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Full Name of Author — Nom complet de l'auteur

Daniel Gary Syrotuik

Date of Birth — Date de naissance

January 16, 1950

Country of Birth — Lieu de naissance

Canada

Permanent Address — Résidence fixe

6408 - 17 ave
Edmonton, Alta
T6L 1N4

Title of Thesis — Titre de la thèse

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Dr. S.W. Mendryk

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RESISTIVE TORQUE ANALYSIS OF THE NAUTILUS LEG EXTENSION MACHINE

by

DANIEL GARY SYROTUIK

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE

OF DOCTOR OF PHILOSOPHY

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DATED April 18, 1984

THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled Resistive Torque Analysis of the Nautilus Leg Extension Machine submitted by Daniel Gary Syrotuik, in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

S.W. Mendryk
Supervisor

Donald G. Bellow

S. Hunka

John F. Kramer

A. N. Belcastro

Murray H. Smith

John A. Alexander
External Examiner

Date April 11, 1984

DEDICATION

To that one person who always believed, when the outlook was doubtful; always encouraged when deadlines looked hopeless; always was patient when frayed emotions wore thin; - my loving wife, Darlene.

ABSTRACT

It was the purpose of this study to determine to what extent the ability of a Nautilus leg extension machine (NLEM) provided resistance that varied in proportion to the biomechanical capability of the quadriceps muscle group. Specifically, this study examined isokinetic human torque curves (HTC) indicative of the variable strength pattern of the quadriceps muscle group of a selected sample of 75 physically active male and female subjects over a 90° range of motion at three pre-determined rates of angular velocity. These curves were compared with machine resistive torque (MRT) curves generated on the NLEM at two pre-determined rates of angular velocity.

Measurements of the HTC were made with a two channel Cybex II isokinetic device at 0.524, 1.048 and 1.572 r/s. Peak torque and torque at 90 (vertical), 105, 120, 135, 150, 165 and 180° (horizontal) were measured from maximal recorded torque achieved during three voluntary leg extensions. These values were transformed to percent of maximum value and plotted to illustrate the human quadriceps torque capability throughout knee extension.

The testing of the NLEM resistive torque utilized a specially constructed leg extension dynamometer which was capable of measuring changes in torque and the angle at which it occurred (33). Angular velocities of 0.263 and 0.524 r/s were selected to approximate the manufacturer's recommended speed for optimal strength benefits. Peak torque and the torque at the same angles as for the HTC were measured and normalized to plot the MRT curves.

Test results demonstrated three distinctive human torque capability curves, representative of the muscle's angle of pull, length/tension and angular velocity interaction.

The mean shape and form of the NLEM's MRT curves were identical in pattern and peak torque, regardless of plate load or level arm angular velocity, and were not similar to the HTCs.

The present study observed that the regulated resistance of the NLEM, via the cam device, did not match the changing biomechanical capability of the quadriceps, at any of the tested angular velocities, regardless of the plate load.

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Many others have been instrumental in some manner in aiding this project to its final completion. My apology to any I have unknowingly overlooked. Listed below are those you have directly influenced the completion of this project.

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A final note of thank you is gratefully extended to Mrs. Joanne Hilger, for her patient and exact typing of this thesis. Her ability to meet my tight schedule has aided in the successful completion of this dessertation.

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CHAPTER I

INTRODUCTION

Statement of the Problem and Purpose of the Study

In recent years a number of new methods for strength training have been promoted amidst claims of superiority over all other forms of resistance training. Most of these methods have been accompanied by the manufacturing of a strength training apparatus or machine. The result has been a dramatic increase in the variety of strength training equipment available for rehabilitation, general fitness programs, body building and athletic conditioning for various sports. The corresponding growth in the number of methods and strength training apparatus have generated considerable confusion among coaches, athletes, therapists and researchers concerning not only how to train, but also the training mode which provides optimal results.

Much of the confusion has been created by various equipment manufacturers' commercial literature, extolling the benefits of their particular training modality. Each manufacturer has designed and constructed resistance training machines which they claim are based on sound scientific principles, and that provide an optimal training stimulus. For example, one manufacturer claims that the essential components of muscular development require "rotary movement, direct resistance, pre-stretching, and unlimited speed of movement" as desirable and essential components that must be engineered into each piece of equipment for optimal results (14, 15, 27, 28). Scientific verification of these claims awaits.

Many of the machines available on the market designed to develop strength have been introduced and used for various periods of time before being subjected to scientific scrutiny. In an attempt to provide this scrutiny and increase the acceptability of their product, manufacturers have from time to time published results of their own studies which may be questioned on the basis of the research design and lack of objectivity. Such results have quite likely been valuable promotional tools but deserve to be examined closely before being used as the basis for either diagnosis or prescription in training programs.

In the search for optimal muscular development through resistance training, Nautilus Sports/Medical Industries built their first proto-type machine in 1948. This initial attempt was followed by successive modifications until the first commercial model was marketed 22 years later in 1970. The Nautilus concept of training was founded on the belief that the basic tool for strength development - the barbell or free weight - was inadequate due to the lack of consideration for the basic biomechanical limitations of the human musculature and skeletal systems. In an effort to rectify these inadequacies the Nautilus designers developed an entire series of exercise equipment, which purport to provided "full-range, direct rotary resistance which automatically adjust to match or balance the torque capabilities" of the various muscle groups exercised (27).

Of particular interest in the Nautilus design, is the concept of variable resistance and its application. Theoretically, as the result of the equipment's mechanics, near maximum resistance is provided throughout the full range of motion, eliciting an optimal training stimulus for the development of muscle strength, if as heavy a weight as possible is used. Nautilus advertising literature states that at the heart of every machine is the exclusive spiral-shaped pulley . . . the Nautilus "cam" (Figure 1) which

> regulates the resistance automatically, instantly . . . providing resistance that meets your requirements in all positions. There is absolutely nothing random about the design of the Nautilus machine . . . function dictates design (27).

The patented cam in each machine acts as a variable lever arm as it rotates during any specified muscular contraction. The changing perpendicular distance (or movement arm) (r) from the weight chain to the cam pivot point, purportedly provides a match between the resistance offered by the exercise machine and the recognized variability in torque generated by the muscle group being trained (41).

The major advantages of a variable resistance mode, such as the type produced by Nautilus Sports/Medical Industries, over constant or fixed resistance training, are two-fold in physiological terms. Firstly, there is an attempt to provide a more uniform stress with respect to the muscles capabilities throughout the entire range of motion; and secondly, there is an attempt to overcome the tendency for muscle failure to occur only at the weakest biomechanical point in the range of motion (21).

To date, evaluation of the Nautilus design and its ability to balance or match the general torque curve of a movement's agonists is lacking (11). The available literature concerning the "cam" and its ability to correctly adjust the load to match the various force output curves of the skeletal muscular system, has been produced by Nautilus Sports/Medical Industries or associated company researchers (50). There is a need to test independently the claims of Nautilus and in particular, the variable resistance component. The need is especially evident in view of the expense of the machines, the lack of published acceptable data that supports these claims and the large number of people in North America that

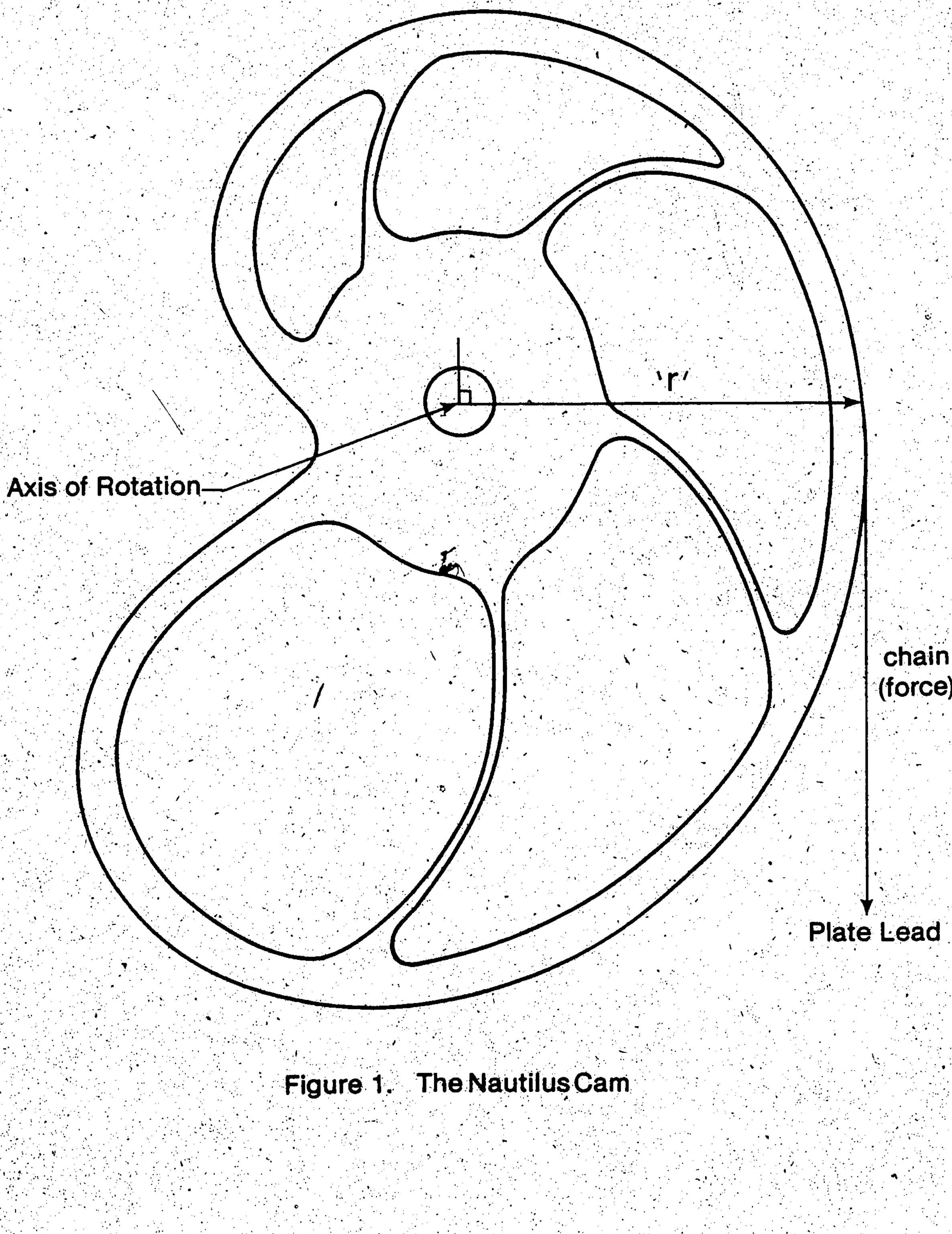

Figure 1. The Nautilus Cam

regularly train with these modalities. The final point can be highlighted by the claim that since its invention in 1948, the apparatus has been used by an estimated 2,200,000 Americans at approximately 2,600 Nautilus weight training centres (57).

It was the purpose of this study to evaluate the ability of a Nautilus apparatus to correctly provide resistance that varies in proportion to the biomechanical capability of the skeletal-muscular system. More specifically, this study examined isokinetic human torque curves (HTC) representing the variable strength pattern of the quadriceps muscle group of a selected physically active sample of males and females over a 90° range of motion, at three pre-determined rates of angular velocity. The HTC curves were compared with the machine resistive torque (MRT) curves generated by a Nautilus leg extension machine (NLEM) at two pre-determined rates of angular velocity.

Limitations of the Study

1. Control over a given subject's level of motivation to perform with maximal effort during the generation of the HTC of the quadriceps muscle group could not be exercised. The experimenter, however, did encourage the subjects to perform maximally through standard verbal instructions.

Delimitations of the Study

1. The generation of the HTC was delimited to 75 healthy male and female athletes of the University of Alberta in Edmonton, 18 – 46 years of age.

2. The MRT data was collected on a two year old Nautilus leg extension machine, which was available to physically disabled athletes.

Definition of Terms (30)

Torque: A force which acts about an axis of rotation. It is the product of force times its perpendicular distance from the axis of rotation.

Load: Refers either to the physical agent which is the source of resistance or to the act of applying the resistance.

Resistance: A force, which when acting in opposition to a contracting muscle, causes tension to develop in the muscle.

CHAPTER II

REVIEW OF LITERATURE

Length-Tension, Angle of Pull, and Velocity of Movement with the Variable Resistance Concept Interaction

It is generally agreed that muscular hypertrophy and strength development are related to the amount of tension or intensity of contraction generated within the muscle during training (1, 2, 3, 4, 5, 6, 7, 10, 12, 18, 20, 21, 22, 29, 31, 35, 43, 48, 51, 52, 55, 58, 59). Constant-load modes of training such as barbells or free weights are readily available, inexpensive, and fulfill this requirement, partially (55).

The resistance that can be applied to a muscle, however, can be set no higher than an individual's estimated maximum strength at the weakest joint position in the range of motion (23). According to early research by Williams and Stutzner (64), this limitation is a result of the muscle length/joint angle relationship. These two factors influence a muscle's ability to produce effort torque by offsetting each other.

Williams and Stutzner explain:

> As a joint moves through its arc, the prime mover muscles become shorter, reducing their ability to exert tension; at the same time the angle of application of the muscle force or forces, usually becomes more advantageous (64).

The data collected by these researchers and later by Lindahl et al (32) and Murray et al (39) illustrated this compensatory phenomenon in the quadriceps muscle group during maximal isometric knee extension measured at various angles. The results clearly show that in spite of the fact the muscle lever arm is in a relatively favourable position to apply force in full extension, the quadriceps muscles are nearly fully shortened and unable to exert maximal tension.

Scudder (54), in a more recent study, confirmed these findings by examining torque curves produced at the knee during isometric and isokinetic exercise by 10 normal male subjects ranging in age from 19 to 29 years. The shape of the isokinetic generated torque curves from knee extension appeared to be dependent not only on the length tension/angle of pull relationship, but also upon the rate of motion. The point in the arc of motion at which peak torque was produced, varied from 112 ± 2° during isometric contraction to 118 ± 2° during isokinetic contraction at 1.572 r/s (90°/s). Osternig (44) earlier reported that the torque curve changed as speed increased and that peak torque occurred at 95° during an angular velocity of 0.524 r/s or 30°/s.

The reported angle of peak torque output, by Moffroid et al (37) does not correspond to the data presented by Osternig, but falls within the range previously published by Scudder (54). Moffroid's research (37) examined the effects of 4 weeks of isometric, isotonic and isokinetic exercise on torque produced by the knee extensors of 60 subjects as measured by a Cybex II dynamometer. Peak torque output occurred at 0.392 r/s or 22.5°/s angular velocity at an angle of 117 ± 2°. The results re-affirmed that the point in the arc of motion at which peak torque is generated, is dependent upon the speed of limb motion. Moffroid and co-workers (37) attributed this finding to a possible lag or delay in exciting the contractile elements of the muscle. A second possible explanation is based on the time required for momentum of the leg to overcome interia (44).

Thorstensson et al (62) presented data on 25 healthy subjects which supported the findings of all authors to date regarding force-velocity relationship and movement of the point of peak torque output.

The results confirmed that isometric contractions performed with a Cybex II set at 0^{o}/s produced the highest torque values. As the angular velocity of the lever arm increased, the angle of peak torque output increased (62).

Angular Velocity versus Peak Torque

Output during Knee Extension (62)

Angular Velocity in 0^{o}/s	Angle of Peak Torque (S.E.±)
0	105^{o}
30	107 ± 1.1^{o}
60	109 ± 1.1^{o}
90	112 ± 1.1^{o}
120	135 ± 1.5^{o}
	Mean for all velocities = 120^{o}

As a result of the reported compensatory interaction between angle of pull, length/tension relationship and velocity of movement, the major disadvantage encountered with constant-load training regimes, is that athletes are forced to exercise with a submaximal workload to get through the weakest point in the range of motion. The point of optimal physiological benefit or maximum tension occurs only during a few degrees in the total desired range of motion. This angle or position may not necessarily correspond to the most important range in terms of an athlete's performance.

In an effort to solve this problem, variable resistance models have been developed. Apparatus featuring cambered pulley wheels, variable-length lever arms, or movement of fluid through hydraulic cylinders, all purportedly provide variable loads which effectively match the shape of typical human strength curves throughout specified ranges of motion and angular velocities (11, 21, 24, 49, 53, 55, 56, 60). The resistance automatically increases at those points where the musculature is strongest and decreases where the muscles are weakest, providing near maximal resistance throughout the range of motion and thus an optimal training stimulus.

Nautilus Sports/Medical Industries of Deland, Florida, is only one manufacturer of resistance training equipment which realized that conventional barbell training failed to elicit maximum training stimulus during muscular contraction.

> The key to overloading the muscle through the entire range of movement lies in matching the resistance offered by the machine to the capabilities of the muscle (41).

> Automatically - variable resistance is an absolute requirement for high intensity exercise. Since movement produces changes in useable strength, it is necessary for the resistance to vary in proportion to the resulting changes in strength (50).

The problem of providing full-range resistance is claimed to be solved by incorporating a cambered shaped pulley (Figure 1). As the radius of the cam alters, it automatically becomes a variable lever arm which provides greater resistance or mechanical disadvantage where the trainee is potentially stronger and less resistance or mechanical advantage where the trainee is potentially weaker (41, 57). In fact, each Nautilus machine has purportedly been specifically designed to "balance" or match the "ideal or unique" strength curve of the movement's agonists. As opposed to a true isokinetic device, which forces an increase in muscular output a pre-set constant angular velocity (37), the manufacturers of Nautilus state:

> The Nautilus cam, in contrast, is not isokinetic, for it maintains no control over movement speed. It is a variable resistance device. But instead of forcing the muscle in whatever condition it is in to determine training load, it accurately varies the load (42).

The key word is "accurately". The Nautilus proponents believe that the elliptical cam pulley system balances the provided load against the muscle's potential strength in each position throughout the full range of functional motion.

> The Nautilus cam instantly, compensates for resulting changes in strength; automatically increasing or reducing the resistance to match your changing strength . . . Nautilus provides correct resistance in every position; lower in your weak positions, higher in your strong positions, and maximum in your strongest positions (40).

> The Nautilus cam perfectly balances this ideal strength curve by changing its radius in direct relation to several impinging factors, including the changing bio-mechanical movement arm (41).

As the manufacturers themselves admit, the Nautilus cam is not an isokinetic device, in that it does not control limb velocity at a constant rate. This observation may question the ability of a fixed cam to match the exact shapes of the torque curves in all trainees at various speeds of contraction.

To date, except for advertising literature extolling the benefits of Nautilus, the sample data from which each Nautilus cam was designed has not been published in a research journal. The recommended speed of contraction that the manufacturer specifies when utilizing their apparatus, suggests a limb velocity that would correspond to somewhere between 30 and 15°/s on the concentric and eccentric phases, respectively. One can only speculate as to what speeds of contraction the original cams were intended to be rotated.

As stated previously, speed of contraction will vary peak torque output, as well as the angle of occurrence of peak torque in a given range of motion. The majority of research is in agreement, that regardless of the mode of training utilized, pure strength can be developed most effectively by low repetition, high resistance exercises taken to failure (2, 3, 7, 18, 22, 35, 58). In order to follow this principle, exercises conducted on the Nautilus equipment will be executed at slow speeds of movement, in spite of specificity which regard to velocity, and training (35, 38). Muscular contractions of a high speed nature (200°s or greater), will reduce the effectiveness of the changing lever arm of the cam, and decrease the machine resistive torque available to the exercising body parts providing less than maximal muscular tension.

Measurement of Maximum Dynamic Strength: Isokinetic Modality

A device or machine that can give a detailed and accurate profile of the interaction between muscle angle of pull, length/tension and speed of contraction, in terms of torque output, is the Cybex II system (Plate 1). This apparatus is considered the best available means of accurately measuring muscle parameters such as maximal torque output, work, power and muscular endurance (13, 17, 36, 37, 38, 44, 46, 47, 61, 62, 63).

Isotonic measurements, commonly performed on weight machines such as "Universal Gym", have the limitation that the strength measured related only to the weakest point in the range of motion during one maximal repetition (17). The Cybex device, by accommodating resistance against a lever moving at a pre-set maximal angular velocity, can record dynamic strength at every point in the range of motion. The machine incorporates a dual channel recorder - dynamometer and electrogoniometer which provides a continuous printout curve of the range of joint angles and peak torque across the entire range of motion of the limb tested.

The literature cites two major drawbacks of this apparatus. Firstly, if a subject applies less torque force to the lever arm than necessary to produce maximal tension at a pre-determined speed, little resistance will be encountered and therefore the reliability and validity of results may be questioned (17). Motivation of each subject to perform maximally is critical. Secondly, the apparatus does not assess eccentric muscle strength (17).

Moffroid et al (37) and Thorstensson et al (62) have reported reliability co-efficients for torque output as high as 0.995 and validity co-efficients between predicted and obtained power of 0.999. To ensure constant velocity of the lever arm throughout the entire range of motion, a reliability correlation of 0.985 was reported for thirty-four points on generated torque curves (37).

CHAPTER III

METHODOLOGY

Subjects

In order to generate data on the HTC for the quadriceps muscle group, permission was obtained from 75 physically active male and female subjects from the University of Alberta to participate in the study. A summary of age, sex and sport/activity of the individuals is presented in Appendix B. The subjects ranged in age from 18 - 46 with a mean age of 22.1 years. In order to minimize error in the generation of HTC, individuals with athletic backgrounds who could be motivated to perform maximally, were selected. Any subjects with pathological conditions associated with the knee joint, surrounding structure or quadricep muscle group, were screened out to insure the production of a true representative normal torque curve.

Testing Protocol for the Human Torque Curve (HTC)

Apparatus

The Cybex II, (Appendix L, Plate 1) is capable of measuring muscular torque output in foot-pounds at pre-selected controlled velocities from isometric contractions (0^{o}/s) to fast functional speeds (300^{o}/s, 5.23 r/s). Once an angular velocity has been selected, the lever arm cannot be accelerated beyond that speed regardless of the input torque. The constant velocity is made possible by an electromotor device which has a feedback loop to the speed selector that automatically and instantaneously adjusts the voltage for variations in torque to insure a maximum and constant

Plate 1. Cybex II Isokinetic Dynamometer and Testing Bench.

velocity. Thus, as more force is exerted against the lever arm of the apparatus, the resistance supplied via the input attachment varies to accommodate this force. The torque output of the muscle is reflected by a dynamometer and displayed on a front gauge dial and a fast response two channel recorder using a heated stylus. The fast response recorder gives a graphic readout of the HTC over the entire range of motion. The gauge assists the subjects achieve maximal effort by supplying a visual feedback on performance (Plate 1).

Although the torque channel was factory calibrated, a daily pre-post testing check was made, using the procedure outlined in Appendix C. The electrogoniometer, which records joint angle, was calibrated before and after all testing sessions following the procedure outlined in Appendix D. Speed selector calibration was conducted by a qualified Cybex engineer at the factory in Long Island, New York immediately prior to the study and then re-checked prior to data collection utilizing the calibration procedure outlined in Appendix E.

Anatomical Considerations

Although one of the largest and most complex joints in the human body, the knee is considered the easiest joint to test on the Cybex II. Anatomical landmarks of the knee are easily palpated so that the axis of rotation for testing is readily located. The mixed gliding and rocking action of the knee joint in extension/flexion causes this axis to shift slightly as the femoral condyles slide anteriorly during flexion and back posteriorly during extension. However, the knee is considered a simple hinge joint, and its rotational axis can be readily aligned with the rotational axis of the Cybex.

The anatomical problems present in knee testing are related to subject comfort and normal hyperextension of the joint. It is desirable to maximally stabilize the thigh in extension/flexion. However, sufficient padding underneath and over the thigh is critical as torque output will be inhibited by discomfort in the working muscles.

Normal range hyperextension may occur at the higher testing velocities because the inertia of the moving limb tends to help the contracting quadriceps muscles overcome the passive resistance of the skin, fascia, joint capsule and articular structures. Thus, the data recorded at higher velocities will tend to have a slightly greater range of motion at the end points.

These factors have no significant effect on torque measurement except possibly during the first one-tenth second of a high torque contraction during which the limb "takes up slack" in the straps and/or compresses the foam padding on the table and shin pad. At lower force levels recorded at higher speeds, this factor is even less significant.

The preceding factors can combine to produce error of ± 5 degrees on the position angle chart, depending on the force and direction of movement. This error value is considered acceptable in clinical applications since a number of studies have shown that manual goniometric measurements are rarely more accurate than ± 5 degrees (9, 34).

General Positioning and Stabilization Guidelines

Each subject assumed a seated position on the testing table. The right knee was aligned with the axis of rotation of the dynamometer. To achieve knee alignment and insure padding under the knee, back space pads were utilized as necessary to move the subject forward or backward and to provide a solid, comfortable backrest. A velcro strap and a football thigh pad secured and stabilized the upper leg. Upper torso and pelvic stabilization was achieved by utilizing an adjustable seat belt and shoulder harness. To provide optimal comfort, a folded towel was inserted between the straps and the subject. During muscular efforts, the long axis of the upper leg lay along the horizontal so that the 90° knee flexion position was achieved with the lower vertical leg.

During the recording of the HTC, the subjects were instructed to firmly grasp the shoulder harness straps at chest level. This insured consistent hand positioning and forced the upper body firmly against the backrest.

A shin pad with velcro strap was fastened to the lower leg proximal to the medial malleolus, but allowing ankle dorsiflexion. A standard lever arm length of 36.83 cm. was selected in order to correspond to the lever arm of the NLEM.

Testing Procedure

Following a familiarization period, as recommended by Johnson and Siegel (26), each test leg was fixed and locked in an anatomical 90° position as measured via manual goniometer, and by turning the velocity selector control to 0°/s. The greater trochanter of the hip, the lateral aspect of the tibial plateau, and the lateral maleolus were the palpated skeletal landmarks for the purpose of standardization. In order to attempt to simulate training speeds recommended for the NLEM, each subject was tested using pre-selected randomly assigned angular velocities of 30, 60, and 90°/s.

Following the setting of the velocity selector at one of the pre-determined angular velocities and the chart recorder at 25 mm/s, all subjects were asked to perform three maximal leg extension and flexion movements (Appendix F). Verbal encouragement to heighten motivation was provided by the test administrator. A maximum of 4 minute recovery was required prior to testing the next assigned velocity. Peak torque and torque output at 90 (vertical), 105, 120, 135, 150, 165, and 180^{o} were measured from the torque curves utilizing the Cybex II Chart Data Card (Appendix G). The repetition with the highest torque output in leg extension was selected for analysis. See Appendix H for an example of a data record sheet.

Testing Protocol of the Nautilus Machine Resistive Torque (MRT)

Apparatus

The Nautilus leg extension machine (NLEM) (Plate 2) was coupled to a cybernetic leg extension dynamometer capable of measuring both isometric and isokinetic torque. The dynamometer consisted of a reversible 0.5hp D.C. "Boston Gear Ratiotrol" electric motor coupled to a 1:600 reduction gear box. The gear box connected to an adjustable aluminum lever arm which was used to duplicate the movement pattern of knee extension (Plate 3). The maximal continuous torque output of the motor was 329.16 ft/lb or 446.34 Nm. The validity coefficient between predicted and calculated torque values was 0.991 (Appendix I). The reliability coefficients which were established by comparing the variabilitiy of each recording point between 15 and 30^{o}/s and 5 and 14 load plates were 0.851 and 0.824, respectively (Appendix I).

Plate 2. Nautilus Leg Extension Machine (NLEM).

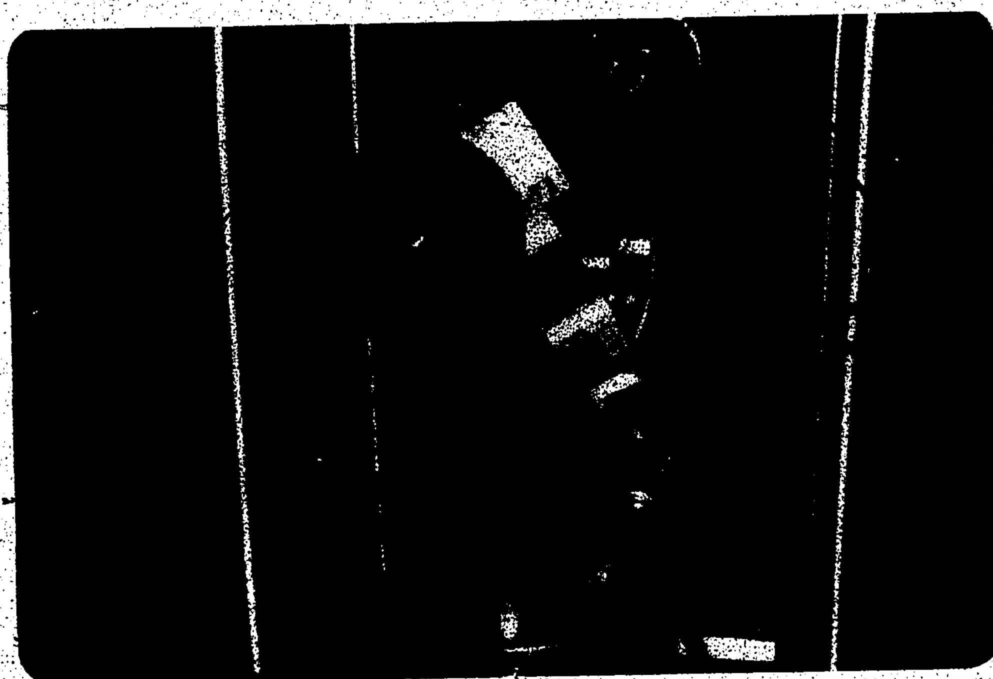

Plate 3. NLEM and Testing Dynamometer Assembly.

Changes in variable load offered by the NLEM were detected by four SR-4 strain gauges positioned on the aluminum lever arm, 11.5 cm from the axis of rotation. The strain gauges were interconnected to form a wheatstone bridge so that when no load was applied to the lever arm, the resistance across one side of the bridge (strain gauges 1 and 4) equaled the resistance across the other side of the bridge (gauges 2 and 3, Figure 2). Provided that internal resistance with each gauge was equal, voltage across the bridge was balanced and no pen chart movement occurred on the torque channel of the recorder. Any force exerted on the lever arm, altered the strain gauges' internal resistance, resulting in a measurable voltage change across each side of the bridge (33). The amount of change in resistance of the gauges was calibrated to have a direct linear relationship with the amount of strain incurred by the lever arm.

Changes in lever arm angle were measured by an electrogoniometer which consisted of a ten-turn potentiometer. Because the potentiometer would only be required to rotate through approximately one-quarter of a turn (90°), a 15 volt input signal was connected to provide sufficient voltage for pen deflection on the position angle channel.

Applied resistive torque and the angle of the dynamometer lever arm were recorded by a Grass Model 79 E.E.G. and Polygraph Data Recording System with a four channel fast response recorder with ink stylus. The recorder gave a permanent graphic readout of the MRT over the entire range of motion.

A variable voltage rheostat connected to the 0.5 hp motor was capable of adjusting the voltage input and permitted lever arm velocities between 0 and 45°/s (0 to 0.785 r/s). A set of photo-electric cells connected to a timing clock capable of measurement to 0.01s insured

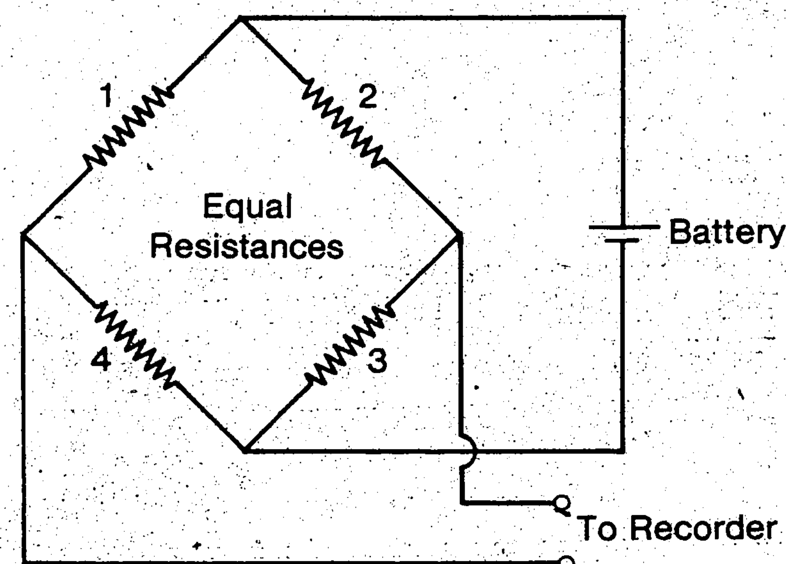

Figure 2. Wiring of strain gauges to form Wheatstone Bridge. (33)

a lever arm velocity accurate to .02s. By breaking the light beam emitted from the first pair of photo-electric cells, the lever arm started the timing device and stopped the clock after passing the second pair of timing lights at the terminal end of the arc of motion (Plate 4). To allow for any acceleration or deceleration in the lever arm as the motor engaged the load of the NLEM, the photo-electric cells were placed 120° apart. Any significant variation in the dynamometer lever arm velocity could be double checked by irregularities that might have appeared in the slope of the angle position printout.

Pre and post calibration of the torque channel was accomplished by rotating the lever arm until it was in a horizontal position (180°) and placing calibrated disc weights on the arm to determine pen deflection on the torque channel (Appendix I). With the lever arm distance set at 0.368 m (1.2 ft) to correspond to the lever arm of the NLEM, one millimeter of pen deflection from the baseline equalled 5 Nm (± 0.3 Nm.) of torque (3.68 ft/lb ± 0.22 ft/lb). In the horizontal position with no load applied, there was a slight, but constant deflection of the strain gauge as a result of the aluminum lever arm mass. Since this represented a variable but consistent error factor in the recording of torque, it did not significantly alter the MRT curves. A torque channel chart recording data card was developed to measure the torque tracings from the pen recordings (Appendix J).

Pre and post calibration of the angle position channel was completed utilizing spirit levels and constructing a linear relationship between the starting and finishing arc of motion. A vertical or 90° position of the lever arm was determined when the level bubble was stationary and fixed in the center of the lever (Plate 5). This position

Plate 4.- NLEM Testing Dynamometer Lever Arm in the Terminal Position (180°) with Photo Cell Control System.

Plate 5. Initial Position (90°) of the Testing Dynamometer with Spirit Level Attachments.

corresponded to the baseline on the angle position chart. Following this measurement, the motor moved the lever arm through 90° to the horizontal position (180°) as determined by the second spirit level. This position represented the top of the chart recording pen. On the basis of these two extreme points a data recording card was designed to determine lever arm angle every 15° through the 90° range of motion (Appendix J). Manual goniometer recordings of the lever arm confirmed the validity of measurement for each corresponding angle ($r = 0.991$).

Testing Procedure

The NLEM (Plate 2) was prepared for analysis by removing the seat, the shin padding, the cam assembly cover and the forward sprocket cover. The recording leg extension dynamometer was aligned with the axis of rotation of the NLEM and the lever arm adjusted to apply torque at the centre point of the shin bar, 0.368 m (1.2 ft) (Plate 6). The entire apparatus was bolted to a 1.91 cm (0.75 in) plywood plate and secured to the floor to avoid excessive movement or misalignment. Disc weight ballast was added to the NLEM frame to provide additional stabilization.

The photo-electric cell timing lights were set 120° apart, with the second pair stationed to stop the clock when the lever arm reached the horizontal or 180° position. The lever arm velocity was adjusted utilizing the timing clocks to insure constant angular velocity under all load conditions (± .02 s). Lever arm angular velocities of 0.263 r/s (15°/s) and 0.524 r/s (30°/s) were selected to duplicate the manufacturer's recommended speed for optimal strength training results on the NLEM.

Following calibration of the torque and angle recorder channels, both testing velocities were pre-checked with the timing lights in a loaded and unloaded posture. Starting with the lever arm at the 90° or

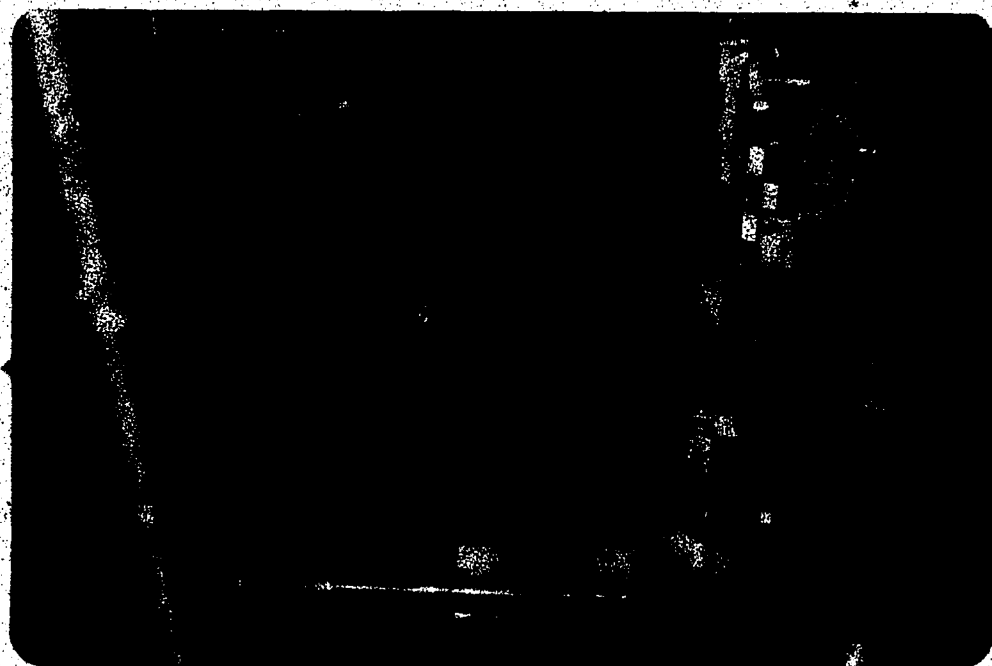

Plate 6. Frontal view of the Testing Dynamometer Positioned on the Shin Bar of the NLEM.

vertical position, load values of 5, 10, and 14 plates on the NLEM were selected and MRT curves were generated using 15 and 30°/s velocities. Printouts of the curves were recorded on a fast response four channel Grass Model 79 E.E.G. and Polygraph recorder (Appendix L). Appendix K contains an example of the MRT curve produced by the NLEM. Peak torque and torque output at 90 (vertical), 105, 120, 135, 150, 165 and 180° (horizontal) were measured from the printouts utilizing the constructed data cards for lever arm torque and angle. In order to insure constant velocity throughout the range of motion, the angle channel recordings were checked for constant slope. A double check with a one second marker channel confirmed constant angular velocity (3 s for 30°/s; 6 s for 15°/s).

Following the generation of MRT curve, the perpendicular distance (r) from the cam pivot point to the load chain was measured using a metal tape, commencing at the vertical NLEM lever arm position (90°) and at 15° intervals up to and including 180°, which corresponded to the horizontal or full extension position (Figure 3). Since the MRT printout is directly related to r, this measurement served as a validity coefficient for the NLEM recording dynamometer.

Data Analysis

Since relative changes in HTC and MRT were to be compared for their main effect, percentage change of peak torque was calculated every 15°, commencing at the vertical or 90° position and concluding, whenever possible, at the horizontal or 180° position. Because of the sensitivity of the NLEM recording dynamometer, a slight anomoly occurred at the full extension position resulting in the last torque value being recorded of 165°. It was believed that the sensitivity of the wheatstone bridge,

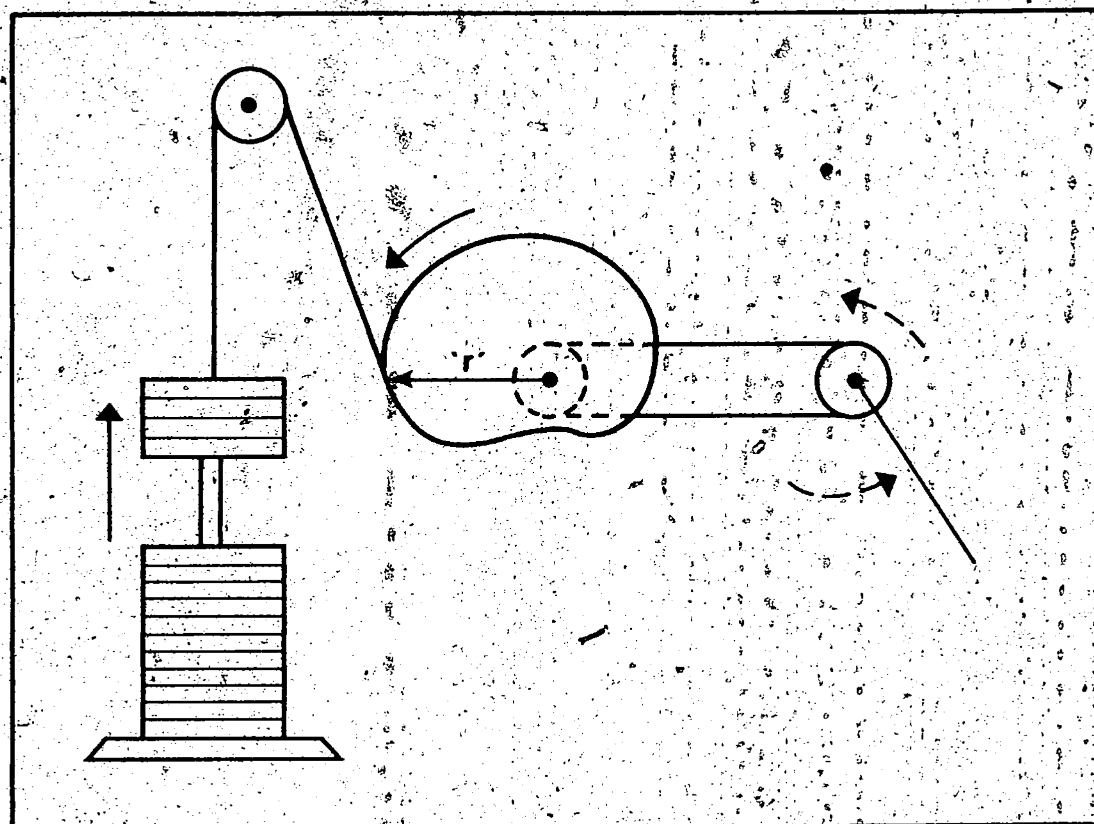

Figure 3. NLEM lever arm, sprocket-cam assembly.

contributed to this artifact as a result of the inertia of mass and the deceleration of the lever arm as it approached the terminal end of the arc of motion.

During the generation of the HTC printout at the slower 30 and 60°/s velocities, the data base for the fully extended or 180° position was reduced, because many subjects did not reach full extension prior to commencing knee flexion.

From the percentage change in peak torque for HTC and MRT, curves were constructed from the means at every 15° and compared for similar shape and form. Variability of each measurement point was also calculated.

Using the measured values recorded from the radius of the cam (r) a Pearson-Product Moment Correlation Coefficient was determined for the MRT and the cam radius length.

Reliability of the NLEM recording dynamometer was calculated by comparing the variability established at each recording point for 15 and 30°/s (Appendix I).

Validity of the NLEM recording dynamometer was determined utilizing the procedure presented in Appendix I.

CHAPTER IV

RESULTS AND DISCUSSIONS

The results and discussion are presented in three major sections: Human Torque Curves of the subjects; Machine Resistive Torque of the Nautilus Leg Extension Machine and a comparison and discussion of the curves generated in both cases.

Human Torque Curve (HTC)

The means and standard deviations for the transformed data generated during knee extension at 0.524 r/s (30°/s), 1.048 r/s (60°/s), and 1.572 r/s (90°/s) are presented in Tables 1, 2, and 3 respectively. Based on the experimental procedure, the torque output data was collected from the human torque curves produced at every 15° of extension, commencing at the vertical or 90° position and completed at 180° or horizontal leg position. A graphic presentation of the results are illustrated in Figure 4.

The angle of pull length-tension relationship of the quadriceps muscle group is clearly depicted by the considerable variation in torque output. The mean shape and form of the three curves are similar, with peak torque output (100 percent) occurring later in the movement as the knee angular velocity increased. The mean angle and standard deviation at which maximal torque was produced in the arc of motion was $115.1 \pm 5.5^\circ$, $123.8 \pm 5.7^\circ$, and $127.2 \pm 22.9^\circ$ for 0.524 r/s (30°/s), 1.048 r/s (60°/s) and 1.572 r/s (90°/s), respectively. The results illustrate the compensatory interaction between angle of pull, length/tension relation-

Table 1

Summary Data of Human Torque Curve (HTC)

at 0.524 r/s (30°/s)

Normalized to Percent of Maximum

Angle (Knee Flexion) (180°–90°)	n (subjects)	$\bar{X}$ (% of Maximum Torque)	S.D. (%)
90°	55	48.0	23.5
105°	75	85.0	12.3
120°	75	95.4	6.9
135°	75	78.5	9.0
150°	74	53.6	10.0
165°	63	28.4	9.5
180°	14	14.0	5.9

Angle of Peak Torque Output = 115.1° ($\pm$ 5.5°)

Table 2

Summary Data of Human Torque Curve (HTC)

at 1.048 r/s (60°/s)

Normalized to Percent of Maximum

Angle (Knee Flexion) 180°–90°	n (subjects)	$\overline{X}$ (% of Maximum Torque)	S.D. (%)
90°	67	48.8	16.6
105°	75	78.5	14.2
120°	75	96.7	3.7
135°	75	91.3	6.3
150°	75	69.2	15.0
165°	69	42.5	12.3
180°	28	22.3	6.9

Angle of Peak Torque Output = 123.8° (± 5.7°)

Table 3

Summary Data of Human Torque Curve (HTC)

at 1.572 r/s (90°/s)

Normalized to Percent of Maximum

Angle (Knee Flexion) 180° ⌐ 90°	n (subjects)	$\bar{X}$. (% of Maximum Torque)	S.D. (%)
90°	71	55.0	9.5
105°	75	77.9	9.6
120°	75	95.0	4.1
135°	75	96.9	3.5
150°	75	82.2	7.9
165°	73	54.1	11.4
180°	39	30.7	10.7

Angle of Peak Torque Output = 127.2° (± 22.0°)

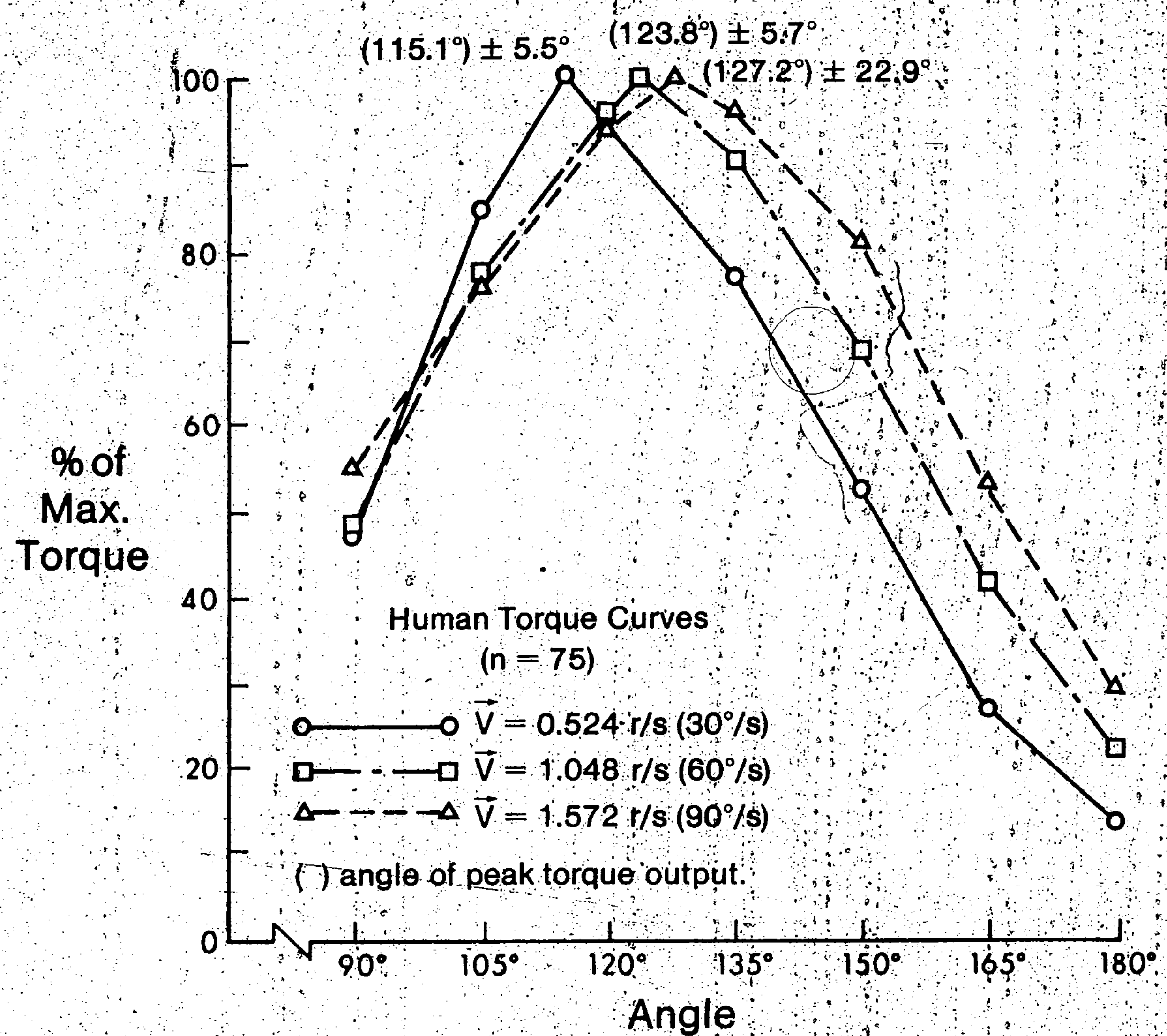

Figure 4. Human torque curves for leg extension at 0.524, 1.048, and 1.572 r/s.

ship and velocity of movement. Consequently, each subject's ability to generate muscular torque is variable throughout the entire desired range of motion.

Machine Resistive Torque of the NLEM

The means and standard deviations for the normalized data of the resistive torque generated during the analysis of the NLEM are presented in Tables 4 through 7. A corresponding graphic representation of the results are illustrated in Figures 5, 6, and 7.

Tables 4 and 5 summarize data recorded every 15° of extension commencing at the vertical or 90° position at 0.263 r/s (15°/s) and at 0.524 r/s (30°/s) respectively. Appendix K contains a sample printout of the MRT of the NLEM as analyzed by the dynamometer at loads of 10 and 14 plates. Each recording point on Figure 4 is the mean for every 15° of motion, calculated from the dynamometer printouts. The mean shape and form of both curves are similar regardless of the plate load or velocity, with peak resistive torque occurring at 165 ± .001°. The standard deviation of all points is very low. This would be expected since the change in the length of the radius (r) from the cam pivot point to the weight chain should be consistent during each 90° arc of motion, independent of load or velocity.

Table 6 and Figure 6 highlight the comparison of three different plate loads (5, 10 and 14 plates) independent of the two testing velocities of 0.263 r/s (15°/s) and 0.524 r/s (30°/s). The mean shape and form of each curve is virtually identical. The slight variation at the start of movement may be a result of a higher percentage of maximal torque necessary to overcome the inertia of the heavier loads. Peak

Table 4

Summary Data of Machine Resistive Torque (MRT)

at 0.263 r/s (15°/s)

Normalized to percent of Maximum

Angle (Knee Flexion) ┌180° 90°	n (Trials)	$\bar{X}$ (% of Maximum Torque)	S.D. (%)
90°	6	63.7	4.2
105°	6	74.4	2.3
120°	6	80.0	1.9
135°	6	87.9	2.2
150°	6	94.5	1.6
165°	6	100.0	0.0
170°*	6	92.4	4.2

Angle of Peak Resistive Torque = 165° (± 0.001°)

* Due to instrumentation, 170° was the last available angle for data collection

Table 5

Summary Data of Machine Resistive Torque (MRT)

at 0.524 r/s (30°/s)

Normalized to Percent of Maximum

Angle (Knee Flexion) 180° / 90°	n (Trials)	$\overline{X}$. (% of Maximum Torque)	S.D. (%)
90°	6	62.1	2.6
105°	6	76.3	1.9
120°	6	82.8	0.9
135°	6	88.6	2.2
150°	6	95.7	0.8
165°	6	100.0	0.0
170°*	6	93.3	2.8

Angle of Peak Resistive Torque = 165° (± .001°)

* Due to instrumentation, 170° was the last available angle for data collection.

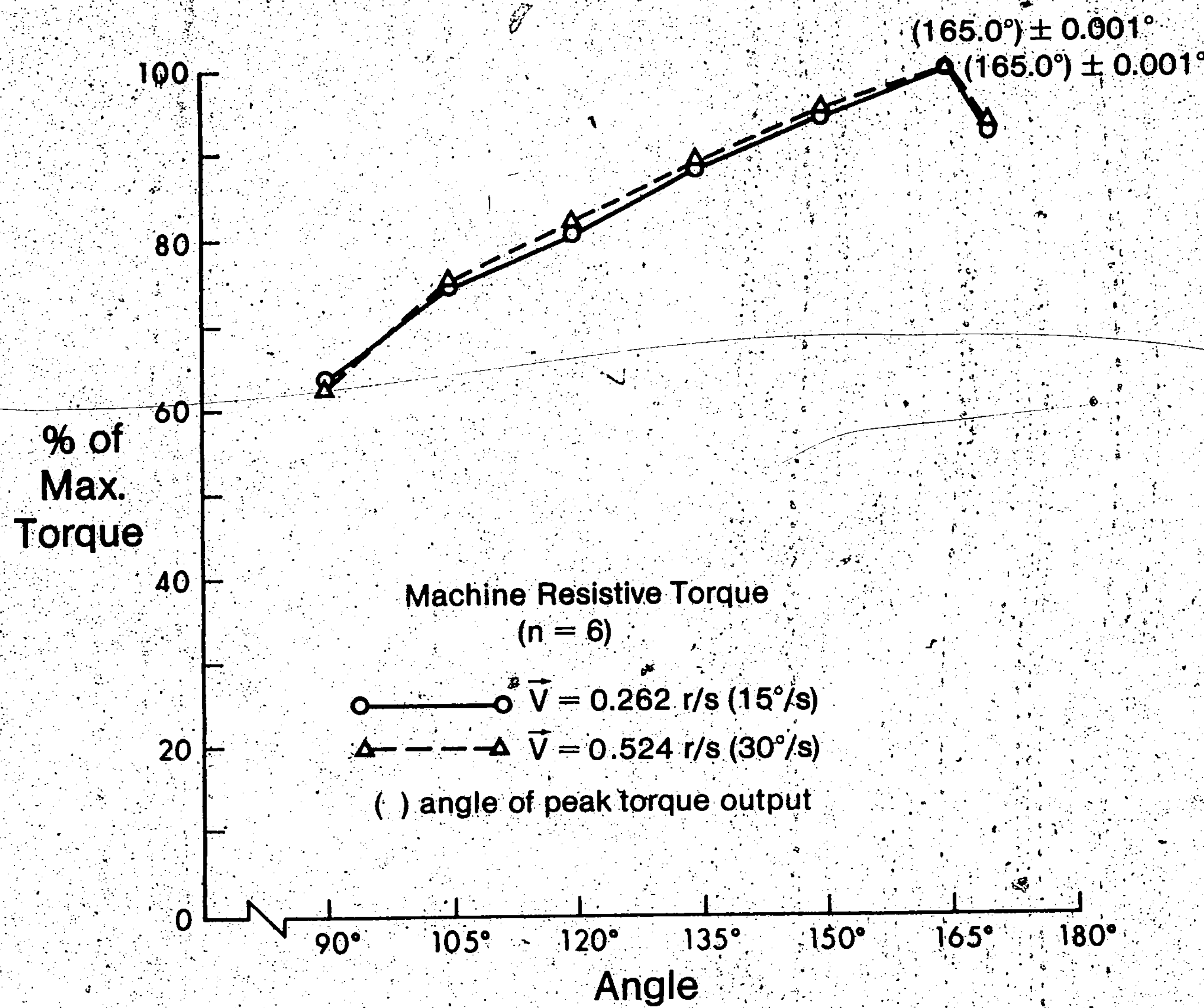

Figure 5. MRT curves at 0.263 and 0.542 radians utilizing 5, 10, 14 load plates.

resistive torque occurred at 165 ± .001° regardless of load.

The slight drop off which occurred during the final few degrees of motion is indicative of the inertia of mass and the deceleration of the lever arm as it approached the terminal end of the arc of motion and not a result of a decrease in radius from the cam pivot point.

Table 7 contains data on the changing biomechanical radius as measured by the perpendicular distance from the cam pivot point to the load chain in cm. The radius increased in a linear manner from 21.8 cm at the start of extension to 26.8 cm at the end of movement. The calculated percentages of MRT demonstrated a Pearson-Product Movement Correlation Coefficient of 0.9956 and 0.9568 ($P < 0.001$) with the radius during 0.262 r/s (15°/s) and 0.524 r/s (30°/s) respectively.

The combined angular velocities and load data is presented in Table 8, providing 12 points of data for each 15° of motion. Figure 7, illustrates that the shape and form of the MRT curve is comparable to the preceding results, with the maximal resistive torque occurring at 165 ± .001°.

A reliability of coefficient of 0.851 ($P < 0.05$) was established with the variability of each recorded data point between 0.263 r/s (15°/s) and 0.524 r/s (30°/s) (Appendix I). A reliability coefficient of 0.824 ($P < 0.05$) resulted when comparing the variability of each data point between 5 and 14 load plates (Appendix I).

Table 6

Summary Data of Machine Resistive Torque (MRT)

of a load of 5, 10, and 14 plates

Normalized to Percent of Maximum

Load (plates)	Angle (Knee Flexion) 180° 90°	n (Trials)	$\bar{X}$. (% of Maximum Torque)	S.D. (%)
5	90°	4	59.1	1.3
5	105°	4	73.0	1.8
5	120°	4	80.2	2.0
5	135°	4	87.6	2.2
5	150°	4	94.9	2.4
5	165°	4	100.0	0.0
5	170°*	4	92.7	4.5
10	90°	4	63.6	2.2
10	105°	4	75.5	0.6
10	120°	4	82.3	0.4
10	135°	4	87.6	0.7
10	150°	4	95.2	0.0
10	165°	4	100.0	0.0
10	170°*	4	91.2	0.0
14	90°	4	65.9	2.2
14	105°	4	77.5	1.4
14	120°	4	83.1	2.5
14	135°	4	89.2	2.9
14	150°	4	95.2	2.7
14	165°	4	100.0	0.0
14	170°*	4	94.7	3.3

Angle of Peak Resistive Torque = 165° (± .001)

*Due to instrumentation, 170° was the last available angle for data collection.

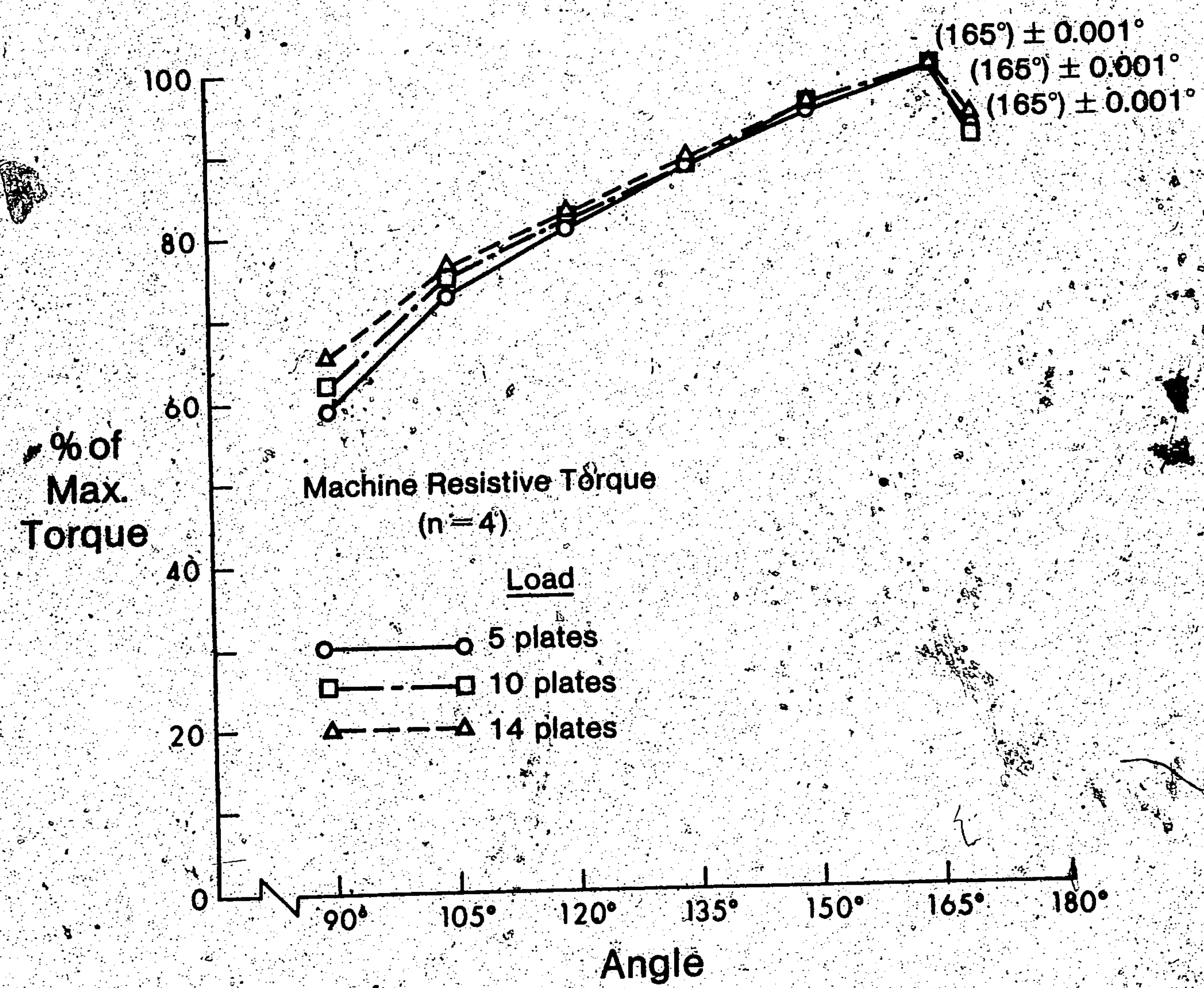

Figure 6. MRT curves for 5, 10 and 14 plates.

Table 7

Radius Length Versus Percentage Torque of MRT Curve

at 0.262 and 0.524 r/s

Angle of Observation (180°, 90°)	Radius: (P) ⊥ distance from the cam pivot point to the load chain (cm)	Percentage Torque of MRT at 0.262 r/s (15°/s)
90°	21.8	63.7
105°	22.8	74.3
120°	23.9	80.9
135°	25.0	87.9
150°	26.0	94.5
165°	26.8	100.0
	*P < 0.001	r = 0.9956*

Angle of Observation (180°, 90°)	Radius: (P) ⊥ distance from the cam pivot point to the load chain (cm)	Percentage Torque of MRT at 0.524 r/s (30°/s)
90°	21.8	62.1
105°	22.8	76.3
120°	23.9	82.8
135°	25.0	88.6
150°	26.0	95.7
165°	26.8	100.0
	*P < 0.001	r = 0.9568*

Table 8

Summary Data of Machine Resistive Torque (MRT)

for Combined Velocity and Loads

Normalized to Percent of Maximum

Angle (Knee Flexion) 180° / 90°	n (Trials)	$\bar{X}$ (% of Maximum Torque)	S.D. (%)
90°	12	62.9	3.5
105°	12	75.3	2.1
120°	12	81.9	1.4
135°	12	88.2	2.2
150°	12	95.1	1.2
165°	12	100.0	0.0
170°*	12	92.9	3.5

Angle of Peak Resistive Torque = 165° (± .001)

*Due to instrumentation, 170° was the last angle for data collection.

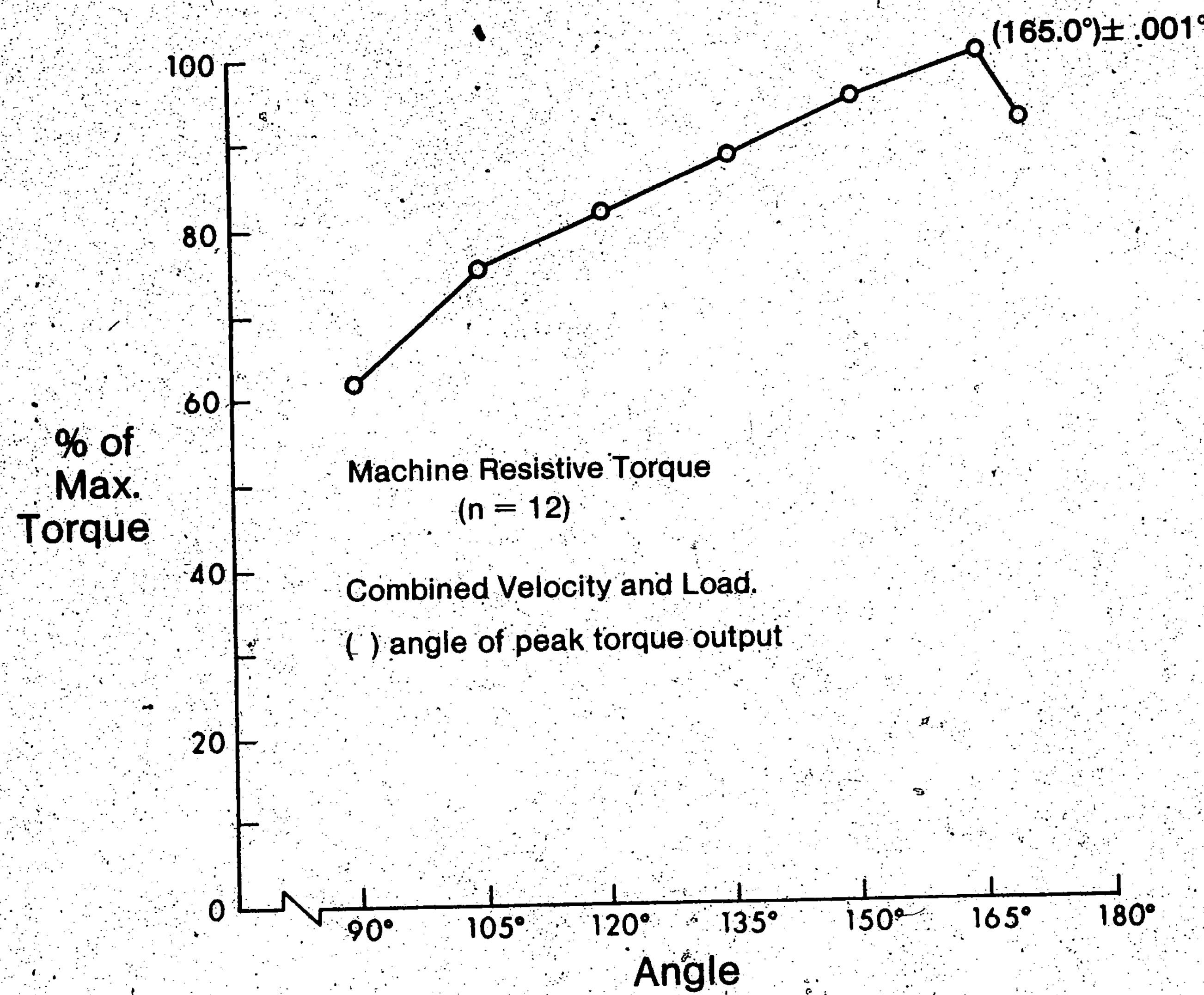

Figure 7. MRT curve represented of combined testing velocities (0.264 and 0.524 r/s) and loads (5, 10 and 14 plates).

Machine Resistive Torque (MRT) Versus Human Torque Curve (HTC)

The shape of the HTC for knee extension, within the limits of this study appears to be dependent upon the angular velocity of limb motion. Using similar instrumentation, Moffroid and associates (37) observed similar results. In their study, maximal peak torque produced at "slower speeds" occurred at 117 ± 2^{o} at 0.392 r/s or 22.5^{o}/s and as velocity increased, peak torque output occurred later in the range of motion.

Although not documenting the exact values, Scudder (54) reported that peak torque occurred at 112 ± 2^{o} during isometric contraction and increased to 118 ± 2^{o} during testing at an angular velocity of 1.572 r/s (90^{o}/s). The results of the present study showed that peak torque output of the leg extensors occurred at 115 ± 5.5^{o} at 0.524 r/s or 30^{o}/s. This value falls within the range reported by both Moffroid (37) and Scudder (54).

Osternig (44) also reported that the torque curve changed as velocity of movement increased. His results indicated that peak torque output was produced at 95^{o} at 0.524 r/s (30^{o}/s). This reported angle of peak torque output by Osternig (44) represents an almost vertical leg position and does not correspond to the present study's findings nor to those of other researchers (32, 62, 65). The author is not in a position to explain this discrepancy. However, Osternig (44) is in agreement with the other researchers that the point in the arc of motion at which peak torque is generated, is dependent on velocity of motion. This observation may be attributed to a possible lag or delay in exciting the contractile elements of the muscle (32) or possibly because of the time required for momentum of the leg to overcome inertia (44).

The results of the present study and related literature illustrate the compensatory interaction between angle of pull, length/tension relationship and the angular velocity of the movement. Each subject's ability to generate muscular torque varied throughout the entire range of motion, with the angle of peak torque varying from 115 ± 5.5° at 0.524 r/s (30°/s) to 127.2 ± 22.9° at 1.572 r/s (90°/s). However, the mean shape and form of the 75 subjects' torque output was similar, regardless of testing velocities.

Because of the inter-related roles of angle of pull, length/tension and velocity of contraction, it would be extremely difficult to specifically manufacture the Nautilus cam in each machine to "balance" or match the "ideal and unique" strength curve of a movement's agonists. Figure 8 clearly shows that the shape and form of the machine resistive torque curve, as determined by the changing radius of the cam, would require considerable modification to achieve a closer correspondence to the human torque curve of the quadricep muscle observed in this study. Although the testing velocities of the NLEM dynamometer only matched one of the angular velocities examined for the 75 subjects (0.524 r/s), the evident difference is too great to match any data collected for the HTC.

Table 9 summarizes the percentage difference between HTC values and the combined machine resistive torque values at the beginning of leg extension (90°), at the mean angle of human peak torque output, and at the last recorded position (165°). Regardless of the velocity of knee extension, MRT increased through the range of motion, peaking at 165°, while HTC peaked at a knee angle of 115 ± 5.5° at the slowest

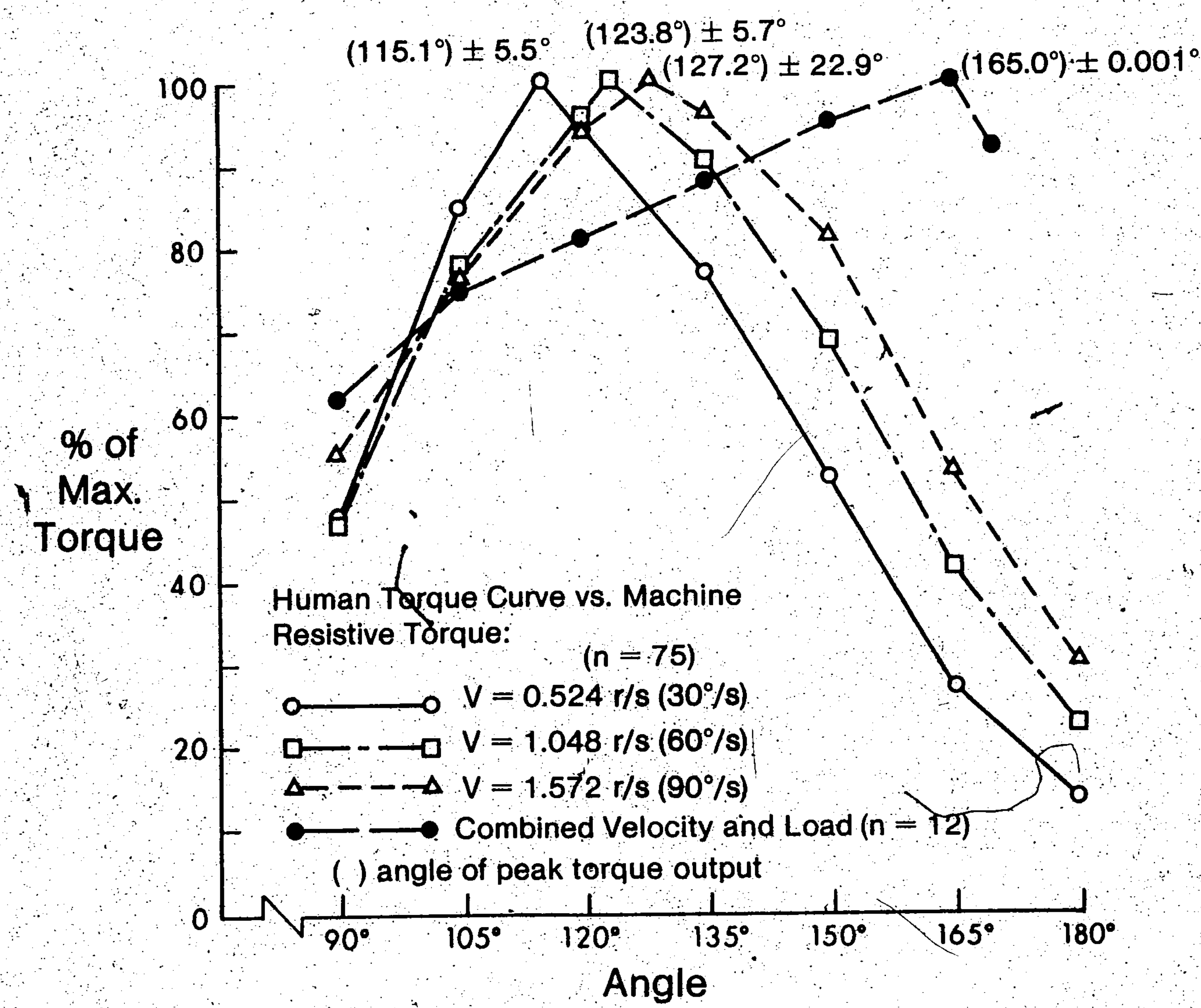

Figure 8. MRT versus H.T.C. of the leg extension, at 0.524, 1.048 and 1.572 r/s.

Table 9

MRT Versus HTC at 90°, Angle of

Peak Torque Output and 165° of Knee Extension

Angle of Lower Leg (Degrees) 180° 90°	HTC Angular Velocity (r/s, °/s)	Percentage Difference Between Mean Human Torque Values and Machine Resistive Torque
		$\bar{X}$.
90	0.524 (30)	-23.7
90	1.048 (60)	-22.4
90	1.572 (90)	-12.5
		$\bar{X}$. = -19.5
Angle of HTC Peak Torque		
115.1 ± 5.5	0.524 (30)	22.0
123.8 ± 5.7	1.048 (60)	17.0
127.2 ± 22.9	1.572 (90)	15.0
		$\bar{X}$. = 18.0
165	0.524 (30)	- 71.6
165	1.048 (60)	- 57.5
165	1.572 (90)	- 45.8
		$\bar{X}$. = 58.3

angular velocity (0.524 r/s) and at 127.2 ± 22.9° at the fastest velocity (1.572 r/s). This represents a mean resistive load of 19.5% above the HTC capability of the knee extensors at the start of movement (90°), and 58.33% above HTC at the extreme range of extension for all velocities utilized to generate the HTC data. During peak quadriceps torque output, the MRT provided a mean resistance of 18% below the leg extensors' maximal capabilities (Figure 9).

The greatest overall discrepancies between the MRT provided and the HTC capability occurred at the slowest limb velocity of 0.524 r/s, where the manufacturers of the NLEM suggest is the more favourable speed of contraction to utilize while training (Table 9). The percentage difference is 23.7 and 71.6% above that which the leg extensors are capable of producing at the start and completion of movement, respectively. At peak human torque output, the NLEM underloads the musculature by 22%.

Based on the results, trainees using the NLEM for quadricep strength training purposes, would not maximally tax muscular capabilities for 29.2° of motion at an angular training velocity of 0.524 r/s; for 29.6° of motion at an angular training velocity of 1.048 r/s; and for 38.8° of motion at an angular training velocity of 1.572 r/s. These ranges translate to an underload for 32.4, 32.8 and 43.1% of the entire range of leg extension respectively (Figure 8, Table 10). By contrast, at the extreme ranges of motion, the apparatus provides excessive load, which exceeds the skeletal-muscular requirements.

Based on the present design, in order for the cam to act as a variable lever arm and alter its radius to change the resistive load appropriately, the cam would, have to rotate through a greater range of motion. The design of the NLEM only allows for a total rotation of 145°.

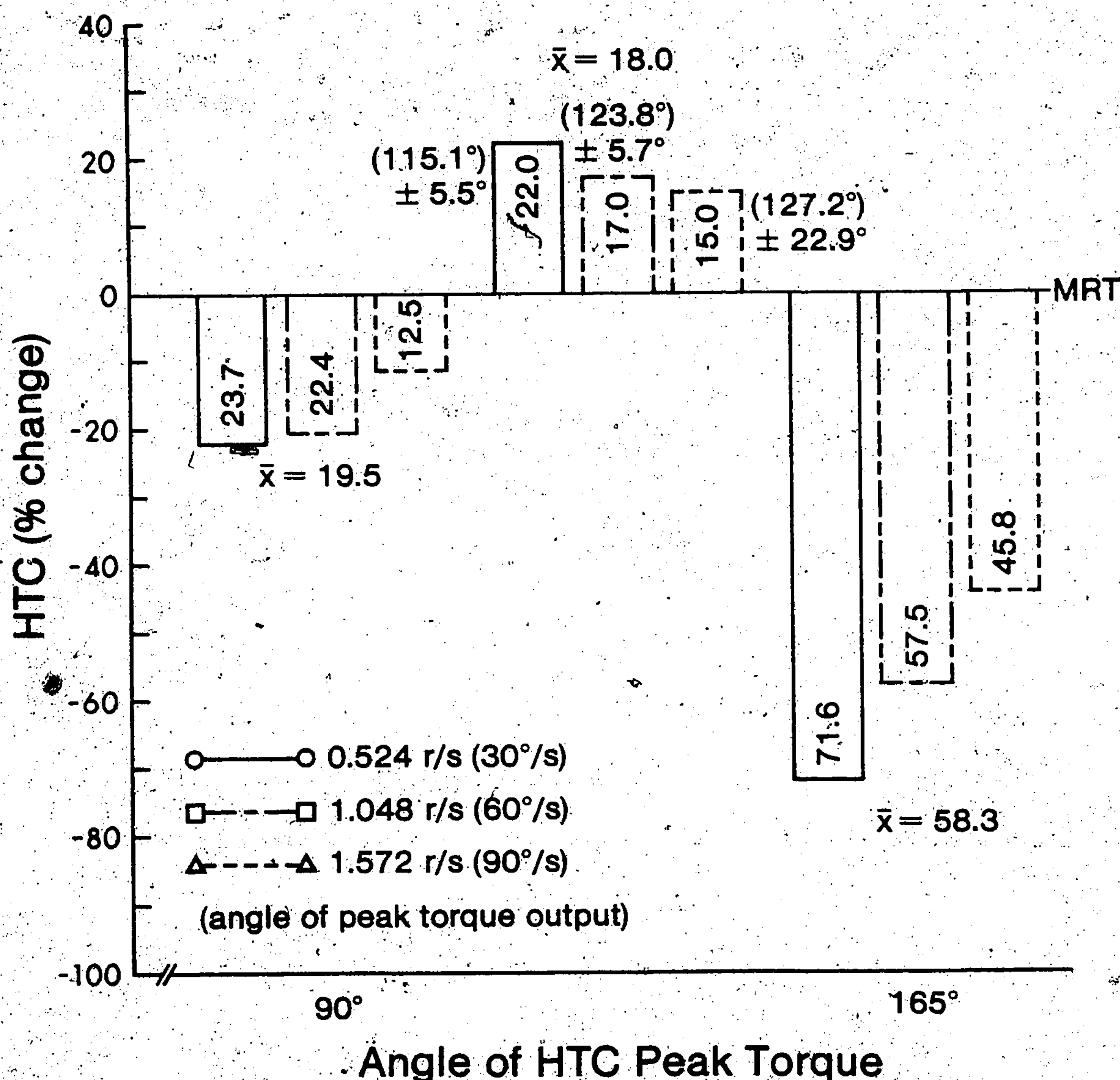

Figure 9. Percentage Difference Between Mean Human Torque Capabilities and Machine Resistive Torque.

Table 10

MRT Versus HTC: Ranges of Load Discrepancy

MRT (n) = 12 HTC (n) = 75

Angular Velocity	Initial MRT and HTC Intersection point (0^{o})	Final MTC and HTC Intersection point (0^{o})	Degrees of Underload (0^{o})	Percentage of Underload for Entire Range of Movement (%)
0.524 r/s (30°/s)	98.6	127.8	-29.2	32.4
1.048 r/s (60°/s)	102.5	132.1	-29.6	32.8
1.572 r/s (90°/s)	102.5	141.3	-38.8	43.1

Consequently the perpendicular distance from the cam pivot point to the load chain increases in a linear fashion without the necessary reduction in length to match the requirement of the knee extensors (Table 7).

The present study concurs with the results of Harman (19) and warrants considerable discussion since the review of related literature revealed very little research on the Nautilus equipment and its design. In Harman's study, a qualitative biomechanical analysis of five Nautilus exercise machines showed that when used as recommended by the manufacturer, resistive torque patterns did not correspond to human torque capabilities. The NLEM was one of five pieces of apparatus which were photographed with 35 mm colour slide film as a subject held both the beginning and ending exercise positions. The projected images were used to construct fiber board models of the cam and to measure the initial and final cam and limb angle positions. Using the models, (r) the perpendicular distance from the axis of rotation to the weight chain of the cam, was measured and machine resistive torque, normalized to percent of maximum, was calculated throughout the range of motion of the moving limb. Computer graphics generated MRT versus limb angle and superimposed curves of human torque capabilities. There was little correspondence between MRT patterns and HTC curves for the muscle groups examined. Harman (19) concluded that the cam shapes would require considerable modification to achieve a closer match between MRT and HTC patterns.

The results of Harman (19) and the present study suggest that athletes with patello-femoral chondromalacia avoid training the knee extensors with the NLEM. During the initial 10 - 15° of knee extension, where patello-femoral joint reaction force is at its maximum, the large discrepancy between the quadricep torque capability and the applied resistive torque of the NLEM, would drastically increase retro-patella pressure, possibly aggrevating an already degenerative condition of the articular surface.

Based on the results of this study, the author concludes that the variable resistance system of the NLEM, would require additional engineering modifications to insure a more appropriate match with the strength capabilities of the knee extensors. The Nautilus apparatus, however, has been effective in producing desirable increases in muscular strength, girth and lean body mass (11, 49, 50, 53, 55). The research cited in all cases consisted of short-term studies (four to ten weeks) in which the acquisition of strength following a Nautilus program was compared to a similar exercise training regime utilizing another resistive training apparatus. Results indicated significant improvements as a result of training in both experimental groups, but no significant difference between the two training methods for any of the variables evaluated. The present study may provide the rationale for this observation.

Although the increases in strength for subjects who trained on Nautilus apparatus were significant, no researcher to date has reported gains demonstrated in the "Colorado Experiment", in which a college athlete increased his strength in the leg press from an initial value of 32 repetitions with 400 pounds of resistance to 45 repetitions with 840 pounds of resistance (50). According to Plese (50), the same college athlete gained 63 pounds in lean body weight and lost 18 pounds of body fat. Results of this magnitude in such a brief period of training (28 days) have not been substantiated by other studies and exceed those observed in any published training study, that additional investigation with a larger sample of athletic and non-athletic populations seems warranted (8, 11, 45, 49, 53, 55, 60, 65).

On the basis of the data and results obtained in this study, it appears that the rationale for no significant increases in strength gains by Nautilus trained subjects over other modes of resistance training, may be due to the poor match or duplication of the MRT to the HTC of the muscle groups trained. Since muscle hypertrophy and strength development are related to the amount of tension or intensity of contraction generated within the muscles during training, the MRT would be expected to be advantageous to this development when matched or balanced correctly. The present results indicate a resistive load during the initial and final phases of movement which the quadriceps muscle group may not overcome and a less than maximal resistive load during the middle ranges where the angle of pull and length/tension relationship is optimal for maximal force generation (Table 10). Empirical observation of trainees using the NLEM seems to support this evidence. Once a resistive plate load is selected, the trainees initiate the leg extension movement by a quick acceleration or "cheating motion" in order to compensate for the difference between the MRT and the HTC.

It is concluded that the cam shape requires modification to achieve a closer match between the observed MRT of the NLEM and the HTC of the quadriceps muscle group. The major changes in the cam construction that would more accurately alter resistive torque to permit a closer match with the HTC would include a cam machined to reduce the movement arm at the extreme ranges of motion, and a correspondingly greater movement arm length at the stronger ranges, as indicated by the HTC.

CHAPTER V

SUMMARY AND CONCLUSIONS

Throughout the years, man has been interested in finding the most effective means of improving muscular strength and physique. This interest has generated numerous new methods, techniques, protocols and training apparatus designed to produce beneficial results. Many of these new training concepts and/or machines have been introduced and practices for various periods of time before being subjected to scientific scrutiny. In the early 1970's a new resistance training design was unveiled amidst claims that it was scientifically designed to produce optimal increases in muscular strength and hypertrophy in a relatively brief period of time (14, 15). This design, which in actuality incorporated several different pieces of equipment, was designed around a system of weights, sprockets and chains. The various pieces of equipment, collectively called Nautilus Machines, developed by Nautilus Sports/Medical Industries of Deland,Florida, claimed superiority because the cam shaped pulley could regulate the resistance applied to the exercising muscles and match the muscles biomechanical needs.

To date, evaluation of the Nautilus design and its ability to balance or match the ideal torque curve of a movement's agonists, is lacking. There is a need to test directly the claims of Nautilus and, in particular, the variable resistance component of their apparatus. The need is especially evident in view of the expense of the equipment, the lack of acceptable published data that supports these claims and the large number of people that regularly train with this modality.

It was the purpose of this study to generate and examine human torque curves (HTC) representing the variable strength pattern of the quadriceps muscle group of a selected athletic sample over a 90° range of motion at three pre-determined angular velocities. These curves were compared with the machine resistive torque (MRT) curves generated by a Nautilus leg extension machine (NLEM) at two pre-determined angular velocities.

Seventy-five physically active male and female subjects from the University of Alberta generated human torque curves of the right quadricep muscle group on a Cybex II dynamometer at pre-selected randomly assigned velocities of 0.524, 1.048 and 1.572 r/s (30, 60, 90°/s). Peak torque output and the torque output at 90, 105, 120, 135, 150, 165 and 180° were determined from the maximal recorded torque achieved during three voluntary leg extensions. These values were transformed to percent of maximum and plotted to illustrate the human torque capabilities at various angles of knee extension.

The testing for the Nautilus leg extension machine's resistive torque involved a special leg extension dynamometer capable of measuring changes in torque and the angle at which it occurred. Lever arm velocities of 0.263 and 0.524 r/s (15 and 30°/s) were selected to duplicate the manufacturer's recommended speed for optimal benefits from the NLEM. Starting the dynamometer lever arm in the 90° or vertical position, load values of 5, 10 and 14 plates were selected and the MRT output was recorded. Peak torque output at 90, 105, 120, 135, 150, 165, and 170° were measured from the generated torque curves. The normalized data was plotted to illustrate the machine resistive torque capabilities.

Using the curves for the human quadricep muscle group and the NLEM resistive torque, relative differences in HTC and MRT were compared for their main effect.

The results indicated:

1. Three distinctive human torque curves with similar shape and form were produced illustrating the joint angle of pull and length/tension relationship of the quadricep muscle group and the skeletal system.
2. The mean angle and standard deviation at which maximal human torque was produced in the arc of motion was 115.1 ± 5.5, 123.8 ± 5.7 and 127.2 ± 22.9° for 0.524 r/s (30°/s), 1.048 r/s (60°/s) and 1.572 r/s (90°/s), respectively. This data corresponded very closely with the data of other researchers, (44, 54) indicating that the angle of peak torque output was dependent upon the angular velocity.
3. The mean shape and form of the NLEM's resistive torque is identical regardless of the plate load or velocity.
4. Regardless of the velocity of extension, the machine resistive torque increased linearly throughout the range of motion, peaking at 165 ± .001° of extension.
5. The calculated percentages of MRT demonstrated a Pearson-Product Moment Correlation Coefficient of 0.9956 and 0.9568 ($P < 0.001$) when compared to the perpendicular distance from the cam pivot point to the load chain (r) during 0.262 r/s (15°/s) and 0.524 r/s (30°/s), respectively.

6. The MRT provided a mean load of 19.5% above the HTC capabilities of the knee extensors at the start of movement (90°) and 58.3% above maximum at the extreme range of extension for the three velocities utilized to generate the HTC data.
7. The MRT did not accommodate the mean peak quadricep torque output. The MRT provided a mean value of 18% below the leg extensors maximum capabilities.
8. The greatest overall difference between the MRT and the HTC occurred at the slowest human limb velocity of 0.524 r/s (30°/s) where the manufacturer of the NLEM suggests is the more favourable speed of contraction to utilize while training.

Although utilizing different methodology, the results of the present study concur with previous research, which found little correspondence between the MRT and the HTC for the muscle groups examined (19).

The results of the present study and related literature illustrate the compensatory interaction between angle of pull, length/tension and angular velocity of movement. On the basis of the data, it was concluded that the regulated resistance of the Nautilus cam did not adequately regulate the machine's resistive torque to meet the changing biomechanical capabilities of the knee extensors.

Implications and Recommendations

The results of the present study have contributed to the general body of knowledge in the area of resistance training. More specifically, the present data is the first to address on a sound scientific basis, the variable resistance component of the Nautilus Leg Extension Machine.

Since the present study does not support the Nautilus cam concept and its ability to correctly match the variable strength curve of the quadriceps muscle group, the author highly recommends that future research be directed at evaluating other Nautilus machines currently on the market. In particular, the Nautilus Pullover Machine, from which the original concept was constructed in 1948, should be examined since it has the ability to rotate through 270° of motion. The greater range of rotation may allow for the cam to change its radius more appropriately than the NLEM, with its limited range of only 145°.

The physical educator, coach, and physical fitness enthusiast may consider the present results when purchasing resistance training apparatus.

How cost effective are the Nautilus apparatus when compared to other resistance modalities? Since other forms of resistance training such as free weights have been found to produce increases in strength and muscle hypertrophy as great as a comparable Nautilus program, should a coach spend $60,000.00 to purchase the complete range of Nautilus equipment, when $5,000.00 of free weights and barbells may be more cost effective? The Nautilus apparatus may have other benefits which may justify the cost such as rotary movements and resistance in the position of full muscular contraction, but these benefits would certainly have to be overwhelming when considering the purchase of such equipment.

Certainly there is empirical support for the notion of stressing a muscle completely throughout a range of motion if maximum benefit is desired. Experimental encouragement from the results of isokinetic training by Pipes (49) and Thistle et al (61) found isokinetic training procedures superior to isotonic, presumably because the isokinetic procedure permitted muscular tension to remain maximal throughout the range of motion.

The results of the present research suggest that the Nautilus leg extension machine does not have suitable characteristics to fulfil the aforementioned requirement and therefore should not be considered an acceptable alternative to isokinetic training devices. Future research may be directed at other resistance training apparatus, that may accommodate more accurately, the torque curves of the skeletal muscular system.

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APPENDICES

APPENDIX A

HTC and MRT Raw Data

HTC

V = 0.524 r/s		% of Maximum Torque							Angle of 100% Applied Torque	Peak Torque
Subj.	M/F (Age)	90°	105°	120°	135°	150°	165°	180°	(Activity)	Ft/lbs*
1	F(18)	74.0	96.0	91.3	66.6	49.3	22.2	—	108 (B-ball)	162
2	M(18)	5.0	65.8	97.0	86.4	56.0	25.3	—	123 (B-ball)	237
3	M(23)	52.9	100.0	96.0	70.5	53.9	32.2	—	105 (B-ball)	204
4	F(23)	Ø	75.0	99.2	88.2	35.2	—	—	116 (B-ball)	136
5	M(21)	31.0	91.0	99.4	71.5	37.3	18.1	—	115 (B-ball)	193
6	M(25)	28.8	70.8	99.2	86.4	56.4	25.2	—	119 (B-ball)	250
7	M(23)	69.9	99.0	93.2	75.7	51.4	18.4	—	108 (B-ball)	206
8	M(40)	74.5	98.6	81.6	58.8	35.2	11.7	—	104 (Dis. Run)	153
9	M(24)	18.7	78.1	100.0	84.3	56.2	18.7	—	120 (Dis. Run)	192
10	M(46)	Ø	62.5	100.0	83.3	56.2	28.0	—	120 (Dis. Run)	192
11	F(25)	Ø	53.3	95.5	95.5	73.3	48.8	22.2	126 (Dis. Run)	135
12	M(23)	76.2	97.5	98.7	76.8	48.7	15.0	—	114 (Dis. Run)	160
13	M(32)	Ø	60.4	97.6	87.5	55.8	27.9	—	123 (Dis. Run)	258
14	M(22)	84.2	98.2	95.1	73.6	47.3	16.6	—	113 (Football)	228
15	M(20)	77.8	95.4	89.3	68.7	42.7	13.7	—	113 (Football)	262
16	M(20)	Ø	74.6	91.9	81.0	65.8	—	—	114 (Football)	237
17	M(19)	Ø	61.2	98.2	82.3	57.7	31.0	—	117 (Football)	232
18	M(19)	55.0	94.9	95.7	69.4	45.7	25.4	—	114 (Football)	236
19	M(21)	Ø	68.8	96.6	80.0	53.3	28.5	23.0	116 (Football)	270
20	M(18)	64.8	95.6	94.2	74.6	52.1	34.7	—	108 (Football)	276
21	M(21)	48.6	93.2	89.1	70.2	52.7	28.3	—	109 (Football)	222
22	M(22)	Ø	60.6	96.9	86.8	63.2	38.3	—	123 (Football)	297
23	M(21)	11.0	92.6	97.0	75.0	52.9	—	—	116 (Football)	272
24	M(25)	47.1	89.1	86.9	68.1	47.8	19.5	—	111 (Football)	252
25	M(21)	4.3	91.3	97.8	80.4	43.4	—	—	115 (Football)	276
26	M(21)	4.7	80.9	99.2	85.7	57.9	34.1	—	117 (Football)	252
27	M(25)	55.8	98.8	87.2	66.8	44.7	27.3	87.0	107 (Football)	344
28	M(19)	4.0	86.1	94.2	69.3	44.4	31.6	—	114 (Football)	297
29	M(21)	53.2	96.7	87.0	60.4	42.7	—	—	108 (Football)	248
30	M(21)	23.2	67.6	100.0	82.3	—	—	—	120 (Football)	284
31	M(23)	29.1	82.2	94.7	67.7	31.2	—	—	114 (Rugby)	192
32	M(23)	Ø	66.6	98.7	74.0	51.0	38.6	—	119 (Football)	243
33	M(20)	44.7	86.4	99.6	85.7	61.0	35.5	9.2	123 (Football)	259
34	M(24)	70.5	98.1	89.7	67.2	44.8	18.6	—	110 (Football)	214
35	M(21)	—	90.0	96.1	76.9	48.8	23.0	Ø	114 (Football)	260
36	M(20)	63.4	96.1	98.0	86.5	58.6	37.5	19.2	116 (Football)	208
37	M(18)	—	—	77.7	88.8	85.1	62.9		112 (Football)	216
38	M(25)	30.3	83.1	97.8	72.7	49.3	28.5	—	114 (Football)	231
39	M(21)	73.8	92.3	98.4	80.0	61.5	28.7	—	120 (Football)	195
40	M(20)	23.5	76.4	99.0	91.1	67.6	40.6	14.7	123 (Football)	204
41	M(23)	60.8	94.2	95.6	81.8	60.8	36.2	—	112 (Football)	276
42	M(25)	27.1	88.3	97.6	79.0	52.7	—	—	116 (Rugby)	258
43	M(25)	30.0	94.5	96.6	80.0	50.0	22.5	—	114 (Football)	240
44	M(21)	87.1	95.7	86.4	73.5	52.1	25.7	—	105 (Boxing)	140
45	F(21)	61.4	90.3	99.3	79.5	54.2	25.9	—	118 (T & F)	166

HTC

Subj.	M/F (Age)	90°	105°	120°	135°	150°	165°	180°	Angle of 100% Applied Torque (Activity)	Peak Torque Ft/lbs*
		V = 0.524 r/s	% of Maximum Torque							
46	M(24)	68.5	95.6	95.6	78.0	47.8	23.1	—	114 (Dis. Run)	251
47	M(22)	30.8	88.2	98.5	82.3	52.9	23.5	—	115 (Sprinter)	204
48	M(21)	21.0	78.9	100.0	84.2	55.2	31.5	—	120 (T & F)	228
49	F(18)	—	73.6	98.0	82.8	55.2	23.6	—	116 (T & F)	152
50	M(24)	—	71.8	100.0	82.8	57.2	25.5	—	120 (B-ball)	192
51	M(24)	88.5	100.0	84.3	56.2	32.8	11.4	—	105 (X-C Skiing)	192
52	F(18)	—	78.0	100.0	86.1	64.2	33.3	8.1	120 (Dis. Run)	123
53	M(28)	43.4	98.6	98.6	80.6	49.6	28.9	8.2	111 (Golfer)	145
54	M(18)	75.7	91.9	97.4	84.8	65.1	42.4	12.1	117 (Sprinter)	198
55	M(22)	—	78.9	99.5	84.2	59.6	30.7	—	119 (Sprinter)	228
56	F(19)	51.0	95.7	90.4	65.9	46.8	22.3	—	108 (Dis. Run)	94
57	F(20)	—	55.0	100.0	92.6	75.0	47.7	15.4	120 (X-C Skiing)	136
58	F(19)	47.4	83.2	98.5	91.2	67.8	37.2	—	123 (Swimming)	137
59	M(28)	—	78.7	100.0	89.1	68.3	35.7	—	120 (Racq-Sports)	193
60	F(21)	—	67.6	98.4	93.9	73.6	45.1	9.7	124 (B-ball)	133
61	M(19)	72.6	96.8	95.7	75.7	61.0	36.8	6.8	111 (T & F)	190
62	M(19)	50.8	89.2	97.3	80.3	54.4	18.3	—	114 (Hockey)	224
63	M(24)	53.0	87.6	98.8	80.7	50.0	25.3	—	114 (T & F)	260
64	F(20)	41.0	93.0	88.3	65.1	44.1	14.7	—	111 (Gym)	129
65	F(18)	24.8	83.2	96.0	72.0	44.8	96.0	—	114 (T & F)	125
66	M(23)	33.3	90.9	99.1	82.8	60.6	39.3	15.1	116 (Gym)	198
67	F(18)	11.0	78.6	97.0	94.8	75.0	48.5	—	124 (Fig.Skating)	136
68	F(18)	44.1	81.6	99.2	90.4	66.1	38.1	—	121 (Dis. Run)	136
69	M(20)	60.4	98.4	89.5	71.8	40.6	—	—	111 (Hockey)	192
70	F(19)	74.6	100.0	83.3	63.4	39.6	—	—	105 (Swim)	126
71	F(23)	52.5	87.5	99.3	82.5	61.2	28.1	—	118 (T & F)	160
72	M(21)	60.0	94.2	97.8	77.1	49.2	25.0	—	117 (Wt. Lifter)	280
73	F(22)	—	76.2	97.8	92.0	71.9	46.0	23.7	123 (Wt.Lifter)	139
74	M(25)	68.1	96.9	81.8	63.6	45.4	21.2		102 (Dis. Run)	132
75	F(18)		80.2	95.5	77.7	45.8	—		114 (T & F)	157
		n=55	n=75	n=75	n=75	n=74	n=63	n=14		
		x.=2638.9	x.=6375.4	x.=7156.9	x.=5891.4	x.=3966.5	x.=1794.7	x.=196.1		
		$\bar{x}$.=47.9	$\bar{x}$.=85.0	$\bar{x}$.=95.4	$\bar{x}$.=78.5	$\bar{x}$.=53.6	$\bar{x}$.=28.4	$\bar{x}$.=14.0		

* Ft/lbs of torque may be converted to Nm of torque by multiplying by 1.356.

HTC

V = 1.048 r/s

% of Maximum Torque

Subj.	M/F (Age)	90°	105°	120°	135°	150°	165°	180°	Angle of 100% Peak Torque.	Peak Torque in Ft/lbs *
1	F(18)	47.7	83.3	100.0	87.1	66.6	5.0	—	120 (Track)	132
2	M(25)	61.7	95.5	97.0	82.3	60.0	39.7	13.2	115 (Dis. Runner)	136
3	F(22)	5.0	76.3	95.6	98.2	86.8	62.2	28.9	131 (Wt. Train)	114
4	M(21)	41.3	78.4	97.4	95.6	71.5	45.6	—	126 (Wt. Train)	232
5	F(23)	45.3	80.8	97.8	95.7	74.5	49.6	21.9	126 (Hurdler)	141
6	F(19)	50.0	81.8	97.7	88.6	65.1	31.8	—	123 (Swimming)	132
7	M(20)	41.8	80.2	98.8	83.7	53.4	29.0	—	123 (Hockey)	172
8	F(18)	31.8	67.2	93.1	98.2	87.0	56.8	28.4	132 (Wt. Lift)	116
9	F(18)	—	44.7	88.5	99.1	79.8	57.0	26.3	132 (Skiing)	114
10	M(23)	46.1	79.1	100.0	94.5	73.0	49.4	19.7	120 (Wt. Lift)	182
11	F(18)	28.0	72.8	98.1	88.7	61.6	33.6	—	122 (High Jump)	107
12	F(20)	60.0	90.0	96.6	80.0	53.3	25.8	—	114 (Gym)	120
13	M(24)	—	56.8	93.1	97.0	61.7	50.0	—	126 (Pole Vault)	204
14	M(19)	65.0	89.0	100.0	86.0	65.0	36.0	—	120 (Hockey)	200
15	M(19)	68.3	93.0	100.0	90.5	71.5	47.4	16.4	120 (Track)	158
16	F(21)	16.6	54.5	84.8	98.9	94.9	75.7	42.4	137 (B-ball)	99
17	M(28)	—	46.1	92.3	98.7	79.4	53.8	—	131 (Racquet-b)	156
18	F(19)	27.4	69.0	94.6	98.2	85.8	59.2	—	132 (Swimming)	113
19	F(20)	41.5	83.1	98.0	97.0	81.1	60.3	22.7	126 (X-C Skiing)	101
20	F(19)	65.9	92.3	98.9	85.7	63.7	39.5	19.7	117 (Jogging)	91
21	M(22)	37.8	75.7	98.9	95.7	74.2	46.3	19.4	127 (Sprinter)	190
22	M(18)	68.4	88.4	99.4	94.7	76.3	51.0	18.4	123 (Sprinter)	190
23	M(28)	63.6	90.9	99.2	90.1	68.1	45.4	26.5	118 (Golfer)	132
24	F(18)	—	69.9	93.2	96.1	77.6	44.6	—	126 (Runner)	103
25	M(24)	73.4	97.9	97.9	82.3	54.4	31.9	—	114 (X-C Skiing)	147
26	M(24)	59.4	83.1	96.5	89.1	65.8	29.7	—	130 (B-ball)	202
27	F(18)	—	33.6	85.6	99.2	81.6	48.0	18.4	133 (T & F)	125
28	M(21)	32.6	71.1	92.3	97.2	78.2	45.6	—	129 (T & F)	184
29	M(22)	51.8	80.2	96.2	96.2	77.7	51.8	22.8	129 (Sprinter)	162
30	M(24)	28.3	79.2	99.0	92.4	73.5	35.6	—	124 (Dis. Runner)	212
31	F(21)	45.4	77.2	96.2	91.6	81.8	54.5	—	127 (T & F)	132
32	M(21)	71.8	92.9	97.1	76.0	57.7	32.3	—	114 (Boxing)	142
33	M(25)	71.2	93.0	100.0	90.0	67.3	35.6	—	120 (Football)	202
34	M(25)	42.0	81.0	99.0	90.0	68.0	42.0	—	123 (Rugby)	200
35	M(23)	28.2	72.6	97.8	93.5	77.7	41.0	—	126 (Football)	234
36	M(20)	33.3	46.6	86.6	99.4	81.1	53.3	—	132 (Football)	180
37	M(21)	39.2	77.3	96.4	96.4	78.5	50.0	—	126 (Football)	168
38	M(25)	58.8	89.2	100.0	79.4	58.8	29.4	—	120 (Football)	204
39	M(18)	50.0	83.3	99.4	93.2	73.3	41.1	—	122 (Football)	180
40	M(20)	61.9	89.2	99.4	88.0	70.8	50.0	17.8	119 (Football)	168
41	M(21)	61.1	88.8	99.0	93.5	69.4	38.8	14.8	121 (Football)	216
42	M(24)	66.2	90.6	97.6	83.7	65.1	38.3	20.3	117 (Football)	172
43	M(20)	—	47.6	89.5	99.0	84.2	59.0	27.1	132 (Football)	210
44	M(23)	49.1	81.9	98.3	91.8	72.1	44.8	13.1	123 (Football)	183
45	M(23)	46.4	85.7	98.8	83.3	57.1	—	—	119 (Rugby)	168

HTC

V = 1.048 r/s

Subj.	M/F (Age)	% of Maximum Torque 90°	105°	120°	135°	150°	165°	180°	Angle of 100% Peak Torque	Peak Torque in Ft/lbs*
46	M(21)	31.3	70.4	97.3	93.9	52.1	—	—	124 (Football)	230
47	M(21)	46.6	85.4	100.0	87.0	63.2	—	—	120 (Football)	193
48	M(19)	62.2	91.3	99.2	85.0	60.6	—	—	117 (Football)	254
49	M(25)	67.4	92.2	99.2	86.0	62.7	39.5	13.9	117 (Football)	258
50	M(21)	24.2	78.7	98.9	93.9	68.6	45.4	29.2	123 (Football)	198
51	M(21)	41.6	82.5	98.3	85.0	40.8	—	—	122 (Football)	240
52	M(25)	66.0	93.3	99.0	82.0	57.5	27.3	—	116 (Football)	212
53	M(21)	—	78.0	98.5	89.0	60.0	31.0	—	123 (Football)	200
54	M(22)	—	34.2	84.2	97.3	78.9	52.6	—	138 (Football)	228
55	M(21)	63.1	94.7	98.9	73.6	56.8	37.8	—	114 (Football)	190
56	M(18)	40.5	78.0	98.2	96.5	74.1	41.3	—	124 (Football)	232
57	M(21)	46.0	73.4	94.8	95.8	75.3	49.3	24.1	128 (Football)	215
58	M(19)	65.6	89.5	100.0	86.9	62.5	30.2	—	120 (Football)	192
59	M(19)	33.8	66.6	93.1	98.5	77.9	46.0	—	131 (Football)	204
60	M(20)	74.2	95.4	98.4	81.8	51.5	—	—	116 (Football)	198
61	M(20)	75.3	95.2	97.6	80.9	56.3	23.8	—	118 (Football)	252
62	M(22)	73.3	95.5	99.4	88.8	65.5	23.3	—	117 (Football)	180
63	M(32)	69.2	83.1	97.5	98.0	86.5	52.8	—	126 (Dis. Run)	208
64	M(23)	51.4	90.0	100.0	91.4	63.5	34.2	—	120 (Dis. Run)	140
65	F(25)	48.6	75.6	91.8	100.0	90.9	67.5	36.9	135 (Dis. Run)	111
66	M(46)	39.4	71.0	94.7	99.3	86.8	55.2	25.0	134 (Dis. Run)	152
67	M(24)	45.3	71.0	97.3	96.7	75.0	39.4	—	126 (Dis. Run)	152
68	M(40)	35.2	76.8	100.0	86.4	60.0	48.8	12.0	120 (Dis.Run)	125
69	M(23)	49.1	84.2	98.2	92.3	70.1	42.1	21.0	124 (B-ball)	171
70	M(25)	28.1	73.7	96.7	95.7	68.0	28.1	—	126 (B-ball)	213
71	M(21)	43.5	80.8	99.4	86.5	58.0	25.9	—	121 (B-ball)	193
72	F(23)	48.2	83.9	97.3	94.6	73.2	25.8	—	124 (B-ball)	112
73	M(23)	43.7	68.7	92.7	98.9	87.5	60.4	26.0	132 (B-ball)	192
74	M(18)	31.2	73.9	97.9	92.1	68.7	26.0	—	124 (B-ball)	192
75	F(18)	47.7	83.0	98.7	91.8	71.6	37.7		123 (B-ball)	159
		n=67	n=75	n=75	n=75	n=75	n=69	n=28		
		x.=3275	x.=5890.6	x.=7252.8	x.=6851.2	x.=5190.1	x.=2938.9	x.=626.8		
		$\bar{x}$.=48.8	$\bar{x}$.=78.5	$\bar{x}$.=96.7	$\bar{x}$.=91.3	$\bar{x}$.=69.2	$\bar{x}$.=42.5	$\bar{x}$.=22.3		

*Ft/lbs of torque may be converted to Nm of torque by multiplying by 1.356.

HTC

V = 1.572 r/s

% of Maximum Torque.

Subj.	M/F (Age)	90°	105°	120°	135°	150°	165°	180°	Angle of 100% Peak Torque	Peak Torque in Ft/lbs*
1	F(18)	48.3	69.3	95.1	96.7	87.0	58.0	—	131 (B-ball)	124
2	M(18)	45.2	80.5	98.1	98.1	79.2	37.7	—	126 (B-ball)	159
3	M(23)	45.3	69.7	90.6	98.8	94.1	73.2	45.3	138 (B-ball)	172
4	F(23)	52.7	76.9	96.7	98.9	85.7	39.5	—	134 (B-ball)	91
5	M(21)	49.3	75.9	96.2	95.0	67.9	28.3	—	126 (B-ball)	162
6	M(25)	42.6	71.0	92.3	99.4	86.9	60.3	28.4	132 (B-ball)	169
7	M(23)	53.1	82.2	98.7	98.7	79.7	53.1	17.0	126 (B-ball)	158
8	M(40)	36.8	73.6	96.4	95.6	76.3	45.6	17.5	127 (Dis. Run)	114
9	M(24)	50.7	73.8	92.3	96.9	85.3	55.3	—	132 (Dis. Run)	130
10	M(46)	53.2	82.2	96.7	100.0	88.1	66.1	37.0	135 (Dis. Run)	124
11	F(25)	53.3	74.4	92.2	98.8	92.2	73.3	33.3	138 (Dis. Run)	90
12	M(23)	—	61.4	94.7	96.4	84.2	42.1	—	130 (Dis. Run)	114
13	M(32)	—	37.2	74.5	93.7	84.7	53.1	—	137 (Dis. Run)	177
14	M(22)	52.7	81.0	97.2	97.2	81.0	56.7	24.3	129 (Football)	148
15	M(20)	68.5	89.5	100.0	91.4	68.5	37.1	—	120 (Football)	210
16	M(20)	60.6	86.5	96.0	93.2	70.7	39.3	—	125 (Football)	178
17	M(19)	45.8	70.5	91.7	100.0	88.2	49.4	—	135 (Football)	170
18	M(19)	62.4	87.8	99.3	94.2	75.1	42.0	—	125 (Football)	157
19	M(21)	55.1	84.3	98.3	95.6	77.8	51.8	25.4	124 (Football)	185
20	M(18)	42.1	68.1	93.5	97.8	87.5	64.3	—	126 (Football)	185
21	M(21)	60.2	87.3	97.5	89.7	72.2	49.3	22.8	123 (Football)	166
22	M(22)	55.9	83.9	96.3	99.4	93.2	67.3	—	133 (Football)	193
23	M(21)	41.3	79.3	96.5	98.8	79.3	48.2	—	126 (Football)	174
24	M(25)	—	45.6	85.8	96.7	83.1	56.5	31.5	126 (Football)	184
25	M(21)	56.6	84.9	98.5	93.3	68.8	46.2	—	124 (Football)	212
26	M(21)	55.1	74.7	91.9	100.0	91.9	67.2	34.4	135 (Football)	174
27	M(25)	69.6	90.1	99.1	91.0	69.6	44.6	21.4	117 (Football)	224
28	M(19)	60.8	88.4	99.5	97.6	73.7	45.1	—	123 (Football)	217
29	M(21)	50.2	83.8	97.0	97.0	79.0	43.1	—	126 (Football)	167
30	M(21)	50.5	77.4	96.7	94.6	74.1	45.1	—	130 (Football)	186
31	M(23)	60.8	86.9	97.1	92.7	68.1	34.7	—	123 (Rugby)	138
32	M(23)	58.0	81.4	96.2	98.7	83.9	59.2	22.2	127 (Football)	162
33	M(20)	31.0	66.6	88.1	98.8	94.9	73.4	—	138 (Football)	137
34	M(24)	54.1	84.7	97.2	97.2	87.5	59.7	33.3	127 (Football)	144
35	M(21)	51.0	86.1	97.8	95.7	77.6	46.8	19.1	126 (Football)	188
36	M(20)	48.8	75.0	96.4	96.4	82.1	58.3	37.5	126 (Football)	168
37	M(18)	56.9	82.2	96.2	98.7	91.1	68.3	53.1	132 (Football)	158
38	M(25)	38.2	70.2	91.4	97.8	82.9	57.4	31.9	131 (Football)	188
39	M(21)	60.0	77.1	94.2	97.1	84.2	55.7	25.7	129 (Football)	140
40	M(20)	32.0	66.0	88.8	98.7	88.8	66.6	—	137 (Football)	162
41	M(23)	68.6	88.2	99.0	97.5	82.3	58.3	29.4	124 (Football)	204
42	M(25)	53.3	83.3	98.8	95.5	78.8	47.7	—	125 (Rugby)	180
43	M(25)	61.1	80.0	[illegible]	[illegible]	83.3	46.6	—	129 (Football)	180
44	M(21)	58.8	87.9	100.0	92.7	72.5	46.7	23.3	120 (Boxing)	124
45	F(21)	58.4	76.9	95.5	99.1	84.9	47.7	—	134 (T & F)	113

HTC

V = 1.572 r/s

Subj.	M/F (Age)	% of Maximum Torque 90°	105°	120°	135°	150°	165°	180°	Angle of 100% Peak Torque	Peak Torque in Ft/lbs*
46	M(24)	60.0	83.3	99.4	98.8	81.1	60.0	—	129 (Dis. Run)	180
47	M(22)	51.8	80.2	96.2	96.2	77.7	51.8	22.8	129 (T & F)	162
48	M(21)	46.1	71.7	92.3	99.5	89.7	52.5	—	134 (T & F)	156
49	F(18)	50.0	72.2	92.5	98.1	79.6	55.5	27.7	134 (T & F)	108
50	M(24)	69.2	92.3	99.3	96.1	78.2	45.5	—	124 (B-ball)	156
51	M(24)	71.2	90.9	100.0	91.6	72.7	44.6	18.1	120 (X-C Skiing)	132
52	F(18)	50.0	73.3	93.3	100.0	88.8	60.0	32.2	134 (Run)	90
53	M(28)	65.5	86.5	99.1	92.4	73.9	50.4	30.2	123 (Golfer)	119
54	M(18)	63.5	84.7	97.6	98.8	88.3	63.5	35.2	133 (T & F)	170
55	M(22)	42.8	71.4	92.8	99.4	86.9	60.7	28.5	133 (T & F)	168
56	F(19)	58.4	84.4	98.7	93.5	70.1		—	124 (Dis. Run)	77
57	F(20)	43.6	79.3	95.4	100.0	91.9	68.9	43.6	135 (X-C Skiing)	87
58	F(19)	50.0	75.0	93.7	98.9	92.7	65.6	32.2	136 (Swimming)	96
59	M(28)	44.8	70.8	89.7	100.0	92.1	70.8	42.5	135 (Racquet)	127
60	F(21)	43.8	68.5	87.6	98.8	94.3	74.1	40.4	141 (B-ball)	89
61	M(19)	64.0	88.0	98.6	96.0	80.0	58.6	32.0	129 (T & F)	150
62	M(19)	55.8	81.3	97.6	97.6	77.3	41.8	—	128 (Hockey)	172
63	M(24)	60.7	82.1	92.8	98.8	80.9	41.0	—	129 (T & F)	168
64	F(20)	61.8	86.5	100.0	89.6	71.1	43.2	19.5	120 (Gym)	97
65	F(18)	53.3	83.3	98.8	93.3	71.1	42.2	—	123 (T & F)	90
66	M(23)	—	61.1	90.4	99.3	89.1	66.2	42.0	132 (Wt. Lifter)	157
67	F(18)	42.3	71.7	91.3	98.9	97.8	78.2	35.8	136 (Skating)	92
68	F(18)	55.1	75.5	91.8	97.9	91.8	70.4	39.7	136 (Dis. Run)	98
69	M(20)	46.7	71.4	93.5	96.7	77.9	38.9	—	126 (Hockey)	154
70	F(19)	61.6	85.7	99.1	95.5	69.6	—	—	121 (Swim)	112
71	F(23)	50.8	75.0	92.7	100.0	91.9	64.5	—	135 (T & F)	124
72	M(21)	45.1	76.3	95.6	97.8	47.9	45.6	—	129 (Wt. Train)	186
73	F(22)	53.0	76.5	90.8	100.0	92.8	76.5	46.9	135 (Wt. Train)	98
74	M(25)	53.5	94.6	98.3	96.7	77.0	49.0	16.3	123 (Dis. Run)	122
75	F(18)	44.8	67.2	89.5	100.0	92.8	44.8	—	135 (T & F)	125
		n=71	n=75	n=75	n=75	n=75	n=73	n=39	n=7268.7	
		x.=3768	x.=5844.5	x.=7127.7	x.=72687	x.=6166.9	x.=3950.7	x.=1199.4	x.=9544	
		$\bar{x}$.=55	$\bar{x}$.=77.9	$\bar{x}$.=95	$\bar{x}$.=96.9	$\bar{x}$.=82.2	$\bar{x}$.=54.11	$\bar{x}$.=30.2	$\bar{x}$.=127.25	

* Ft/lbs of torque may be converted to Nm of torque by multiplying by 1.356.

MRT

Lever Arm Length = 1.2 ft or .368 m

vel. degrees/ sec. radians	load in plate	trials	peak torque (Nm)	angle of peak torque	torque (Nm)* at 90°	105°	120°	135°	150°	165°	170°
15°/s 0.262 r/s	5	1	70	165	40	50	55	60	65	70	62
		2	70	165	42	50	55	60	65	70	62
15°/s 0.262 r/s	10	1	126	165	82	95	103	110	120	126	115
		2	126	165	82	95	104	112	120	126	115
15°/s 0.262 r/s	14	1	170	165	115	130	140	150	160	170	167
		2	170	165	115	130	140	155	165	170	165
30°/s 0.524 r/s	5	1	67	165	40	50	55	60	65	67	65
		2	67	165	40	50	55	60	65	67	65
30°/s 0.524 r/s	10	1	126	165	81	96	104	110	120	126	115
		2	126	165	76	95	104	110	120	126	115
30°/s 0.524 r/s	14	1	167	165	110	130	140	150	160	167	155
		2	170	165	107	135	143	150	160	170	155

* Nm of torque maybe converted to ft/lbs of torque by dividing by dividing by 1.356.

MRT

Trials	Angular Vel. in r/s	Plate Load	% of Maximum Torque						
			90°	105°	120°	135°	150°	165°	170°
1	0.262 r/s	5	57.1	71.4	78.5	85.7	92.8	100.0	88.5
2	0.262 r/s	5	60.0	71.4	78.5	85.7	92.8	100.0	88.5
1	0.262 r/s	10	65.0	75.3	81.7	87.3	95.2	100.0	91.2
2	0.262 r/s	10	65.0	75.3	82.5	88.8	95.2	100.0	91.2
1	0.262 r/s	14	67.6	76.4	82.3	88.2	94.1	100.0	98.2
2	0.262 r/s	14	67.6	76.4	82.3	91.7	97.0	100.0	97.0
1	0.524 r/s	5	59.7	74.6	82.0	89.5	97.0	100.0	97.0
2	0.524 r/s	5	59.7	74.6	82.0	89.5	97.0	100.0	97.0
1	0.524 r/s	10	64.2	76.1	82.5	87.3	95.2	100.0	91.2
2	0.524 r/s	10	60.3	75.3	82.5	87.3	95.2	100.0	91.2
1	0.524 r/s	14	65.8	77.8	83.8	89.8	95.8	100.0	92.8
2	0.524 r/s	14	62.9	79.4	84.1	89.8	94.1	100.0	91.1

Summary (%)

	V = 0.262 ($x.$, $\bar{x}.$, σ^2)			V = 0.524 ($x.$, $\bar{x}.$, σ^2)		
	$x.$	$\bar{x}.$	σ^2	$x.$	$\bar{x}.$	σ^2
90°	382.3	63.7	4.3	372.6	62.1	2.6
105°	446.2	74.4	2.3	457.8	76.3	1.9
120°	485.8	80.9	1.9	496.9	82.81	0.9
135°	527.4	87.9	2.2	531.6	88.6	2.2
150°	567.1	94.5	1.6	574.3	95.7	0.8
165°	600.0	100.0	0.0	600.0	100.0	0.0
170°	554.6	92.4	4.2	560.7	93.3	2.8

$n = 6$ $\qquad n = 6$

MRT

	5 plates			10 plates			14 Plates		
	$x.$	$\bar{x}.$	σ^2	$x.$	$\bar{x}.$	σ^2	$x.$	$\bar{x}.$	σ^2
90°	236.5	59.2	1.3	254.5	63.6	2.2	263.9	65.9	2.2
105°	292.0	73.0	1.8	302.0	75.5	0.6	310.0	77.5	1.4
120°	321.0	80.3	2.0	329.2	82.3	0.4	332.9	83.1	2.5
135°	350.4	87.6	2.2	350.7	87.6	0.7	357.9	89.3	3.0
150°	379.6	94.9	2.4	380.8	95.2	0.0	380.9	95.2	2.7
165°	400.0	100.0	0.0	400.0	100.0	0.0	400.0	100.0	0.0
170°	371.0	92.7	4.9	364.8	91.2	0.0	379.1	94.7	3.4

MRT

Combined % Torque from Velocities and Plate Loads (n = 12)

	90°	105°	120°	135°	150°	165°	170°
x.	754.9	904.0	983.1	105	1141.3	1200	1114.9
$\bar{x}$.	62.9	75.3	81.9	88.3	95.1	100	92.9
σ^2	3.5	2.1	1.4	2.2	1.3	0.0	3.5

NLEM

Radius Data

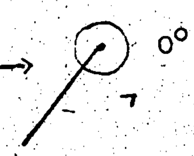
(r)

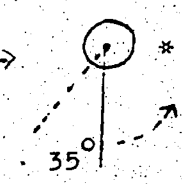
in cm

8° intervals

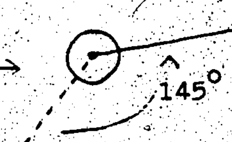
Range = 145°

Observation	"r"
1	19.3
2	19.8
3	20.5
*4	21.2
5	21.8
6	22.3
7	22.8
8	23.4
9	23.9
10	24.5
11	25.0
12	25.5
13	26.0
14	26.4
15	26.8
16	27.2
17	27.5
18	27.5
19	27.5





* Start position of NLEM analysis



APPENDIX B

Age, Sex, and Sport/Activity Characteristics of the Sample

Age, Sex, and Sport/Activity

Characteristics of the Sample

(N = 75)

Age (Years)	Sex	Sport/Activity
18	F	Basketball
18	M	Basketball
23	M	Basketball
23	F	Basketball
21	M	Basketball
25	M	Basketball
23	M	Basketball
24	M	Basketball
21	F	Basketball
21	M	Boxing
40	M	Distance Runner
24	M	Distance Runner
46	M	Distance Runner
25	F	Distance Runner
23	M	Distance Runner
32	M	Distance Runner
24	M	Distance Runner
18	F	Distance Runner
19	F	Distance Runner
18	F	Distance Runner
25	M	Distance Runner
22	M	Football
20	M	Football
20	M	Football
19	M	Football
19	M	Football
21	M	Football
18	M	Football
21	M	Football
22	M	Football
21	M	Football
25	M	Football
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21	M	Football
25	M	Football
19	M	Football
21	M	Football
21	M	Football
23	M	Football
20	M	Football
24	M	Football
21	M	Football
20	M	Football
18	M	Football
25	M	Football
21	M	Football
20	M	Football
23	M	Football
25	M	Football
18	F	Figure Skating
20	F	Gymnastics
23	M	Gymnastics
28	M	Golf
19	M	Hockey
20	M	Hockey
23	M	Rugby
25	M	Rugby
28	M	Racquetball
24	M	X-Country Skiing
20	F	X-Country Skiing
19	F	Swimming
19	F	Swimming
21	F	Track and Field
22	M	Track and Field
21	M	Track and Field
18	F	Track and Field
18	M	Track and Field
22	M	Track and Field
19	M	Track and Field
24	M	Track and Field
18	F	Track and Field
23	F	Track and Field
18	F	Track and Field
21	M	Weight Lifting
22	F	Weight Lifting

M = 57 F = 18 $\bar{X}$. = 22.1

APPENDIX C

Cybex II Torque Channel Calibration

Cybex Torque Channel

Calibration

Recorder Scale Selector (ft/lb)	Lever Arm * (in)	Weight (lb)	Graph Reading Peak
360	30	70.0	5 major divisions
180	31	32.5	5 major divisions

* Distance from the centre of the Cybex input shaft to centre of T-tube (lever arm length)

Calibration Procedure

1. Turn on power and allow for five minutes warm-up.
2. Select appropriate scale to be calibrated (180 or 360 ft/lb).
3. With speed selector ON at 30° per second or 0.524 radians and the recorder ON, but no torque applied to the lever arm:
   a) Select #3 position on Damping control.
   b) Select slow chart speed (5 mm/s).
   c) Align stylus with baseline of chart grid paper using "Zero Adjust Button".
   d) Check to see baseline does not shift when range scale is changed from 180 to 360. Baseline shift of this nature can be corrected by adjusting with a small screwdriver, the potentiometer on the top right side of the recorder (marked zero null).
4. Attach balance weighed disc weights (± .1 lb) to the T-tube at the lever arm length indicated for the scale to be calibrated.

5. Dynamic calibration is performed by manually lifting the weighted T-bar to the vertical position and allow gravity to swing it down until the weights contact the floor. As the weighted arm passes the horizontal, the graph recording will show this value as a maximum point on the curve (5 major divisions on the graph paper). If this point is above or below the correct torque value, adjust the recorder and make it read the correct value by turning the appropriate potentiometer (180 or 360) through the holes on the top right side of the recorder (marked accordingly). Turning the pot clockwise will increase the reading and counter clockwise will decrease it.

Torque Measurement Accuracy

360 foot-pound scale = ± 4.0 foot-pounds.

180 foot-pound scale = ± 2.5 foot-pounds.

Torque Measurement Repeatability

(Reliability)

360 foot-pound scale = ± 2.0 foot-pounds.

180 foot-pound scale = ± 1.0 foot-pound.

Test-retest reliability = 0.995 (37)

Maximum Instantaneous Torque Capability:

360 foot-pounds

Maximum Continuous or Repetitive Torque Capability

240 foot-pounds

APPENDIX D

Cybex II Position Angle Calibration

Cybex Position Angle Calibration

There are two scale settings (150° and 300°). Since the joint pattern of this study did not exceed 150°, this was the scale selected.

Procedure

1. Turn on power and allow for five minutes warm-up.
2. Select degree scale (150°).
3. Set chart speed at 5 mm/s.
4. Set input to CCW (counter-clockwise).
5. While depressing the zero button, use position angle Zero Adjust Knob to adjust stylus to zero baseline. Release Zero Test Button.
6. Adjust position angle channel stylus to zero baseline by turning the goniometer dial on the dynamometer clockwise.
7. Re-check steps #5 and #6 until the stylus does not deviate from zero baseline when the Zero Button is pressed or released.
8. Using the white line under the goniometer dial as an index mark, rotate the dial clockwise 150°. If the stylus traces a line on the top line of the graph, no adjustment is necessary. If the stylus lies above or below the top line, repeat step #5 through #8 to verify the reading. If no adjustment is necessary, proceed to step #9.
9. Locate the "Deg. Cal." screw on the recorder panel. Using a 7/16 inch wrench, slightly loosen the locking nut that secures the screw. With a standard slot screwdriver, turn the screw to move the stylus line precisely to the top of the line on the Position Angle chart. Using the screwdriver to hold this position, snug down the locking nut. Re-check calibration by repeating steps #5 through #8.

<u>Position Angle Measurement Accuracy</u>
(stylus deflection relative to actual movement of input arm)

150 degree scale = ± 1.5 degrees

<u>Position Angle Measurement Reliability</u>
(consistency of stylus response to any specific electrogoniometer position)

150 degree scale = ± 1.0 degree

On the position angle channel, appropriate subject stabilization and careful setting of anatomical 0^{o} or neutral position are the most important factors affecting test accuracy (26).

APPENDIX E

Cybex II Speed Selector Calibration

Cybex Speed Selector Calibration

Procedure

1. Turn on power and allow for five minutes warm-up.
2. Attach adjustable arm with push-button, locking collar with thumb-screw and handgrip.
3. Adjust speed to 180°/s (3.144 r/s).
4. Using a stopwatch, determine the time necessary to complete fifteen revolutions in either direction. Be sure to keep the dynamometer torque gauge needle above zero for the entire timing duration. Complete at least one full revolution before starting timer.
5. Calculate actual R.P.M.: Divide 900 by the number of seconds it takes to complete 15 revolutions. The results is the actual R.P.M. of the input shaft.
6. If the R.P.M. is 30 (± .3) the tachometer is reading correctly and requires no adjustment. If the actual R.P.M. is less than 29.7 or greater than 30.3, repeat the timing and calibration procedure to check for human error.

Test - retest reliability = .985 (37).

APPENDIX F

Example of Cybex II Leg Extension/Flexion

Printout

Example of Cybex II Leg Extension/Flexion Printout at 60°/s

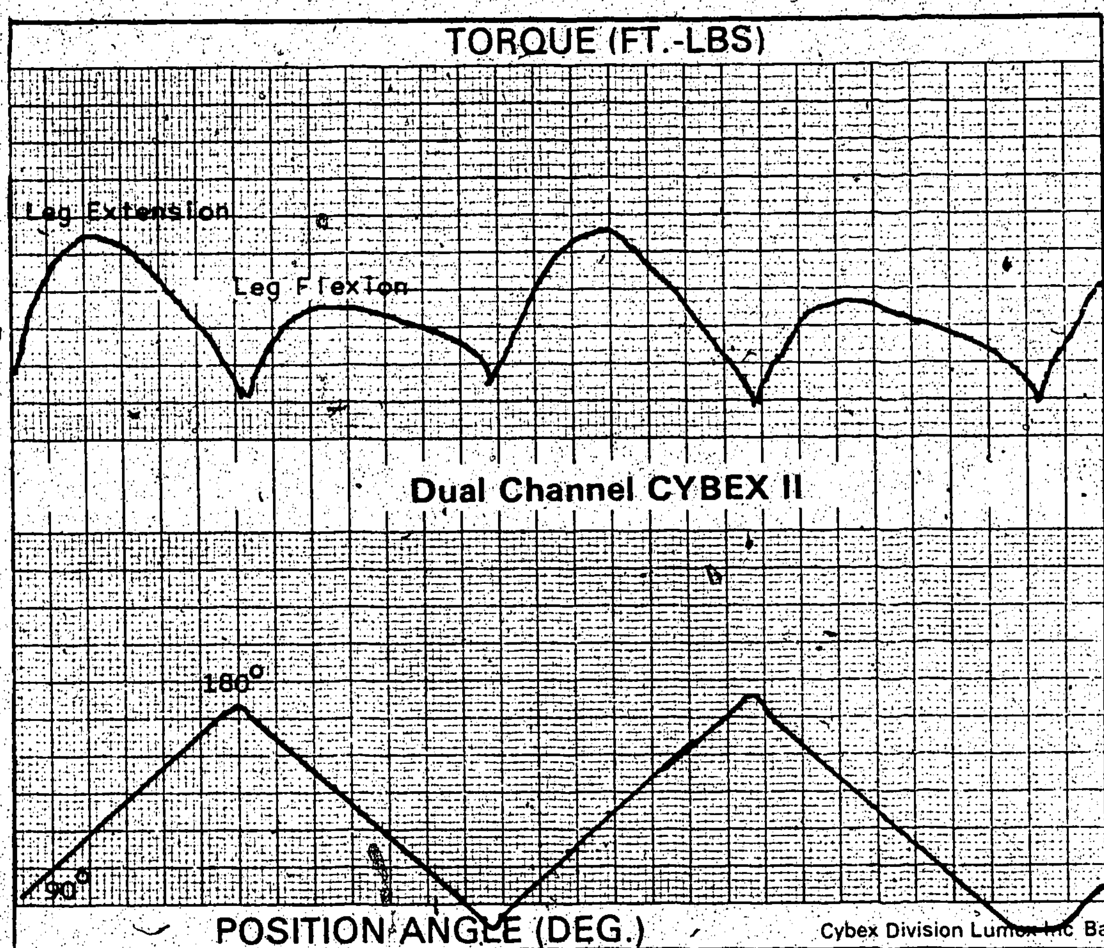
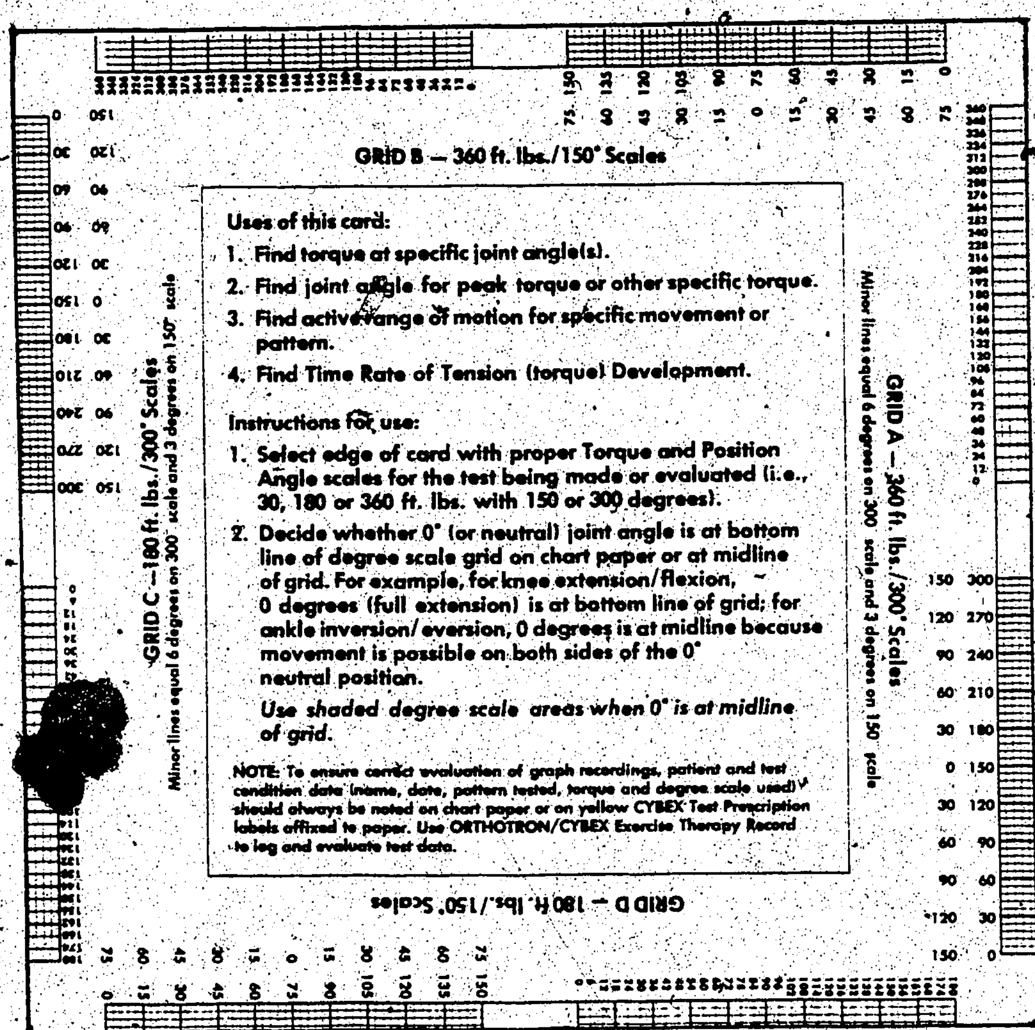


Chart Speed = 25 mm/s
Torque Scale = 360 ft/lb
Angle Scale = 150°

APPENDIX G

Cybex II Chart Data Card

Cybex II Chart Data Card



APPENDIX H

Data Record Sheet

SPORT/ACTIVITY: ______________________

SEX: ______ M ______ F

AGE: ______

1. TESTING VELOCITY __________ °/sec.

MAXIMUM TORQUE __________________ ft./lbs.

ANGLE	TORQUE
0°	ft./lbs.
15°	ft./lbs.
30°	ft./lbs.
45°	ft./lbs.
60°	ft./lbs.
75°	ft./lbs.
90°	ft./lbs.
105°	ft./lbs.

2. TESTING VELOCITY __________ °/sec.

MAXIMUM TORQUE __________________ ft./lbs.

ANGLE	TORQUE
0°	ft./lbs.
15°	ft./lbs.
30°	ft./lbs.
45°	ft./lbs.
60°	ft./lbs.
75°	ft./lbs.
90°	ft./lbs.
105°	ft./lbs.

3. TESTING VELOCITY __________ °/sec

MAXIMUM TORQUE __________________ ft./lbs.

ANGLE	TORQUE
0°	ft./lbs.
15°	ft./lbs.
30°	ft./lbs.
45°	ft./lbs.
60°	ft./lbs.
75°	ft./lbs.
90°	ft./lbs.
105°	ft./lbs.

APPENDIX 1

NLEM Recording Dynamometer Calibration

NLEM Recording Dynamometer Calibration

Lever Arm Length = 0.368 m (1.2 ft)

One pound = 4.448 n (Kg.m/s^2)

Resistance (lbs)	Newtons (n)	Unit of Chart Paper	Actual Torque (ft/lbs)	(Nm)	Recorded Torque (ft/lbs)
10.00	44.48	4.4	12.0	16.36	12.00
21.25	94.57	7.9	25.5	34.80	25.66
35.75	159.00	11.7	42.9	58.51	43.15
45.75	203.48	14.5	54.9	74.88	55.22
57.00	253.53	18.0	68.4	93.29	68.80
70.00	311.36	22.1	84.0	114.58	84.51
91.25	405.88	28.8	109.5	149.36	110.16
127.00	564.88	34.5	152.4	207.87	153.31
137.00	609.37	42.3	164.4	224.24	165.39

1 mm of graph paper = 5 Nm ± .3 Nm (3.68 ft/lbs ± 0.22 ft/lbs)

Validity coefficient between predicted and calculated values r = 0.991

a) Reliability coefficient (established by comparing the variability of each recording point between 15 and 30°/s)

r = 0.851

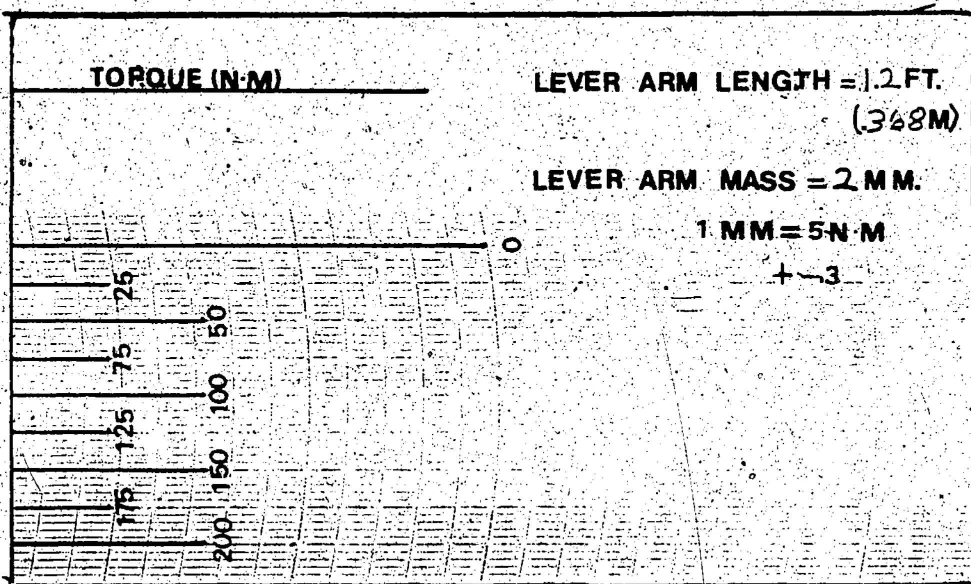
b) Reliability coefficient (established by comparing the variability of each recording point between 5 and 14 load plates).

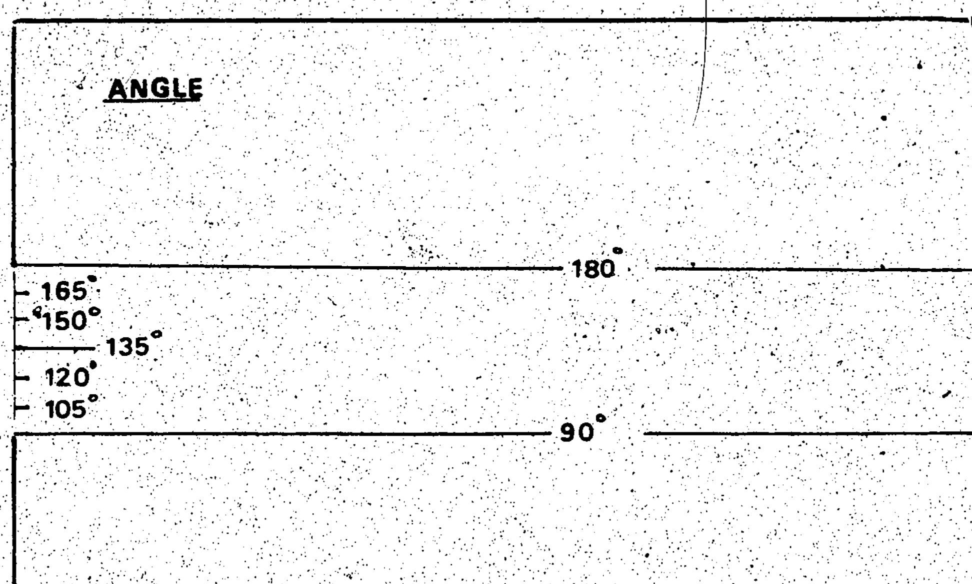
r = 0.824

APPENDIX J

NLEM Chart Recording Data Cards

NLEM Chart Recording Data Cards

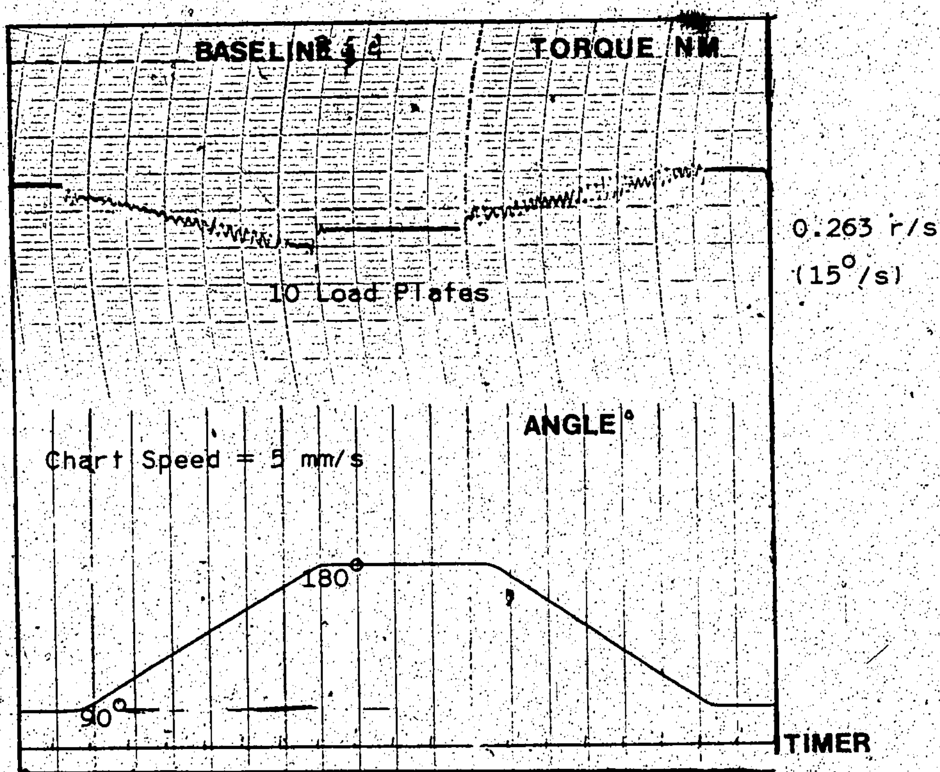


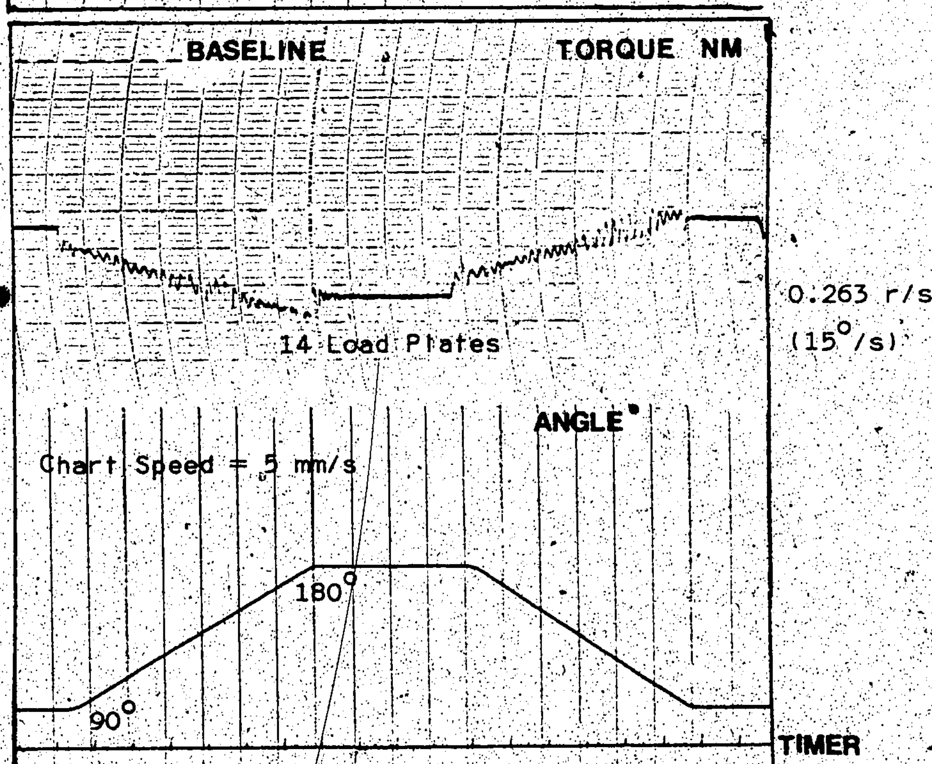


APPENDIX K

Example Machine Resistive Torque Printout of NLEM

Example of Machine Resistive Torque Printout of NLEM





APPENDIX L

Equipment List

Equipment List

Cybex II Dynamometer, Speed Selector and Two-Channel Recorder

Manufacturer: Cybex Div. of Lumex Inc.,
2100 Smithtown Ave.,
Ronkonkoma, New York.
11779

Nautilus Leg Extension Machine (NLEM)

Manufacturer: Nautilus Sports/Medical Industries,
P.O. Box 1783,
Deland, Florida.
32720

NLEM Dynamometer and Speed Control

Manufacturer: Technical Services Division,
University of Alberta,
Edmonton, Alberta
T6G 2G6

NLEM Recorder - Grass Model 79 E.E.G. and Polygraph
Data Recording System (79-4P-2)

Manufacturer: Grass Instrument Co.
101 Old Colony Ave.,
Quincy, Massachucettes
02169

Photocell Control System

Manufacturer: Layfayette Instrument Co.,
P.O. Box 5729,
Layfayette, Indiana
47903