	2
01L27	4	74.41	73.56	70.25	293.94	503.66	113.85	1	2
02R12	1	92.00	88.17	91.23	204.17	218.07	103.08	1	1
02R12	2	89.19	84.61	85.71	222.10	206.44	129.30	1	1
02R12	3	88.34	77.64	85.12	185.67	202.52	126.35	1	1
02R12	4	84.69	79.34	82.14	162.87	183.98	118.72	1	1
02R18	1	79.51	74.24	73.39	236.37	263.93	166.87	1	1
02R18	2	76.28	64.47	71.27	215.37	239.11	174.57	1	1
02R18	3	76.88	69.15	70.08	176.52	208.60	146.39	1	1
02R18	4	73.05	67.70	68.30	167.60	199.06	148.83	1	1
02R30	1	60.99	40.35	59.08	124.54	225.86	119.64	1	1
02R30	2	57.00	56.74	53.35	279.32	297.51	45.52	1	1
02R30	3	54.62	53.35	51.09	235.68	256.19	45.93	1	1
02R30	4	54.62	52.33	51.65	130.61	195.96	81.72	1	1
03R09	1	78.74	59.55	74.07	124.25	166.73	85.11	2	1
03R09	2	78.15	61.50	73.05	79.20	118.18	77.86	2	1
03R09	3	86.98	84.10	76.03	142.92	158.03	74.93	2	1
03R09	4	80.19	62.44	74.41	93.67	129.71	69.41	2	1
03R18	1	66.77	60.91	66.77	163.27	214.54	105.10	2	1
03R18	2	57.68	46.89	45.36	75.22	133.40	161.68	2	1
03R18	3	57.59	51.48	52.24	131.04	155.52	87.54	2	1
03R18	4	43.66	18.52	38.06	17.35	73.97	103.34	2	1
03R30	1	60.99	57.00	57.68	205.51	457.40	155.87	2	1
03R30	2	58.27	55.89	50.76	145.04	357.76	130.55	2	1
03R30	3	55.81	46.97	52.67	125.80	355.37	154.89	2	1
03R30	4	54.28	52.71	48.76	270.80	372.40	84.18	2	1
04R06	1	77.05	75.35	76.20	64.81	79.54	52.92	2	1
04R06	2	98.28	95.22	95.82	89.98	105.24	64.29	2	1
04R06	3	81.46	74.58	77.98	63.20	84.25	57.78	2	1
04R06	4	69.83	66.85	68.55	66.47	83.46	54.46	2	1

ID	Rep	PT	T-5	T+5	A-5	A55	A+5	G	L
04R15	1	33.30	32.53	30.67	88.85	91.61	42.07	2	1
04R15	2	38.57	15.12	34.83	6.59	38.35	80.95	2	1
04R15	3	36.19	35.00	32.70	61.90	76.44	48.19	2	1
04R15	4	41.45	38.48	40.09	108.99	115.17	49.20	2	1
04R24	1	31.81	27.95	31.56	99.78	115.48	52.80	2	1
04R24	2	34.91	31.22	34.74	97.11	111.65	51.46	2	1
04R24	3	35.89	32.15	34.11	86.08	103.96	61.99	2	1
04R24	4	36.87	34.96	36.74	105.07	125.90	55.11	2	1
06R06	1	130.48	125.55	118.75	131.81	146.12	77.67	2	1
06R06	2	115.70	113.32	108.82	91.21	106.03	72.20	2	1
06R06	3	128.61	124.02	113.23	117.21	134.00	84.38	2	1
06R06	4	128.35	118.84	125.38	91.03	121.08	100.68	2	1
06R15	1	104.14	102.27	102.19	233.33	266.42	124.22	2	1
06R15	2	86.39	83.84	80.61	218.54	233.53	66.39	2	1
06R15	3	76.54	71.44	70.93	97.88	142.87	136.74	2	1
06R15	4	106.95	104.99	106.35	226.78	261.54	117.20	2	1
06R27	1	70.46	65.07	68.38	173.24	222.87	96.92	2	1
06R27	2	58.70	55.94	55.47	174.15	222.37	46.91	2	1
06R27	3	69.57	67.70	62.56	190.31	244.87	45.68	2	1
06R27	4	71.10	70.38	69.40	222.61	268.90	51.14	2	1
07R09	1	113.23	111.70	109.75	194.90	208.08	120.35	1	1
07R09	2	110.68	109.24	107.97	183.69	201.04	119.79	1	1
07R09	3	107.29	103.55	106.10	177.79	197.41	127.76	1	1
07R09	4	104.82	102.78	103.80	182.48	192.27	112.18	1	1
07R21	1	80.32	72.88	73.44	267.91	297.56	107.01	1	1
07R21	2	82.31	75.26	76.20	263.70	284.89	115.13	1	1
07R21	3	76.83	66.85	71.57	240.71	275.43	138.57	1	1
07R21	4	75.60	69.10	68.34	234.04	258.68	100.81	1	1
07R30	1	64.86	61.76	59.46	197.98	691.62	119.12	1	1
07R30	2	65.37	64.39	55.60	301.30	370.91	74.79	1	1
07R30	3	63.45	52.58	61.37	263.47	467.87	66.96	1	1
07R30	4	63.33	60.10	56.79	310.41	376.85	81.42	1	1

ID	Rep	PT	T-5	T+5	A-5	A55	A+5	G	L
08L30	1	11.34	9.93	10.88	35.23	98.04	15.33	2	2
08L30	2	10.01	8.56	7.93	27.61	49.49	19.37	2	2
08L30	3	15.12	10.67	15.08	22.72	104.21	19.34	2	2
08L30	4	14.16	13.33	11.50	39.73	111.46	9.82	2	2
09L12	1	92.59	91.91	89.70	198.09	221.36	126.58	1	2
09L12	2	91.23	89.70	86.22	218.00	231.65	101.01	1	2
09L12	3	90.04	85.71	89.45	161.90	189.60	138.21	1	2
09L12	4	90.38	86.39	89.36	183.32	207.74	124.62	1	2
09L21	1	74.58	69.70	72.46	235.20	262.67	104.22	1	2
09L21	2	72.33	69.27	68.72	220.57	243.40	84.03	1	2
09L21	3	69.91	69.61	65.45	253.97	273.10	62.83	1	2
09L21	4	65.24	64.94	64.73	233.84	256.42	82.73	1	2
09L24	1	64.09	62.94	62.94	213.67	256.33	114.91	1	2
09L24	2	62.99	61.16	62.60	201.12	259.75	102.94	1	2
09L24	3	55.77	54.32	54.28	191.99	228.17	80.68	1	2
09L24	4	57.59	57.08	54.75	229.94	256.20	42.35	1	2
10L06	1	96.41	93.61	93.19	96.76	111.40	57.13	1	2
10L06	2	95.05	92.00	94.71	79.28	93.59	55.69	1	2
10L06	3	93.70	91.23	92.59	110.55	121.39	62.74	1	2
10L06	4	93.10	91.32	91.32	97.28	108.52	60.26	1	2
10L18	1	64.47	62.35	61.67	126.87	149.88	127.91	1	2
10L18	2	64.81	61.84	63.11	180.05	198.03	106.10	1	2
10L18	3	59.55	57.42	57.76	152.52	173.55	100.25	1	2
10L18	4	59.21	58.10	58.36	175.03	186.96	90.24	1	2
10L24	1	49.40	49.01	45.02	155.61	172.69	40.22	1	2
10L24	2	49.01	47.95	48.16	164.51	190.42	46.98	1	2
10L24	3	47.53	45.83	46.59	174.21	199.00	75.32	1	2
10L24	4	42.81	41.41	41.67	160.47	177.78	39.65	1	2
11L06	1	147.89	145.09	145.34	165.38	180.86	105.90	1	2
11L06	2	146.53	141.43	143.39	156.30	170.05	105.84	1	2
11L06	3	140.59	138.55	138.21	162.13	176.92	95.94	1	2
11L06	4	140.59	136.25	138.29	140.03	158.59	99.98	1	2

ID	Rep	PT	T-5	T+5	A-5	A55	A+5	G	L
11L30	1	76.41	70.21	63.03	233.17	317.24	110.38	1	2
11L30	2	65.20	61.25	60.44	186.71	260.79	104.68	1	2
11L30	3	70.72	64.05	67.57	218.56	309.04	118.50	1	2
11L30	4	63.88	58.87	59.89	170.42	248.78	107.19	1	2
12L21	1	105.93	101.34	101.85	339.51	375.60	209.78	1	2
12L21	2	98.28	97.26	94.80	324.11	372.98	159.40	1	2
12L21	3	96.33	92.42	90.98	294.16	339.99	140.94	1	2
12L21	4	95.48	78.57	92.59	266.05	315.09	150.25	1	2
12L24	1	96.07	84.95	91.32	323.44	371.81	155.70	1	2
12L24	2	95.90	77.05	91.66	314.69	359.67	168.52	1	2
12L24	3	94.88	89.62	91.74	346.95	404.44	162.08	1	2
12L24	4	90.04	79.25	89.11	336.64	370.96	158.27	1	2
13R06	1	94.97	90.47	91.57	94.54	109.25	62.71	2	1
13R06	2	83.93	82.99	79.93	81.12	93.36	64.76	2	1
13R06	3	95.82	92.25	89.28	68.88	82.67	59.19	2	1
13R06	4	86.05	82.31	84.78	76.77	87.19	60.33	2	1
13R18	1	57.17	56.49	55.30	141.81	152.90	56.68	2	1
13R18	2	57.68	56.66	54.79	136.63	150.15	53.30	2	1
13R18	3	58.61	57.85	55.47	128.54	141.74	64.73	2	1
13R18	4	49.78	47.48	48.84	119.79	131.82	51.18	2	1
13R27	1	51.48	50.03	48.72	219.95	236.43	34.29	2	1
13R27	2	44.38	40.18	44.09	139.82	160.27	58.81	2	1
13R27	3	48.55	46.85	46.64	179.53	195.49	54.84	2	1
13R27	4	49.14	46.17	47.36	175.16	195.08	40.73	2	1
14L06	1	125.12	120.45	120.28	156.27	166.69	83.28	2	1
14L06	2	120.03	98.71	107.88	32.57	65.49	75.55	2	1
14L06	3	117.06	115.02	108.14	60.53	75.88	47.96	2	1
14L06	4	121.39	18.86	117.56	42.10	15.98	80.04	2	1
14L21	1	85.29	76.92	83.59	285.88	315.35	73.73	2	1
14L21	2	82.10	74.12	80.40	87.58	159.83	122.79	2	1
14L21	3	77.13	74.75	76.07	154.67	219.79	139.62	2	1
14L21	4	76.49	70.00	74.58	80.05	139.20	143.89	2	1

ID	Rep	PT	T-5	T+5	A-5	A55	A+5	G	L
14L30	1	75.56	72.84	72.59	172.46	241.01	91.81	2	1
14L30	2	67.45	53.90	67.36	152.12	244.64	100.08	2	1
14L30	3	74.62	60.01	74.20	177.54	288.36	94.48	2	1
14L30	4	71.61	67.87	68.08	166.99	235.80	111.41	2	1
15R06	1	99.98	96.50	98.20	95.12	108.83	78.97	1	1
15R06	2	90.64	89.28	84.27	85.76	95.24	67.58	1	1
15R06	3	79.34	78.07	76.88	92.25	99.00	62.74	1	1
15R06	4	80.36	76.45	78.91	73.71	81.28	62.69	1	1
15R18	1	76.88	75.26	74.24	208.14	225.66	63.16	1	1
15R18	2	77.13	74.67	76.54	195.29	218.12	80.60	1	1
15R18	3	77.73	75.18	73.90	165.81	184.50	61.77	1	1
15R18	4	79.85	79.42	74.50	224.58	235.93	67.60	1	1
15R24	1	61.59	60.86	59.08	208.27	231.70	67.56	1	1
15R24	2	66.30	64.47	63.07	167.65	195.30	70.58	1	1
15R24	3	66.47	59.59	66.34	240.49	269.87	79.77	1	1
15R24	4	67.96	64.35	66.47	253.47	276.92	75.96	1	1
16R18	1	95.45	90.79	90.18	249.14	276.65	86.56	2	2
16R18	2	82.71	80.43	81.05	188.87	215.63	81.01	2	2
16R18	3	85.52	84.91	80.96	166.11	191.52	79.43	2	2
16R18	4	77.36	69.89	75.60	172.67	196.23	68.32	2	2
16R24	1	66.21	62.74	59.93	128.44	196.96	88.33	2	2
16R24	2	88.42	76.96	84.43	199.41	291.31	149.96	2	2
16R24	3	89.91	85.35	89.91	171.25	283.26	111.53	2	2
16R24	4	78.63	77.01	75.03	287.82	311.58	47.49	2	2
17R09	1	41.45	37.63	36.78	66.51	72.24	32.56	2	1
17R09	2	39.92	34.40	36.78	53.91	66.05	31.43	2	1
17R09	3	43.24	37.97	40.77	60.84	71.98	35.41	2	1
17R09	4	33.47	22.43	32.53	44.41	52.28	35.97	2	1
17R18	1	45.36	44.94	40.86	120.91	133.74	38.87	2	1
17R18	2	44.00	41.96	40.09	47.34	59.81	47.65	2	1
17R18	3	45.36	41.71	42.64	46.71	61.36	42.05	2	1
17R18	4	34.91	33.89	33.64	33.93	42.44	47.33	2	1

ID	Rep	PT	T-5	T+5	A-5	A55	A+5	G	L
17R30	1	31.30	29.77	30.62	80.46	105.75	28.86	2	1
17R30	2	44.21	41.88	42.26	62.87	95.51	30.74	2	1
17R30	3	45.45	40.69	44.94	65.31	106.49	40.11	2	1
17R30	4	31.01	29.69	30.62	29.47	42.59	29.11	2	1
18R12	1	97.43	96.75	96.24	188.26	209.08	92.17	1	1
18R12	2	98.62	98.03	95.22	203.19	218.36	90.05	1	1
18R12	3	97.86	97.69	96.84	228.82	238.67	113.30	1	1
18R12	4	101.17	97.60	99.05	213.76	223.15	96.18	1	1
18R15	1	91.66	90.04	90.21	220.81	243.74	117.46	1	1
18R15	2	87.83	84.86	85.63	202.95	230.62	93.60	1	1
18R15	3	87.24	86.05	86.13	232.89	248.35	68.17	1	1
18R15	4	86.39	85.46	84.86	232.28	254.06	85.01	1	1
19R12	1	125.12	121.30	124.36	240.33	273.24	137.06	1	1
19R12	2	119.69	113.91	119.69	219.16	260.23	137.73	1	1
19R12	3	116.97	115.02	111.87	233.89	247.46	140.62	1	1
19R12	4	111.02	108.82	109.75	215.03	241.36	123.19	1	1
19R15	1	109.41	100.83	106.95	245.02	270.58	136.23	1	1
19R15	2	105.42	99.98	103.04	249.69	271.12	137.95	1	1
19R15	3	108.31	103.63	104.65	268.35	286.88	144.36	1	1
19R15	4	103.72	84.01	99.81	188.74	255.02	142.17	1	1
19R24	1	85.67	77.60	84.31	295.37	334.27	120.32	1	1
19R24	2	82.65	69.70	81.93	290.13	328.51	105.26	1	1
19R24	3	79.47	73.27	74.67	301.84	320.66	98.58	1	1
19R24	4	77.13	72.63	73.39	282.69	316.20	72.13	1	1
20R12	1	67.11	64.73	65.41	139.75	149.61	67.02	2	1
20R12	2	67.87	66.85	66.34	140.05	150.74	65.26	2	1
20R12	3	56.40	53.01	55.98	102.41	113.23	71.96	2	1
20R12	4	76.28	71.44	74.67	126.53	141.99	56.23	2	1
20R24	1	52.96	47.40	50.12	159.03	190.46	47.39	2	1
20R24	2	50.59	47.99	49.78	107.17	136.20	36.37	2	1
20R24	3	48.84	47.44	47.65	70.94	90.11	46.19	2	1
20R24	4	49.27	45.53	47.82	115.98	159.89	60.30	2	1

ID	Rep	PT	T-5	T+5	A-5	A55	A+5	G	L
21L12	1	65.58	64.30	63.96	138.44	148.63	73.54	2	2
21L12	2	70.00	59.89	67.53	112.70	149.04	125.06	2	2
21L12	3	56.06	52.16	54.70	135.30	146.45	104.05	2	2
21L12	4	54.37	51.39	54.03	100.65	134.06	109.63	2	2
21L15	1	79.51	75.18	78.57	175.72	199.06	95.95	2	2
21L15	2	74.16	73.48	70.50	112.68	134.80	103.81	2	2
21L15	3	70.93	68.13	68.13	130.99	163.70	126.47	2	2
21L15	4	80.27	72.54	76.11	155.36	185.22	86.65	2	2
21L30	1	49.35	40.82	45.23	125.81	287.94	79.29	2	2
21L30	2	57.42	53.94	56.66	282.47	514.02	89.20	2	2
21L30	3	52.50	48.33	49.14	156.73	291.46	74.23	2	2
21L30	4	47.02	46.93	42.09	233.99	357.09	33.37	2	2
22L06	1	141.43	140.33	137.19	166.48	174.87	99.38	2	2
22L06	2	138.97	137.70	136.76	164.50	173.94	94.08	2	2
22L06	3	134.13	132.85	132.85	148.68	168.70	84.90	2	2
22L06	4	133.79	129.71	130.99	157.67	166.76	95.95	2	2
22L21	1	66.60	64.86	64.22	225.58	244.84	106.40	2	2
22L21	2	66.13	64.01	59.97	210.22	220.77	93.38	2	2
22L21	3	72.42	71.27	67.62	219.70	238.61	89.02	2	2
22L21	4	74.28	68.34	72.93	249.91	267.02	101.40	2	2
22L27	1	55.77	54.03	54.24	146.64	185.30	102.48	2	2
22L27	2	56.06	54.11	54.66	166.91	214.30	92.34	2	2
22L27	3	53.60	52.92	52.84	53.45	8.39	62.44	2	2
22L27	4	58.70	54.92	57.42	154.51	209.43	114.91	2	2
23R18	1	33.81	32.53	32.28	94.88	101.13	40.35	2	1
23R18	2	37.21	34.23	40.69	33.58	42.36	70.08	2	1
23R18	3	33.38	31.34	33.13	38.02	45.90	45.99	2	1
23R18	4	26.33	22.77	27.78	23.26	29.97	57.00	2	1
23R27	1	13.97	13.63	13.80	26.60	32.42	6.27	2	1
23R27	2	14.78	13.97	13.85	30.38	38.62	4.06	2	1
23R27	3	15.80	14.99	15.80	16.48	21.85	10.70	2	1
23R27	4	15.76	15.46	15.16	21.09	27.42	6.99	2	1

ID	Rep	PT	T-5	T+5	A-5	A55	A+5	G	L
24R12	1	51.31	48.67	47.99	99.59	110.08	78.88	2	1
24R12	2	51.73	49.27	50.20	98.99	104.30	56.00	2	1
24R12	3	47.40	46.47	47.14	97.50	102.25	35.20	2	1
24R12	4	53.18	51.99	50.80	97.62	105.65	51.28	2	1
24R18	1	29.39	25.57	26.76	52.66	79.67	80.95	2	1
24R18	2	31.43	29.56	30.92	45.93	55.97	24.77	2	1
24R18	3	36.44	33.64	34.91	47.38	57.02	38.62	2	1
24R18	4	38.82	36.61	38.14	64.41	75.92	38.58	2	1
24R24	1	21.66	19.58	20.85	44.65	62.66	37.23	2	1
24R24	2	19.83	19.79	18.22	30.43	37.90	25.85	2	1
24R24	3	30.45	28.46	29.77	41.72	63.77	40.60	2	1
24R24	4	30.62	26.76	29.48	74.97	104.78	45.42	2	1
25R09	1	109.75	109.16	106.61	188.70	200.61	102.79	1	1
25R09	2	117.65	114.25	117.31	192.48	218.06	109.75	1	1
25R09	3	108.22	98.71	106.86	160.81	183.91	113.96	1	1
25R09	4	103.29	98.96	101.76	150.23	169.54	108.97	1	1
25R15	1	92.42	90.30	91.40	229.49	255.84	116.34	1	1
25R15	2	100.07	97.35	95.05	225.06	254.95	117.56	1	1
25R15	3	98.45	94.29	97.26	230.71	264.83	107.52	1	1
25R15	4	96.50	93.78	93.86	221.88	252.41	125.12	1	1
27R21	1	104.91	100.15	104.06	323.62	390.53	227.62	1	2
27R21	2	101.85	94.12	100.83	330.23	374.77	193.07	1	2
27R21	3	97.43	92.59	92.25	311.08	341.90	190.23	1	2
27R21	4	98.45	97.09	96.33	319.75	364.79	203.97	1	2
27R12	1	128.61	119.60	127.67	279.11	295.92	182.51	1	2
27R12	2	121.64	111.79	119.52	256.64	274.44	174.51	1	2
27R12	3	118.67	114.34	117.31	226.80	260.60	147.89	1	2
27R12	4	118.33	113.40	116.46	221.85	246.63	152.96	1	2
28L06	1	115.27	109.33	106.18	116.55	134.25	67.62	2	2
28L06	2	132.77	130.31	122.58	121.42	141.09	89.42	2	2
28L06	3	124.96	118.58	123.51	112.39	136.29	89.43	2	2
28L06	4	123.09	111.19	122.83	131.74	140.87	99.77	2	2

ID	Rep	PT	T-5	T+5	A-5	A55	A+5	G	L
28L21	1	65.11	55.89	61.59	136.74	199.15	149.91	2	2
28L21	2	80.57	76.20	77.09	232.26	260.97	110.44	2	2
28L21	3	80.74	77.30	78.02	249.10	277.48	108.92	2	2
28L21	4	77.09	72.88	73.05	256.17	278.84	96.41	2	2
28L27	1	68.00	56.36	67.40	170.54	254.67	136.79	2	2
28L27	2	61.03	54.28	56.91	141.82	215.16	91.79	2	2
28L27	3	48.46	47.14	47.44	139.55	180.49	101.86	2	2
28L27	4	50.76	50.12	47.65	147.05	195.68	88.08	2	2
29R09	1	150.78	148.32	140.75	255.85	269.68	158.29	1	1
29R09	2	150.86	142.96	149.25	252.40	265.24	161.59	1	1
29R09	3	148.74	145.43	146.87	250.04	266.54	156.61	1	1
29R09	4	148.40	148.23	146.79	265.64	285.48	153.13	1	1
29R15	1	120.54	110.26	120.28	281.02	321.73	203.44	1	1
29R15	2	122.15	115.02	119.69	303.96	340.55	196.14	1	1
29R15	3	117.56	111.28	117.14	258.18	311.02	187.14	1	1
29R15	4	117.65	111.02	115.10	276.44	315.55	169.09	1	1
29R24	1	107.88	97.77	104.99	397.27	450.75	212.47	1	1
29R24	2	103.21	95.31	102.19	376.96	422.07	206.52	1	1
29R24	3	100.75	97.43	99.81	408.41	447.73	204.15	1	1
29R24	4	96.92	91.15	94.97	366.17	395.88	194.68	1	1
30R27	1	56.62	53.81	54.83	226.33	239.35	49.11	2	1
30R27	2	54.07	48.89	52.41	176.26	198.58	76.67	2	1
30R27	3	65.54	61.80	63.54	209.79	237.71	87.12	2	1
30R27	4	62.90	61.50	60.23	246.46	272.64	74.08	2	1
30R30	1	104.14	99.22	88.94	366.86	732.68	253.80	2	1
30R30	2	102.87	92.17	97.52	505.02	674.18	137.52	2	1
30R30	3	95.39	86.13	90.47	465.97	646.36	119.95	2	1
30R30	4	96.75	86.30	86.98	479.44	490.96	123.36	2	1
31R06	1	188.78	174.38	186.50	196.08	218.07	136.11	1	1
31R06	2	188.08	182.81	183.87	213.01	249.06	140.19	1	1
31R06	3	177.02	171.57	173.51	186.70	210.99	124.51	1	1
31R06	4	165.08	157.35	160.51	205.52	203.75	121.41	1	1

ID	Rep	PT	T-5	T+5	A-5	A55	A+5	G	L
31R15	1	153.58	146.11	148.32	344.76	762.20	222.31	1	1
31R15	2	149.42	140.92	143.81	354.31	801.98	238.76	1	1
31R15	3	142.03	138.04	134.21	353.65	790.24	178.34	1	1
31R15	4	136.59	106.52	131.92	357.92	378.13	175.54	1	1
31R30	1	104.14	99.22	88.94	366.86	732.68	186.49	1	1
31R30	2	101.51	77.39	98.88	236.91	793.94	203.80	1	1
31R30	3	95.39	86.13	90.47	465.97	646.36	119.95	1	1
31R30	4	96.75	89.19	86.98	473.08	537.23	123.36	1	1
32R09	1	92.17	83.25	82.65	138.33	156.76	93.51	2	1
32R09	2	103.21	100.58	96.58	164.22	175.22	88.38	2	1
32R09	3	109.24	100.92	108.56	140.48	172.81	97.79	2	1
32R09	4	109.49	105.84	107.63	157.91	180.99	90.28	2	1
32R15	1	88.77	83.33	88.09	193.67	227.01	108.76	2	1
32R15	2	82.14	74.33	79.17	169.06	205.61	134.06	2	1
32R15	3	76.28	64.30	75.18	124.32	163.51	121.98	2	1
32R15	4	72.03	63.62	68.81	145.29	174.86	114.36	2	1
32R24	1	40.56	27.39	34.28	70.75	204.21	56.49	2	1
32R24	2	32.02	29.73	30.58	110.97	165.62	57.48	2	1
32R24	3	38.27	34.49	30.54	72.28	197.11	69.96	2	1
32R24	4	35.80	34.40	34.23	87.57	211.75	62.28	2	1
33R06	1	129.71	128.95	123.34	159.39	167.03	99.64	2	1
33R06	2	135.32	132.18	135.32	155.76	167.70	89.13	2	1
33R06	3	126.14	124.11	122.66	137.22	146.99	92.14	2	1
33R06	4	116.72	72.71	111.19	76.07	112.34	81.76	2	1
33R18	1	109.75	99.98	103.55	270.68	304.16	109.17	2	1
33R18	2	104.31	99.47	100.32	145.73	180.79	118.92	2	1
33R18	3	95.31	94.71	92.68	191.55	217.40	87.55	2	1
33R18	4	91.23	76.88	88.51	102.65	138.74	133.06	2	1
34L15	1	95.65	88.60	90.30	270.93	282.88	134.03	2	2
34L15	2	98.37	56.91	88.43	121.36	237.20	198.38	2	2
34L15	3	105.42	91.15	102.44	256.30	281.05	137.58	2	2
34L15	4	77.98	73.65	67.53	149.52	210.34	153.07	2	2

ID	Rep	PT	T-5	T+5	A-5	A55	A+5	G	L
34L27	1	89.28	54.28	88.68	182.60	315.13	187.95	2	2
34L27	2	84.35	81.63	81.38	223.15	304.81	145.62	2	2
34L27	3	72.97	67.19	69.91	184.79	258.12	132.85	2	2
34L27	4	78.91	78.15	70.42	271.04	324.00	138.24	2	2
35R12	1	130.65	122.92	128.01	248.82	274.94	135.93	2	1
35R12	2	126.48	115.87	126.31	254.55	282.70	167.85	2	1
35R12	3	122.83	114.34	119.43	245.24	272.31	146.36	2	1
35R12	4	121.47	117.73	117.14	247.08	265.14	121.09	2	1
35R15	1	116.80	111.62	109.75	296.13	322.60	120.45	2	1
35R15	2	90.72	85.46	87.32	212.74	233.48	90.38	2	1
35R15	3	103.80	99.22	98.20	269.08	281.79	118.32	2	1
35R15	4	101.68	82.31	96.50	225.19	251.32	133.41	2	1
35R27	1	83.67	77.98	83.08	321.50	368.96	67.38	2	1
35R27	2	85.03	78.15	81.80	354.90	382.74	61.80	2	1
35R27	3	78.23	74.07	72.63	295.29	326.64	41.74	2	1
35R27	4	72.54	70.93	63.03	283.66	306.86	49.23	2	1
36L06	1	151.03	148.40	146.36	150.45	170.64	106.54	1	2
36L06	2	150.78	148.74	146.19	171.25	185.60	91.47	1	2
36L06	3	139.14	119.18	137.10	159.20	180.11	97.65	1	2
36L06	4	145.60	144.07	141.18	164.22	183.18	92.32	1	2
36L21	1	83.25	80.61	82.74	266.62	302.96	93.52	1	2
36L21	2	81.04	75.94	76.71	279.08	299.56	90.32	1	2
36L21	3	84.27	76.37	82.31	226.18	258.62	107.52	1	2
36L21	4	81.63	79.59	76.88	185.86	217.25	79.32	1	2
36L30	1	72.54	68.89	71.10	201.63	272.96	188.31	1	2
36L30	2	72.97	69.23	70.76	273.75	338.71	154.70	1	2
36L30	3	74.07	73.82	68.47	299.82	364.48	150.16	1	2
36L30	4	79.59	73.48	74.75	294.74	398.24	151.43	1	2
37R09	1	142.54	134.81	138.72	219.52	244.84	140.39	1	2
37R09	2	134.55	128.18	132.18	219.47	233.29	134.67	1	2
37R09	3	130.14	125.97	127.16	236.20	246.01	135.35	1	2
37R09	4	131.33	125.72	130.48	207.98	230.84	146.00	1	2

ID	Rep	PT	T-5	T+5	A-5	A55	A+5	G	L
37R18	1	91.23	85.37	89.79	255.04	282.18	144.46	1	2
37R18	2	90.72	82.82	84.86	155.72	194.09	190.75	1	2
37R18	3	99.47	87.83	94.29	179.06	222.77	234.85	1	2
37R18	4	91.49	75.60	88.51	125.32	164.71	178.50	1	2
37R30	1	73.35	69.32	68.13	331.19	531.62	90.96	1	2
37R30	2	76.11	73.56	70.80	321.90	587.72	104.24	1	2
37R30	3	67.74	63.07	64.35	319.39	519.13	79.67	1	2
37R30	4	74.45	72.03	70.46	291.31	613.27	130.70	1	2
38L12	1	131.75	129.37	130.31	288.90	310.35	161.09	1	2
38L12	2	128.44	124.87	125.89	245.79	266.44	169.63	1	2
38L12	3	123.68	121.13	120.71	256.45	277.07	150.61	1	2
38L12	4	127.50	123.09	122.92	284.11	294.39	152.31	1	2
38L15	1	128.61	121.64	127.93	297.15	331.95	179.54	1	2
38L15	2	117.22	114.42	115.61	260.66	293.02	172.75	1	2
38L15	3	113.74	112.13	112.47	271.97	299.08	173.47	1	2
38L15	4	101.59	100.92	100.83	258.07	289.00	145.38	1	2
39L06	1	107.97	105.59	107.20	91.24	114.61	82.91	2	2
39L06	2	114.25	111.96	112.89	119.75	132.69	69.63	2	2
39L06	3	108.99	106.61	103.89	107.45	121.15	61.58	2	2
39L06	4	113.32	110.85	107.97	106.91	118.50	72.66	2	2
39L15	1	78.07	77.39	71.61	181.14	191.38	112.44	2	2
39L15	2	83.84	81.12	81.46	189.99	214.90	121.80	2	2
39L15	3	80.95	78.49	78.23	121.06	145.52	91.04	2	2
39L15	4	74.58	72.46	72.88	196.70	217.41	86.16	2	2
39L27	1	52.67	50.33	51.01	135.76	163.05	65.96	2	2
39L27	2	47.44	46.34	45.66	188.84	209.01	39.62	2	2
39L27	3	50.84	48.67	49.95	182.54	206.84	60.44	2	2
39L27	4	54.58	53.05	50.67	228.68	243.58	59.32	2	2
40R09	1	114.68	111.79	113.66	203.17	200.14	118.30	1	2
40R09	2	108.31	105.76	106.35	172.19	191.42	117.39	1	2
40R09	3	102.61	99.39	100.41	186.62	196.35	96.46	1	2
40R09	4	104.82	103.97	104.65	158.70	181.07	98.92	1	2

ID	Rep	PT	T-5	T+5	A-5	A55	A+5	G	L
40R18	1	84.44	82.31	83.25	240.35	270.26	158.25	1	2
40R18	2	81.97	79.17	81.38	231.68	256.08	156.00	1	2
40R18	3	76.20	75.18	74.41	187.54	213.88	113.06	1	2
40R18	4	83.42	82.14	81.97	231.71	256.17	129.30	1	2
40R27	1	72.42	71.27	71.18	266.70	310.43	168.11	1	2
40R27	2	66.39	63.41	65.62	213.44	268.14	137.60	1	2
40R27	3	63.03	62.22	60.01	230.46	265.45	95.83	1	2
40R27	4	57.89	56.19	56.83	219.54	241.72	78.32	1	2
42R12	1	148.06	137.53	141.69	306.87	337.79	197.74	1	1
42R12	2	144.24	132.94	138.72	247.50	289.45	193.56	1	1
42R12	3	139.40	130.22	137.70	249.89	304.95	188.13	1	1
42R12	4	134.30	133.62	126.91	271.41	285.66	162.61	1	1
42R15	1	125.21	121.64	119.01	283.84	352.69	217.73	1	1
42R15	2	126.14	117.65	119.43	313.19	336.02	181.92	1	1
42R15	3	125.72	121.22	119.26	323.40	346.57	177.30	1	1
42R15	4	115.95	114.25	106.61	293.90	310.03	165.09	1	1
42R27	1	97.77	88.26	96.58	378.07	419.61	164.28	1	1
42R27	2	100.49	90.13	95.31	400.20	445.74	160.28	1	1
42R27	3	98.88	95.56	92.51	393.39	441.54	132.35	1	1
42R27	4	85.46	81.55	85.37	362.34	410.87	117.86	1	1
43R06	1	58.19	55.89	53.52	64.05	75.37	47.65	2	1
43R06	2	54.28	52.58	52.50	68.36	74.69	36.69	2	1
43R06	3	52.16	48.08	48.76	66.13	68.26	38.30	2	1
43R06	4	57.08	54.37	55.04	64.99	75.87	49.20	2	1
43R18	1	56.49	49.52	52.92	123.82	149.92	91.93	2	1
43R18	2	18.52	16.82	14.02	13.21	23.69	48.17	2	1
43R18	3	27.18	21.92	26.84	68.13	73.78	17.64	2	1
43R18	4	19.79	19.54	16.99	7.07	12.39	83.71	2	1
43R24	1	19.50	17.29	18.86	47.16	60.57	39.70	2	1
43R24	2	20.81	18.01	20.00	66.16	73.25	24.48	2	1
43R24	3	24.00	21.75	23.70	60.46	71.42	19.02	2	1
43R24	4	15.16	14.61	13.08	39.16	43.39	12.12	2	1

ID	Rep	PT	T-5	T+5	A-5	A55	A+5	G	L
44R09	1	112.89	108.56	109.92	199.87	197.23	103.51	2	1
44R09	2	112.81	111.45	112.47	171.50	204.67	111.59	2	1
44R09	3	116.12	115.02	114.17	186.14	209.53	100.78	2	1
44R09	4	111.28	111.02	110.26	172.05	197.04	99.74	2	1
44R18	1	84.52	80.61	81.72	231.14	257.65	80.36	2	1
44R18	2	79.08	76.03	75.09	236.20	253.54	96.87	2	1
44R18	3	82.06	79.08	80.27	216.44	238.25	84.53	2	1
44R18	4	76.37	75.52	76.20	221.55	245.66	89.67	2	1
44R30	1	53.01	49.40	50.16	166.66	238.36	84.87	2	1
44R30	2	52.92	52.16	50.63	203.98	243.78	110.21	2	1
44R30	3	51.77	50.84	49.99	178.59	230.37	78.43	2	1
44R30	4	48.84	46.59	48.16	179.16	232.45	96.46	2	1

VITA

Jo-Anne Lesley Lee Bogner was born in Kingston, Ontario, Canada on July 5, 1961 to Dr. JAN and D. Joy Lee. She lived in Canada, Massachusetts, and Colorado before settling in Blacksburg, VA in July, 1974. She was the first girl born to the Lee Family in approximately 135 years, and has three brothers. In 1987, she was married to David Bogner.

In 1972, she was first introduced to whitewater, paddling a two-man covered canoe with her father on a Class IV river. Two years later, she made the transition to kayak, and has been active in whitewater competition ever since. Bogner has been ranked as an expert kayaker by the American Canoe Association since 1976, and in 1978 won the Junior Women's National Championship. Since then, she has placed 4th in individual competition three times at the National Championships, in 1983, 1988, and 1989. In 1990, she qualified as a member of the National Development Team, as well as winning a spot on the North Team to compete in the 1990 Olympic Festival, where she placed 5th. In 1991, Bogner will train to qualify to compete in the World Championships, and in 1992 to qualify to compete in the U.S. Olympic Trials in hopes of making the 1992 Olympic Team.