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A Comparison of Three Cam Profiles as Measured by EMG and Angular Displacement

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A COMPARISON OF THREE CAM PROFILES AS MEASURED BY

EMG AND ANGULAR DISPLACEMENT

by

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ABSTRACT

A COMPARISON OF THREE CAM PROFILES MEASURED BY EMG, ANGULAR DISPLACEMENT, AND TORQUE

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Old Dominion University, 1993
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The purpose of this study was to determine if variations in cam profiles cause differences in muscle contraction as measured by surface EMG, knee joint angular displacement, and torque. There were seven hypotheses tested. The ten subjects were adult male volunteers (18-24 years) who participated in a counterbalanced treatment design study testing three variously shaped cams over five lifting tests. The results indicated that for the EMG data, the cam and lifts effect had significant Wilk's values. For the cam effect the consistent cam had the highest millivolt value. For the lift effect, the pre 1 rep max had the highest millivolt value. Results for the angular displacement demonstrated a significant Wilk's value for the cam effect only. The easy cam had the greatest degrees of displacement. Of the torque analysis, only the concentric torque showed significance at the 0.05 level.This study supports the earlier findings that the consistent cam efficiently loaded the muscle at more points in the range of motion and was able to maneuver throughout a greater arc in this same range than the easy or hard cams. However, even though the preliminary data showed differences in speed of movement, it could not be determined if there were actual differences in the amount of work produced by the cams.

DEDICATION

This study is dedicated to God for his strength and my parents for their understanding and support. I also dedicate this study to my co-workers at the Portsmouth YMCA pool for covering my classes and my friends for open ears and arms. Without their support, I would have not gotten through this ordeal.

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Introduction

Strength athletes as well as the general population of exercise enthusiasts use some form of resistance exercise to maximize strength gains during training. The main objective of resistance exercise techniques is to apply a resistive force to achieve maximal muscle loading despite the biomechanical and physiological limitations of the individual (Thistle, Hislop, Moffroid, Lowman, 1967). Skeletal muscle increases its strength capacity by working against a greater functional load. Conditioning of the muscle occurs by varying the muscular tension or resistive load (Komi and Buskirk, 1972). Resistance is the force that acts in opposition to a contracting muscle causing tension to develop (Hislop and Perrine, 1967).

A limitation of full strength development arises when force generated by the muscles during a contraction is not maximum throughout all phases of the movement. Strength equipment manufacturers have devised variable resistance machines which utilize cams to adjust the resistance in accordance with the lever characteristics of a particular joint movement. Theoretically, it is possible to alter cam shapes to compensate for variations in muscular tension. Muscle tension could then accommodate tensions loaded specifically to the size and shape profile of the rotating cam.

All previously known machines have utilized only one non-adjustable cam profile to vary resistive exercise training. Harman (1984) concluded that the cam shapes of five Nautilus machines would require considerable modification to achieve closer correspondence between the machine resistive torque and human torque capability.

There appears to be little research regarding the specific type of resistance exercise equipment that incorporates a cam which controls tension at various points in the range of movement. Likewise, each type of cam loaded variable resistance exercise machine proposes to produce strength curves representing maximal contraction throughout the full range of motion. Optimal contractions would theoretically result in more rapid strength capacity and subsequent gains. The common brand names of cam controlled equipment are Nautilus, Eagle-Cybex, Paramount, and Polaris.

The rationale for this study was in regards to the differences in EMG (mv) at various angles throughout the range of motion and subsequent variations in strength curves. Assessment of strength curves reveal that greater average torque is produced through the range of motion during concentric vs. eccentric contractions (Gray and Chandler, 1989).The findings indicated that eccentric training may require the performance of many more repetitions than concentric training in order to obtain muscle fatigue.

Statement of the Problem

There will be no significant differences between three distinct cam shapes upon vastus medialis response as measured by EMG, angular displacement, and torque during a series of five leg extension tests.

Purpose of the Study

The purpose this study was to determine if variations in cam profiles cause differences in muscle contraction as measured by EMG and knee joint angular displacement. The investigation sought to reveal the particular joint angle in the range of motion where the peak muscle recruitment occured. Force-tension curves could be constructed from the angular displacement and torque measurements during submaximum and maximum contractions (both concentric and eccentric phases). Statistically significant findings ($p<0.05$) among the three cam profiles would show which mechanisms demonstrated the greatest change in force of contracting muscle. The conclusions would give reason to suggest application in rehabilitation, strength training, and reconditioning settings.

Hypotheses

1. There will be no significant differences ($p<0.05$) in muscle recruitment as determined by surface electromyographic (EMG) activity of the quadricep group.
2. There will be no statistically significant differences in

angular displacement as measured by degrees of displacement.

3. There will be no significant interaction between the cam and phase effect for the EMG measurements.
4. There will be no significant interaction between the cam and phase effect for the angular displacement measurements.
5. There will be no significant differences in peak torque.
6. There will be no significant differences in concentric torque.
7. There will be no significant differences in eccentric torque.

Significance of the Study

Lack of scientific research regarding cam controlled variable resistance exercise machines demonstrates a need for scientific investigation in this area. Clinical observations have noted each cam in use to be unique to the respective equipment manufacturer and specific to each muscle group and associated joints. If cam variations are significantly different between equipment brands they may not load the contracting muscles the same at various angles and muscle lengths. This may account for the reported feeling that some equipment is harder or easier to negotiate given the resistance is held constant between the cam loaded devices. As a result, the existing shapes are designed to alter the resistance movements specific to the joint angle of pull.

Altering the profiles may exert variations of muscular effort specific to the cam shape. This concept is considered unique since the prior art and science of this principle has historically utilized only one cam specific to each machine. By providing an adjustable profile device, muscle groups may engage in variable or accommodating resistance exercises specific to the joint angle of pull and length of contracting muscle. The concept of providing an adjustable cam may provide means to alter resistance loads between cams specific to the joint angle of pull and muscle contracting length.

Presently, there does not appear to be a weight training or rehabilitation equipment manufacturer to offer an adjustable cam concept or device for the purpose of varying strength training techniques. All previous machines have utilized only one nonadjusting profile to vary the resistive exercise training.

Delimitations

This study was delimited as follows:

1. Ten subjects participated in the study.
2. Each subject had previously participated in a regular weight training program.
3. All subjects were males with body fat at 12% or less as determined by a caliper skin fold test.
4. The EMG was performed only on the quadricep of the dominant side.
5. Knee concentric and eccentric extension was the only

exercise analyzed.

6. Subjects were limited to three cam profiles; the easy, hard, and consistent.

Limitations

1. Verbal encouragement was given which influenced motivation and perceived exertion.
2. The subject population was limited to the male gender.
3. The possible anticipatory effect from subject interaction interfered with maximum performance effort.
4. Subjects performed in an artificial cue on demand situation.

Assumptions

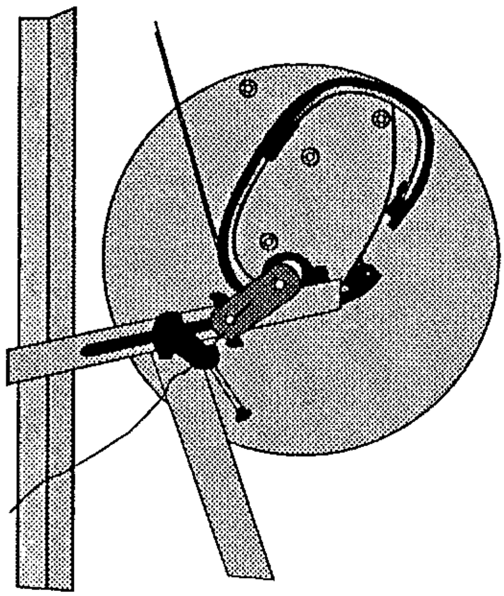
1. Subjects refrained from training the lower extremities, as instructed.
2. There was no subject interaction as to discussion of the testing sessions.

General Methodology

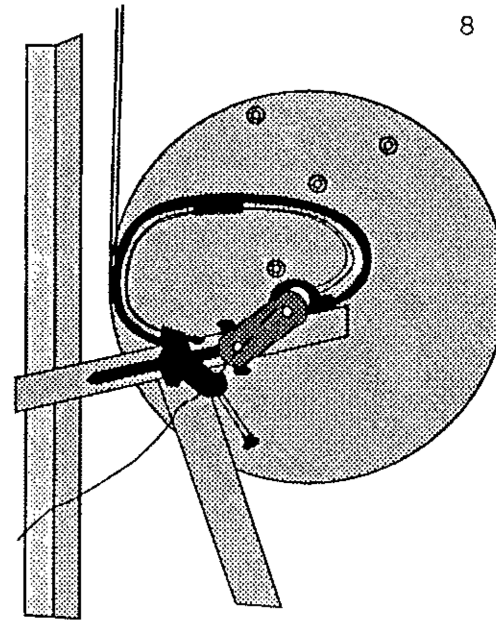
The study consisted of a quasi experimental, repeated measures methodology with counterbalancing of the three cams. Ten males participated in three laboratory testing sessions. The variation in tension throughout the arc of movement were recorded by electromyographic activity produced in the quadriceps of the dominant leg. Changes in force during the lift of the knee extension exercise were measured by a potentiometer interfaced to a computer sampling system. A video record was made of each participant's performance to ensure accurate reattachment of the electrodes and aid in future presentations of the research. After a general warm-up period, subjects performed a series of maximum and submaximum contractions, testing a differently shaped cam on each of the three consecutive testing days, spaced 24 hours apart. Each test consisted of a 1 rep max, followed by a timed series of 10 lifts each for 50% of their 10 rep max, 75% of the 10 rep max, and 100% of the 10 rep max. The test was concluded with a second 1 rep max to determine the effects of fatigue.

Independent and Dependent Variables

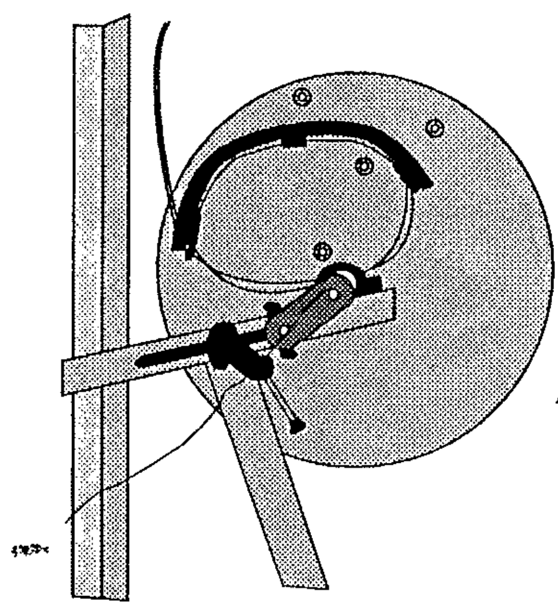
The independent variables were the three different shaped cam profiles. The first cam controlled the tension consistently during the leg extension movement. The second cam varied the tension by lessening it at the beginning of the lift, increasing it during the middle, and again lessening it at the end of the arc of motion. The third cam was a reversal of the second. This cam increased the tension initially, then lessened it at the middle of the movement, then increased it at the end. Diagrams of the cam profiles are found in Figure 1. The dependent variables included the electromyographic (EMG) activity, the angular displacement and the torque of the knee extension exercise.



a. Cam-E



b. Cam-H



c. Cam-C

Figure 1. Specific Cam location on the Leg Extension Machine to depict Required Degree of Effort: Easy, Hard or Consistent.

Operational Definitions

1. Cam-C. The force is loaded at equal intensity throughout the arc of movement and is referred to as the "consistent" cam.

2. Cam-E. A reduced force is applied initially, increasing the load of the force during the middle part of the movement, with another reduction of force at the end (Easy-Hard-Easy). This cam is called the "easy" cam.

3. Cam-H. The application of force throughout the range of motion is applied greater initially, dispersing the force in the middle of the movement, with force loading greater again at the end (Hard-Easy-Hard). This is called the "hard" cam.

4. EMG Activity. The electrical stimulus of the muscle during contraction is measured by utilizing bipolar surface electrodes placed on the vastus medialis of the dominant extremity.

5. Angular Displacement. The distance turned through or the amount of rotation expressed in terms of either radians, revolutions, or degrees. It is the product of angular velocity and time.

6. Torque. The force at length of radius. It is another term to describe the moment of force.

Summary

The variations in cam profiles of resistive exercise equipment and effect on muscle loading is a problem in strength and rehabilitation settings. These concepts were presented and the specific problem examined in this study was illuminated. Terms used in this study were defined and limitations and deliminations of the study were examined.

CHAPTER 2

Review of Literature

There has appeared in the literature a myriad of theories about muscle contraction and strength training. What is reviewed here are those theories which are most relevant to the emphasis of this paper; the effect of three differently shaped cams on the muscle fiber recruitment and fatigue.

Principles of Progressive Resistance Exercise

The term "progressive resistance exercise" (PRE) was first adopted in the early 1940s by Thomas L. Delorme and associates to describe a form of exercise that exposes the muscle to increasingly heavier loads as it adapts to the stress of the weight placed upon it. The gradual muscle adaptation process results in increased strength and hypertrophy (DeLorme, Watkins, 1948). PRE uses small muscle loads initially, then increases them after each set of ten repetitions, thereby warming up the muscle in preparation to exert maximum power for the last ten repetition set. DeLorme provides guidelines for determining the appropriate exercise load for each set of ten repetitions. The first set uses 50% of the ten rep max. The second set uses 75% of the ten rep max. The third set uses 100% of the ten rep max.

In evaluating progressive exercise techniques, the program variations in relation to the development of skeletal muscle must be assessed. The importance of these attributes have application in improving athletic performance, treatment of various disabling conditions, and improving the effectiveness of normal working muscle. Barney & Blangerter (1956) compared the scientific method of PRE to the traditional method regarding the production of muscular strength and hypertrophy. The programs of PRE used to compare the two were the exercise method developed by DeLorme and Watkins consisting of the traditional bulk program (DeLorme, Watkins, 1951) and the traditional power program (Macqueen, 1954). Each of eighty subjects performed a series of leg extension exercises. All three programs of exercise produced strength gains, increasing nearly 60% the weight a man could lift through a complete range of motion in knee extension during eight weeks of training. The two traditional programs produced similar results in production of strength increase and absence of production of hypertrophy. The DeLorme-Watkins program produced strength gains to nearly the same extent as the traditional programs, but also caused a significant production of hypertrophy. It was concluded that the DeLorme method was superior to the traditional programs when both increases in strength and hypertrophy are desired.

The prime objective in resistance exercise is to apply a resistance which can achieve maximal muscle loading despite various biomechanical and physiological factors. Factors which limit the resistance applied in exercise are biomechanical in nature and include torque, skeletal instability to resistance loads, and strength of stabilizing or supporting muscles. Physiologic factors include the length-tension characteristics of the muscle itself, subconscious limitation of voluntary effort, efficiency of exercise performance, and spacity and tremor (Thistle, Hislop, Moffroid, Lowman, et al., 1967).

Types of Muscle Contractions

There are three basic types of muscle contractions; isotonic, isometric and isokinetic. The term isotonic refers to a muscle contraction in which resistance remains at a constant level. It is a type of dynamic contraction. An isometric contraction is simply a muscle contraction in which there is no joint movement. The resistance may be too much for the muscle to overcome or may be immovable. In such a situation, the resistance is in direct ratio to the force applied. An isokinetic contraction is dynamic but the speed of motion is held constant by a special device. In this way, resistance is in direct ratio to the varying force applied through the full course of natural movement. In isokinetic exercise, the speed of the motion is a controllable variable and is constant. The resistance offered by the machine equals the individuals. Accommodating resistance exercise is a term used to refer to the type of program where the apparatus assures optimal exercise under maximum muscular tension at a constant speed.

In a preliminary study by Thistle and others (et al., 1967) an accommodating resistance exercise program was compared with isotonic resistance and isometric techniques for differences in total work and maximal exerted force. From the study it was apparent that accommodating resistance exercise can adapt to true muscle force capacity and permit natural muscle torque curves.

Muscle Adaptation to Training

All regimes of muscle training are designed to stimulate the process of adaptation. The adaptation process follows the principle of specificity; the muscles improve their capacity for the specific type of mechanical demand placed upon them, rather than in any generalized way. The energy requirements of most functional activities fall within four basic types of mechanical demand. First, a demand on the muscle's strength capacity either statically or at the slower shortening speeds of the tension-velocity curve. Second, a demand on the muscle's strength capacity at the higher shortening speeds where tension would be limited by fiber power developing capacity. Third, a demand on the muscle's endurance capacity for relatively high rate/short duration power outputs. Fourth, a demand on the body's endurance capacity for relatively low rate/extended duration power outputs.

The untrained muscle's first response to intensive exercise loading is activation of previously dormant fibers, evident in rapid gains observed in early training stages. Following this, development of specific energy potential depends on the exercise being sufficiently demanding to stimulate physiological changes in the specific energy mechanisms. The potential changes include the number of myofibrils becoming active at various shortening lengths, the fibers capacity for frequency of firing, the amount of sarcoplasmic protein stored by the muscle, and the energy storing capacities and energy converting efficiencies of the intermediate metabolic systems. Regardless of how they occur physiologically, muscular adaptations can and do occur specifically to the different energy output demands imposed. The important difference between the various exercise methods is how efficiently they obtain the desired improvements or how far they can carry the improvement of a specific energy output potential (Perrine, 1968).

Basic Mechanics of Muscular Outputs

Every muscle fiber is a complete mechanical energy system in itself. It contains components to produce, to absorb, and temporarily store the energy. A fiber's power developing potential is the limiting factor for how much tension it can develop at any shortening speed on its tension-velocity curve beyond the point where a tension supporting limit would affect the theoretical power curve. The external mechanical output capacity of a muscle must be measured in terms of the energy it develops at, or transmits from, some skeletal point. For static activities, a muscle's capacity is the maximum amount of force it can develop statically in specific joint positions and by the amount of time it can maintain a static contraction. For dynamic activities, a muscle's capacity would be quantified by three factors. First, the maximum amount of force it can develop at all points in a range of joint movement. Secondly, the maximum amount of force it can develop at different speeds of joint movement. Third, the maximum number repetitions or total time duration the muscle can repetitively accomplish a given amount of work.

The term strength represents that tension capacity of the muscle and is expressed relative to some speed of shortening. Endurance represents the working-time capacities of muscle and is expressed relative to some average work rate (Perrine, et al., 1968).

Exercise Mechanics

All isometric or isotonic exercise systems have certain inherent mechanical limitations which prevents their ability to impose a maximal mechanical demand on a muscle with respect to some of the often critical energy output potentials (Perrine, et al., 1968). Isometric exercise occurs against a load that prevents external movement and offers resistance inherently proportional to the muscles static tension developing capacity at one shortening length. Resistance is always a force which, when acting in opposition to a contracting muscle will cause tension to develop in the muscle. Load refers to the physical agent which is the source of resistance or it refers to the act of applying the resistance (Hislop, Perrine, 1967). There is no external dynamic work accomplished. The resulting improvement is in the low-speed strength category and primarily affects only the fibers active at the one shortening length exercised (Perrine, et al., 1968). The clinical value of isometric exercise is limited to the extent that the demands it places on the neuromuscular system parallel the individual's needs (Hislop, Perrine, et al., 1967).

Isotonic exercise occurs against load which allows movement but offers basically a constant resistance through a range of movement. Generally, the term "isotonic" is applied to any form of dynamic exercise where the resistance is not proportionate to the muscles actual dynamic force curve (Perrine, et al., 1968). The resistance has its greatest mechanical advantage on the muscle at the extremes of the range. It is here that the lever system is most extended (flexed), and loads the muscle greatest at these points. Closer to mid-range where the lever is most efficient (fixed resistance has least effect), the load on the muscle is proportionally less (Hislop, Perrine, et al., 1967). Consequently, the magnitude of the resistance is limited to the largest load that can be moved at the weakest point in some range of movement. Also, the exercise speed is subject to considerable acceleration and is thus unstable and difficult for a muscle to develop maximum power output. (Perrine, et al., 1968). The clinical value of isotonic exercise is limited by its ability to impose maximal tension and work demands on a muscle throughout its range of action (Hisop, Perrine, et al., 1967).

Isokinetic exercise occurs against a load which allows movement at a mechanically fixed rate of speed and offers resistance proportional to the muscles dynamic tension developing capacity at every point in its shortening range and at an optimal shortening speed. The desired exercise speed always occurs immediately, with resistance developing as a function of the amount of tension the muscle can develop at that speed. This fact is contrary to the isotonic principal of resistance first and speed second (Perrine, et al., 1968). The load is the result of the mechanical process of energy absorption which the isokinetic device performs in order to keep the exercise speed constant. The resistance can accommodate all factors causing force variations through the range of motion. With resistance accommodating the varying external force at the skeletal lever, the muscle is able to maintain a state of maximum contraction through its full shortening range (Hislop, Perrine, et al., 1967).

Torque Relationships of Contractions

Human muscular strength can be operationally defined as the ability of a muscle or muscle group to exert maximal force in a single voluntary effort. This can be measured isometrically, isotonically, or isokinetically. (Hislop & Perrine, 1967). Studies that have examined the interrelationship of these three modes of testing are not in agreement. A large body of literature suggests little relationship between isometric and isotonic strength (Clark & Henry, 1961; Henry & Whitley, 1960; Osternig, Bates, James, 1977; Smith & Whitley, 1963). Henry and Whitley (et al., 1960) propose the concept of neuromotor specificity as a theoretic framework from which to interpret these results. Neuromotor specificity means that the performance of an individual on one task cannot accurately predict his performance on another task. This concept encompasses strength tests, since they demonstrate classic motor performance phenomena (learning, warming up decrement, and reminiscence) and can, therefore, be viewed as simple motor tasks (Smith, 1974). In conflict with the report by Henry and Whitley (et al., 1960) are a number of studies indicating a large common variance among strength-testing modes, with correlations ranging from 0.69 to 0.86 (Carlson, 1970; Nelson & Fahrney, 1965; Singh & Karpovich, 1966).

Borges (1989) asserts that isometric torque is neccessary for maintenance of posture, and isokinetic torque is neccessary for movements (walking, running). In a study of knee extension and flexion torques in groups of men and women aged 20-70, he found a reduction of muscle torque with age. It may be partly explained by a reduction in fiber areas, but the decrease of myokinase activity in type II fibers and the loss of motor units due to degenerative changes in motor neuron or axon must also be taken into consideration.The results of the study were in accordance with other findings of higher isometric than isokinetic torque and decreasing torque with increasing isokinetic velocity for knee extensor muscles (Osternig, 1975 and Thorstensson, 1976).

Resistance training is an effective method of attaining and maintaining muscular strength and is widely used in conditioning, general fitness and rehabilitation programs (Atha, 1981, Gettman and Pollack, 1989). Due to the biomechanical arrangement of muscles within the bony levers of the skeletal system, the magnitude of muscular strength is dependent on the joint configuration (joint angle) at the time of measurement and varies throughout the range of motion (ROM) (Kulig, Andrews, & Hay, 1984). Variable resistance strength training machines attempt to accommodate the muscle's changing level of force output throughout the ROM by varying the resistance produced by the machine. Kulig (et al.,1984) reports strength gains resulting from overloading the muscle at all points throughout the ROM are thought to be superior to strength gains resulting from a constant resistance that overloads the muscle only at a specific critical joint configuration (i.e. the "sticking point" in the ROM).

Research by Graves, Pollock, Jones & Colvin (1989) supports the effectiveness of variable resistance training. Their study showed that full ROM variable resistance training resulted in uniform strength increases throughout the full ROM while limited ROM variable resistance training produced only limited strength benefits in the unworked ROM.

Researchers have found the machine resistive torque curve to be flatter and peak earlier in the ROM (flexion to extension) than the pre-training knee extension torque curve. The data suggest that machine resistive torque of variable resistance exercise machines does not perfectly correspond to muscular torque capability. Furthermore, the findings support the concept that some variable resistance training machines can provide a uniform training stimulus throughout a full ROM.

Numerous studies have demonstrated that significant increases in isometric and dynamic strength are obtained from both variable and constant resistance training (Manning, Graves, Carpenter, Leggett, Pollock, 1990, Anderson & Kearney, 1982, Gettman & Pollack et al., 1981, Grave, Pollock, Jones, Calvin, Leggett et al, 1989, Berger, 1962, Brown & Wilmore, 1974, Coleman, 1977).

In relation to progressive resistance exercise, Mikesky and coworkers (1991) found that increases in muscle fiber cross sectional area do not account for all observed increases in muscle mass. Other mechanisms play a role, such as fiber hyperplasia.

Manning and colleagues (et al, 1990) investigated the effect of constant resistance and variable resistance training on full ROM strength development. Results indicated significant improvements in both isometric and dynamic muscular strength. The training stimulus from both constant and variable resistance knee extension exercise was sufficient to elicit full ROM training responses when the exercise was performed slowly and with an eccentric component.

It is interesting to note that "an angular specific training response" has been identified for isometric exercise. Knapik, Mawdsley, and Ramos (1983) showed that isometric exercise training at one specific joint angle can increase muscular strength 20^0 from the angle at which training is performed. Other studies have demonstrated that, at joint angles greater than 20^0 from the training angle, little transfer of isometric training occurs (Gardner, 1963, Lindh, 1979). It is possible that the submaximal training stimulus provided by a constant resistance at the strongest positions in the ROM is sufficient to elicit a significant training response.

Torque and Joint Angle

A description of the relationship between torque exerted by a muscle group and the joint angle is useful in both rehabilitative and strength training. Awareness of these variations can be used to identify abnormal conditions and devise maximally effective training regimes. Torque may be defined as the product of a force that acts about an axis of rotation times its perpendicular distance from the axis.

The relationship between torque and the body segment position (joint angle) is determined by three major factors: the cross-sectional area of the muscle, the length-tension relationship of the muscles, and the mechanical characteristics of the lever system. The greater the cross-sectional area of the muscle, the greater the amount of contractile protein (actin and myosin), and consequently the more force that can be developed (Ikai, Tukunaga, 1968).

Individual muscles act on one or more levers (bones) to produce movement in a body segment. Muscles are attached to bones at various locations, and thus each muscle produces a different torque around the joint angle. Consequently, plots of torque versus joint angle at various body segments represent the sum of the torques of the individual muscles (dependent on the muscles lever lengths and cross-sectional area) and the lengths of these individual muscles at a particular joint position.

A number of researchers have described the torque-joint angle relationship in isometric, isotonic, or isokinetic testing for a number of muscle groups. The current discussion is limited at this time to studies that used subject postures similar to those of this investigation (knee extension muscle groups), because different postures will markedly influence the shape of the curve. One study which examined all three torque measurements found isometric torque to be the highest, followed by isotonic and isokinetic torque (Knapik, Wright, Mawdsley, Braun, 1983). Other studies on knee extension were in general agreement with Knapik (et al., 1983) and reported the same general inverted U-shaped curve (Clark, Elkins, & Martin, 1950; Haffajee, Moritz, Svantesson, 1972; Lindahl, 1969; Osternig, 1975; Scudder, 1980; Houst, Lebow, & Beyer, 1957). Peak isometric torque was recorded from 85 ^{0} to 130^0 (Haffajee, Moritz, Svantesson et al., 1972), with most studies indicating 60^0 (Houst, Lebow, Beyer et al., 1957; Lindahl et al., 1969; Scudder et al., 1980; Williams, Stutzman, 1959; Thorstensson, Grimby, Karisson, 1976).

Jensen and colleagues (1991) compared interaction of pre-load and angle every five degrees in the range of movement. They found that over the whole torque curve, there was a significant difference in average torque values of both concentric and eccentric, no significant differences in peak torque in either contraction, and a significant shift in peak torque angle with concentric contractions only.

The use of power as an indicator of muscle function is based firmly on physical and biological principles, but is difficult to obtain. Consequently, power can be predicted from the easily obtained measure of peak torque. Rothstein and colleagues (1983) report a high correlation when comparing peak torque power values for subjects at given speeds. They report that linear regression equations can be used to predict power from the more easily obtained isokinetic measure of peak torque. However, the equations appear to be both speed and population specific.

The relationship between power and peak torque has also been pointed out by Moffroid and Kusiak (1975). They suggest the use of "peak power" (peak torque divided by time of contraction) to overcome the difficulty in determining the area under the torque curve. They further suggest that while "peak power" is not an actual measure of power because of inappropriate units (Nm/sec), it could be used as a meaningful representation of actual power. Rothstein and associates (et al., 1983) argue that the substitution is not appropriate because the conclusion is based on the correlation of work, and therefore power, and peak torque but did not report the nature of this relationship. If one value is substituted for another there is a distortion in representation because the power measurements are not speed specific. In other words, in order to represent power validly by predicting it from peak torque, appropriate linear regression equations must be used.

While peak torque analysis only records and reports muscle function at one point, researchers indicate the predictability of total work from PT to be good (Kannus P, 1988, Knapik, Jones, Bauman, Harris, Wright, 1982). Burdett and Van Swearingen (1987) showed PT to be a highly reliable measure. In further support of the use of peak torque analysis, Kannus and Jarvinen (1989) showed that the predictability of peak torque acceleration energy and average power from peak torque was statistically and clinically significant.

In conclusion, they stated that peak torque acceleration energy (PTAE) and actual power (AP) offered little additional information to that attained by more simple measurement, the PT analysis. Kannus and Yasuda (1992) further agree that the predictability of angle specific torques (AST) from peak torque (PT) was good, and therefore AST analysis offered little additional information about thigh muscle function than that obtained through simpler and more commonly used measurement PT.

Joint Strengthening

A joint is a torque-transmitting mechanism. Joints, like muscles, will also respond to repetitive training and develop greater capacity. In isotonic training, the mechanical advantage factor allows a potentially dangerous differential to exist between muscle and joint capacities. Any isotonic training load must be limited to a fraction of the muscle's actual torque developing capacity at the optimum point in its shortening range. This isotonic load is all the joint must carry in any position. The joint is trained to handle only a fraction of the peak torque that the muscle frequently develops during intense activities. Isometric exercise repetitively loads a joint with a high static torque which repetitively focuses all the load on a few of a joints bearing surface. Consequently, this method poses the logistical problem of strengthening the many possible joint positions. Isokinetic exercise of joints is optimal, loading the joint with all the torque the muscle can develop at every point in a dynamic range of movement (Perrine, et al., 1968).

Biomechanics of the Knee

The human knee is the largest and most complex joint in the body, located between the body's two longest lever arms. Herzog and coworkers (1991) state that strength curves relate a measure of maximal voluntary force of a group of synergystic muscles, typically a resultant knee joint movement, to a measure of muscular length, typically a joint angle. Theoretically and experimentally they found that the shape of strength curves is primarily determined by the force-length properties of the individual muscles within a synergistic group. Knowing this, it is possible to determine the contribution of individual muscles to the total force of the synergistic group. This information may be used for practical application in sports or for evaluating strength curves in rehabilitation settings.

Fatigue Curves

The present study was designed to examine the EMG and angular displacement produced by three different cam profiles. The differences in muscle loading and subsequent fatigue might have an effect on the strength curves produced by the cams. Generally, muscle fatigue is considered to occur when the torque recorded from a given contraction is one-half that of the initial torque produced. Patton and coworkers (1978) conducted a study on isokinetic fatigue and found that when sex and strength levels were excluded the pattern followed a curvilinear (quadratic) form similar to other types of contractions. However, when sex and strength were controlled statistically, the fatigue patterns became linear and demonstrated negative but significantly different slopes. They suggest that isokinetic fatigue patterns are functions of strength levels.

Because isokinetics comprise ingredients of both isotonics and isometrics, they may be inherently different. However, it might be logical that isokinetic fatigue patterns would reflect some characteristics of both isotonic and isometric patterns. Investigators reported quadratic fatigue patterns from males performing isotonic contractions at rapid rates (Clarke & Stull, 1969, Stull & Clark, 1970). Other reports support the findings but only when all subjects were combined in the overall trend effect (Patton, Hinson, Arnold, Lessard et al., 1978). Additional similarities are noted between Patton and coworkers (et al., 1978) and Kroll (1968, 1971) who concluded that fatigue patterns of maximal isometric contractions followed by short recovery periods were different for high and low strength males and females. Kroll (et al., 1968, 1971) further noted a quadratic component in the trend of high strength males and females while the low strength subjects demonstrated only a linear trend.

Barnes (1981) conducted an experiment to compare isokinetic fatigue curves at four different contractile velocities (60^0, 120^0, 150^0, and 300^0/sec). The data obtained suggested a linear decline in torque. The slopes of the fatigue curves for each of the test velocities were negative and statistically highly significant. Results failed to demonstrate the combination of linear and quadratic fatigue patterns resulting from other forms of muscular contraction as reported by Clarke & Stull (et al., 1969), Stull & Clark (et at., 1970), and Kroll (et al., 1968). Barnes (et al., 1981) suggests that the predominantly linear fatigue pattern found, actually describes the muscular fatigue pattern during the initial stages of fatigue. Had the fatiguing exercise led to complete exhaustion, perhaps the quadratic pattern might have been more apparent, as in the previously reported study by Patton and associates (et al., 1978).

Furthermore, research indicates that isokinetic fatigue patterns resulting from serial contractions performed at different contractile velocities are highly similar (Barnes, et al., 1981). Theoretical support for a "specificity of speed" notion comes in part from investigations by Grimby & Hannerz (1977) who demonstrated that normal, size-related recruitment of human motor units may be altered to allow large, phasic motor units to precede the smaller tonic ones under special circumstances. If isokinetic contractions performed at different speeds to involve selective recruitment of functionally different motor units then it might be expected that fatigue curves associated with these different contractile velocities would reflect the endurance characteristics of the specific motor units involved. Barnes (et al., 1981) however, suggests no such distinction.

Both concentric and eccentric contractions are important components of dynamic activities. Because of this, athletes, recreationists, and therapists should be aware of the relationship between eccentric and concentric muscle endurance.

Golden and Dudley (1992) found that the initial decrease in strength after performance of an eccentric exercise bout is comparable for eccentric, concentric, and isometric muscle actions. Recovery of strength, however, appears to occur more rapidly for eccentric than isometric actions. They suggest that performance of a prior bout of eccentric but not concentric actions can essentially erradicate decreases in strength after a subsequent bout of eccentric exercise. They further suggest that neural factors are in part, responsible for adaptations to eccentric exercise.

Kramer and associates (1991) found that the effect of activation force (on the knee) tended to be more pronounced during eccentric than concentric muscle actions, and at the faster angular velocities.

Thorstensson and Karlsson (1976) evaluated concentric muscle fatigue of the quadriceps following a maximal effort 50 repetition bout at 180^0/sec. The fatigue index was calculated by dividing the averaged peak torque values during the last three contractions by the first three. The peak torque production decreased by 45% of the initial values. Nilsson and coworkers (1977) studied concentric muscle fatigue of the quadriceps following a maximum effort 100 repetition bout at 180^0/sec. Peak torque, work, and power declined rapidly up to the 50th contraction. Thereafter the values remained decreased by 45-55%. Both studies document approximately a 45% decrease in peak torque production following 50 high velocity concentric quadriceps contractions.

Komi and Viitasalo (1977) studied EMG, muscle glycogen, blood lactate, and force changes produced by the quadriceps and glutei muscles during 40 maximal effort concentric and eccentric contractions. When the last three contractions were compared to the first three, eccentric muscle tension decreased by 35% and concentric by only 13%.

Nilsson (et al., 1977) and Thorstensson and Karlsson (et al., 1976) found, in separate studies, that concentric quadriceps peak torque at higher velocities (180^0/sec.) and higher repetitions (50 or more), decreased by 45% as compared to Komi and Viitasalo (et al., 1977) who found decreases of only 13% at lower velocities (30^0/sec.). It is difficult to compare the study by Komi and Viitasalo (et al., 1977) to that of Thorstensson and Karlsson (et al., 1976) or Nilsson (et al., 1977) because of differences in speeds of contraction, number of repetitions, and the muscle groups tested. It is evident however, from the studies of Komi (et al., 1977) that muscle fatigues to a much greater extent when exercised eccentrically at low velocities than it does when exercised concentrically.

In contrast to the Komi (et al., 1977) investigation, the results of a study by Gray and Chandler (1989) suggest that maximal effort concentric contractions of the quadriceps femoris muscle at high velocity (180^0/sec.) for 40 repetitions lead to significantly greater fatigue than eccentric contractions under the same conditions. The discrepancy may be partly explained by differences in velocities tested, muscles exercised, and/or equipment used to provide the exercise.

The difference in the fatigue between eccentric and concentric exercise bouts may be explained by examining characteristic torque curves. Concentric torque curves have a dome appearance consisting of a round top and a wide base. Eccentric torque curves have a wide base that rises to a sharp peak. Therefore, it would appear that there is greater work or average torque produced throughout the range of motion (ROM) during a concentric contraction than during an eccentric contraction. In conclusion, from the above findings it seems that high velocity eccentric training may require many more repetitions than high velocity concentric training in order to obtain muscle fatigue.

Electromyographic Activity (EMG) and Muscle Contractions

An EMG at best represents the major changes in currents and voltages that occur whenever muscle fibers are being activated by their motorneurons. Electromyography can indicate not only the start and end of muscular activity but also something about the number of active motor units and frequency at which they fire (Loeb & Gans, 1986).

Because an increase in the "intensity" of muscular activity increases either the frequency of excitation, or the number of motor units involved, or both, integrated electromyographic data have demonstrated a positive linear relationship to muscle tension (Bigland and Lippold, 1954; Inman, 1952; Ralston, 1961). The use of the EMG technique which yields integrals of muscle action potential provides, therefore, a method of measuring muscular involvement elicited by a contraction which is both objective, unbiased, and independent of the relative strength of the individual.

Hinson and Rosentswieg (1973) used EMG to compare muscular tensions produced in isokinetic, isotonic, and isometric contractions. They found that no single contraction type was found which produced the greatest muscle action potential (MAP) for all subjects. Strength gain due to a given exercise program varied with the individual and the motor unit involvement elicited by the type of contraction employed. In their research, the isometric method of contraction produced the greatest muscle action potential which is in agreement with works by Asmussen (1968) and provides the rationale for the work of Miller, (1970) who reviewed the influence of training and of inactivity on muscle strength.

On the basis of muscle action potential produced, the isokinetic method of contraction should be favored over the isotonic method since the isokinetic method provides for the full range of motion and produces greater muscle action potential than the isotonic method for a greater number of subjects (Hinson & Rosentswieg et al., 1973). Isokinetic work is not affected by the factor of inertia, as is isotonic exercise. Isokinetic contractions compel a muscle to contract at a maximal force, which varies throughout the entire range of motion (Rosentswieg & Hinson, 1972).

Thistle and coworkers (et al., 1967) compared isokinetic training programs to isometric and isotonic programs and concluded that the isokinetic program, either by itself or in combination with isometric work yielded the greatest strength gains. It has been noted, however, that there may be bias in the evaluation of comparative strength gains. (Falls, 1968; Rosentswieg & Hinson et al., 1972). If a single type of contraction-isometric, isotonic, or isokinetic is used to measure strength gained through a given training program-isometric, isotonic, or isokinetic-the data will necessarily be prejudiced toward the program from which the measurement contraction was chosen. Antoine (1966) utilized isometric, isotonic, and isokinetic strength methods (nonindependently) to indicate that significant improvement occurred in strength but that the various combinations used did not differ significantly. A number of investigations comparing isometric and isotonic methods tend to suggest that no significant difference in strength development takes place if time, angle and effort are considered (Berger, 1963; Coleman, 1969).

In a comparison of isometric, isotonic, and isokinetic exercises by EMG the analysis of variance revealed that isokinetic contractions elicited significantly greater muscle action potential (MAP) than either isotonic or isometric contractions (Rosentswieg and Hinson et al., 1972).

Several studies conducted with muscular training or conditioning have used either concentric or isometric contractions (Petersen, 1960; Hinson & Rosentswieg et al., 1973; Rosentswieg & Hinson et al., 1972). Fewer studies have been found which dealt with eccentric conditions, despite the fact that the greatest overloading of muscle can be achieved in this state (Komi & Buskirk, 1972).

It is interesting to note that studies conducted both on isolated muscle (Levine and Wyman, 1972) and intact human skeletal muscle (Asmussen et al., 1968) show that despite the lowest energy consumption per unit of tension exerted, the greatest maximum tension can be produced in eccentric contractions. Furthermore, the difference in maximum tension between concentric and eccentric contractions increases with faster contraction velocities which points to a possibility for utilizing speed in preparing an improved method of muscle conditioning. Komi & Buskirk (et al., 1972) investigated the effects of eccentric and concentric muscle conditioning on tension and electrical activity (IEMG). They found eccentric conditioning to cause a greater improvement in muscle tension than the concentric conditioning. Neither method caused statistically significant changes in the maximum IEMG or electrical activity per unit of tension. Although electromyographic changes due to conditioning were somewhat different in the two experimental groups, it was not established that either type of conditioning caused increase in the desynchronized firing of motor units.

EMG and Fatigue Effects

Several studies have examined the electrophysiological pattern of fatigue in isometric contractions (Vatine, Blank, Gonen, 1988; Vatine, Blank, Shochina, 1990; Tarkka, 1984; Viitasalo & Komi, 1980; Hakkinen, Kauhanen, & Komi, 1988). The electrophysiological pattern of development is characterized by the duration, maximal amplitude, and total voltage area of the spike increasing, while the frequency decreases (Magora, Gonen, Eimerl, 1976). Studies of the electrophysiological manifestations of the development of fatigue in various human muscles may have significance in the determination of the relative proportion of fast or slow twitch fibers (Tarkka et al., 1984) and in the definition of the site which fatigues first in the peripheral part of the motor unit (Hakhinen & Komi, 1983 and Koceja & Kamen, 1992). Vatine and coworkers (et al., 1988) found the development of fatigue patterns to be similar in different muscle groups. Of the three basic parameters of the electric signal (duration, frequency, and amplitude), the two most demonstrative between the quadriceps and biceps brachii were the duration and frequency. Similar to the biceps brachii, the quadriceps produced a gradual increase in the duration but decrease in frequency.

The shift of duration towards a lower density would indicate that during a sustained isometric contraction there there is a gradual, irregular shift from active smaller motor units (fast phase) towards bigger motor units. This would support investigations proposing that the maintenance of a prolonged isometric contraction against resistance, and the ensuing development of fatigue involves the contractile system (Hakhinen & Komi et al., 1983; Magora, Gonen, Eimerl, et al., 1976). Comparative studies of muscles comprising high proportions of either fast twitch or slow twitch fibers may show definite characteristics typical of each fiber type.

Golnick and associates (1972, 1973, 1984) have found that the muscles of endurance athletes contain a high proportion of slow twitch fibers, while the muscles of non-endurance athletes contain a high proportion of fast twitch fibers. Other investigators have found similar differences in various muscles (Saltin, Henriksson, Nygaard, 1977; Thortensson, 1976). It has been demonstrated that the values of the different electrical parameters become more differentiated between higher or lower concentration of slow and fast twitch fibers during fatigue exercises (Hakkhinen & Komi et al., 1983; Komi & Tesch, 1979, Moritani, Nagata, Muro, 1982; Tarkka et al., 1984; Vatine, Blank, Gonen et al., 1988).

Vatine and coworkers (et al., 1990) studied the electrophysiological development of fatigue in explosive (burst) and endurance athletes in the quadriceps. The duration of spike increased and frequency decreased in both types of sport in the muscles studied. The conclusion was that the initiation of muscle contraction and its early phase is carried out by relatively small, fast-twitch, high frequency motor units, which, as the contraction progresses towards fatigue, are gradually replaced by large, slow-twitch low-frequency motor units. This indicated that the overall pattern of electrophysiological fatigue is not influenced by the type of prolonged physical training. However, the changes of measurement for both frequency and duration were significant in the burst sports and almost insignificant in the endurance sports. This could possible be explained by the gradual activation of motor units of more strikingly different sizes in burst sports, while in endurance sports the onset of contraction is more gradual and carried out by larger motor units.

Dynamic contractions (as opposed to isometric) have also demonstrated momentary decrease in the performance capacity of the neuromuscular system (Komi & Viitasalo, 1977; Hakkinen, Kauhanen, & Komi, 1988).

In examination of muscle fatigue during dynamic fatigue loading, a majority of the experiments have utilized the testing condition in which the resistance is constant throughout the different phases of joint movement. It is also possible to create loading conditions in which the resistance is adapted to follow the specific force-angle relationship of the muscle. This principle of variable resistance, especially during the non-fatiguing maximal concentric contractions, may create optimal conditions for high muscle activation throughout the entire joint movement (Hakkinen & Komi, 1986; Hakkinen, Komi, & Kauhanen, 1987).

The main difference between constant resistance training devices and the variable resistance type lies in the principle of adjusting the resistance during the entire range of movement. The "cam" causes the resistance to vary with the knee angle so that both the beginning and the final phases of the movement have the least resistance while the middle phases have the greater resistance. This arrangement was meant to result in the "normal" force-length relationship of the knee extensor muscles as described by Hakkinen and associate (et al., 1986; et al., 1987).

The magnitude of the effects of the fatigue loading on the neuromuscular system are naturally directly related to the load intensity so that the greater the load the greater the fatigue is. In fatiguing conditions in which the loading is preset as the same, the magnitude of the effects of fatigue may also differ and be related to the type of fatiguing load (Komi & Rusko et al., 1974; Komi & Viitasalo et al., 1977), to the subject material (Kroll, Clarkson, Kamen, & Lambert, 1980), and to the muscle fiber distribution (Thorstensson & Karlsson, 1976).

Kakkinen, Kauhanen, & Komi (et al., 1988) demonstrated that significantly more repetitions were needed to cause fatigue against 60% concentric loading in constant resistance than 60% variable resistance. The fatigue loading against the constant resistance was associated by a gradual decrease in the knee angle of the full extension phase.

An increase in IEMG can be thought to be a failure in the force production capacity of individual muscle fibers. The Hakkinen (et al., 1988) study showed the IEMG of the knee extensor muscles increased during both types of continuous fatigue loading. However, the averaged shape of the IEMG-angle curve changed differently. During the final phase of the fatigue the activation of the muscles was the same for all knee angles in the variable resistance, with an immediate decrease in the maximal isometric force and slight change in the max IEMG of contraction. In the constant resistance the muscle activation decreased for the final knee angular phases of extension.

The finding is in accordance with observations by Hakkinen and associates (et al., 1986, et al., 1987) that the muscle activation of the knee extensors during the one repetition max concentric contraction in a non-fatigued condition stayed on the same maximal level throughout the entire knee angular movement. In conclusion, the findings suggest that repeated concentric contractions of the knee extensors against a variable resistance (resulting in the actual or "true" ascending--descending shape in the force-knee angle curve) may create optimal conditions which may result in great fatigue effects on the neuromuscular system.

Velocity Considerations

The point in the arc of motion at which peak torque is generated is dependent on speed of motion. Moffroid and coworkers (1969) 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 inertia (Osternig et al., 1975) Another explanation for this may be due to a protective damping effect of the series elastic components (Levin & Wyman, 1927). Sandow (1952) states that "relatively considerable time passes before the shortening of the contractile component can extend, and create tension in, the series elastic material for transmission to the lever." This may explain the changes in shape of the torque curve at different speeds of isokinetic motion.

Research further indicates that torque declines with increasing velocity. A high relationship was noted between isometric tests and low velocity isokinetic tests, suggesting that the slower speeds simulate isometric effort (Knapik, Ramos,1980; Osternig, Bates, James et al., 1977; Scudder et al., 1980; Searborne & Taylor, 1984).

Charteris and Goslin (1982) suggest that not only is maximum torque diminished, but force output at all points in the range of motion is also reduced as velocity increases. Investigations find a direct relationship between average power throughout the range of motion and increases in velocity of movement which supports findings for instantaneous power (Charteris & Goslin et al., 1982; Perrine & Edgerton, 1978).

Charteris & Goslin (et al., 1982) further report that as velocity of movement increased peak torque and total work output decreased. In contrast, average power output increased as velocity of movement increased. This was the result of a relatively small decrease in work coupled with a relatively large decrease in time available to accomplish that work. With increases in movement velocity, although the maximum torque decreased the point in the range of motion at which it appeared did not alter.

Perrine & Edgerton (et al., 1978) have suggested that neural inhibition prevents the muscle from generating the tension that it is innately capable of during slow-velocity contractions. Coyle and colleagues (1981) report that slow tension contractions improved performance more than the placebo group at their training velocity and in the absence of changes in cross-sectional girth and without muscle fiber hypertrophy. The high degree of specificity and the inability to detect changes in muscle morphology suggest a significant contribution of neurological factors. Previous investigations have observed training specificity, with improvements being most evident in the training mode (isotonic vs. isometric) and at the joint angle used for isometric training. (Berger et al., 1962; Clark, 1973; Edgerton, 1976).

A possible neurological basis for this specificity of high tension training may involve an ability to recruit more motor units during the activity experienced in training, Komi coworkers (1948) have observed that maximal integrated electromyogram (IEMG) and isometric force increased 38 and 20%, respectively, in the isometrically trained legs of adolescents, whereas IEMG remained unchanged in the contralateral leg. Another adaptation observed by Komi and associates (et al., 1978) more economical usage of the motor units recruited so that a given number of motor units are more efficiently summated, resulting in a higher force output posttraining. Other investigations have found posttraining isometric contractions to have EMG patterns that are temporally more synchronous (Milner-Brown, Stein, Lee, 1975).

Muscle power (high-velocity tension) is enhanced through high velocity training that may also improve output at slower velocities. This transfer effect is of particular interest to rehabilitation patients who cannot tolerate high tension contractions. The stimuli derived from performing maximal fast contractions differs from those produced by slow contractions. One study reported that peak tension was reduced 60% and action rapid enough (300ms to completion) so that the recruitment pattern differed (Smith, Betts, Edgerton, & Zernicke, 1979). Coyle (et al., 1981) suggests that type II fiber hypertrophy is a plausible mechanism for the improvement of the fast group, with the possibility of neurological adaptations that enhance neuromuscular output at and below the training velocity.

Moffroid and Whipple (1970) demonstrated that, while exercise performed at low and high speeds increased both strength and endurance at those particular speeds, the exercise performed at high speed (108^0/s) was superior to that performed at a lower speed (36^0/s), with regard to the general increases achieved in muscle strength and endurance. In addition, it has been reported that a "transfer effect" occurs from isokinetic and isometric activities (Pipes and Wilmore, 1975; Tugl-Meyer, Nordin, Sjostrom, Wahlby, 1979; Lindh, 1979). Research suggests that some degree of transfer can be effected when training and criterion tasks resemble each other in overall characteristics (Bilowit, 1968). Hislop and Perrine (et al. 1967) theorize that exercise with an isokinetic device above 0^0/s velocity is comparable to isotonic exercise and that as a subject's speed of movement diminishes, the action begins to approximate an isometric activity at numerous successive angles of movement. The results achieved from exercise performed as such slow speeds would consequently more closely follow the pattern obtained with a purely isometric activity. In a test for static strength, Searborne and Taylor (1984) found the difference between the 108^0/s group and the controls approached significance ($0.05<P<0.075$). These results seem to support the findings of Pipes and Wilmore (et al., 1975), that a transfer effect is possible between isokinetic exercise at high velocities, and isometric and isotonic strength activities. However, Lindh (et al., 1979), investigating the transfer effect of isometric exercise at specific knee angles on dynamic (isokinetic) strength, reported increases only at low velocities of isokinetic exercises (30^0/s). In conclusion, it would seem that the transfer effect from one form of exercise to another may be a rather complex phenomena.

Investigators have further observed that both long and short isokinetic training programs (30 sec. and 6 sec.) produced approximately similar gains in strength at angular velocities equal to or slower than the training velocities (0^0-300/sec.) (Lesmes, Costill, Coyle, and Fink, 1978). These findings may imply that strength training benefits may be limited to speeds used in training and/or at slower speeds. Practical application to the athlete would encompass training at speeds approximating or exceeding those used during his or her actual sport. These observations are supported by the findings of Pipes and Wilmore (et al., 1975).

Osternig (1975) found that the velocities necessary to produce maximum power increased as the angle of knee extension decreased. At lower angles where the opposing force of the weight of the leg was greater, faster velocities with lower resultant forces were more effective in producing power than slower velocities with higher resultant forces. At higher angles (where opposing force of leg was less) the slower velocities with the higher resultant forces may be more effective in power production.

Summary

Concepts on muscle contraction and strengthening, torque and velocity considerations, fatigue, and electromyography effects have been reviewed. This study will examine these concepts with emphasis on the effects of fatigue on the shapes of strength curves and the effects of varying muscle loads by the different shaped cams.

CHAPTER 3

General Methodology

The following chapter describes the methodology used to investigate the variations in three cam profiles as measured by electromyographic activity, angular displacement, and torque. The subjects and experimental design are described as well as detailed description of the instrumentation and testing procedures which were followed.

Subjects

The study was conducted with a total of ten subjects who were adult male volunteers (18-24 years) from Old Dominion and Norfolk State Universities. Those men expressing interest in participating in the test were subsequently contacted via telephone by the investigator in order to more fully describe the study, answer additional questions, determine eligibility, and schedule an appointment for the preliminary assessment. No financial compensation was provided to the subjects.

Subjects who had knee and/or thigh pathology of their dominant leg within a one-year period prior to the study were excluded due to the performing nature of the experiment. Basic descriptive information about the subjects is provided in Chapter 4. Of sixteen (16) men indicating interest in participation, six did not qualify because of the exclusionary criteria , most commonly because of patella-femoral syndrome. Each subject signed an informed consent which was in compliance with the American College of Sports Medicine policy and the Human Subjects Committee at Old Dominion University (Appendix 1).

Experimental Design

The subjects participated in a counter-balanced treatment design study to determine the biomechanical differences in three variously shaped cam profiles as measured by EMG activity and angular displacement over five lifting tests. An Eagle-Cybex (NY., NY.) leg extension machine was modified to have interchangeable cam profiles. The cam profiles were hidden from the subjects view by a plywood wall, situated between the assigned cam and the seat of the machine.

Following a pre-assessment to determine the one repetition maximum and ten repetition submaximum weight, the subjects performed a series of either maximum or submaximum knee extension contractions under controlled laboratory conditions. Electromyographic activity was recorded using a Kin-Com two channel integrated surface EMG . Amplitude values were measured in millivolts (mV). Voltage signals were amplified with a bandwidth of .5 - 400 Hz. Lead artifact was reduced with impedance greater than .5 Megohms at 50 Hz. Amplified EMG signals were buffered below 58 Hz and above 480 Hz. The EMG signal was then amplified with a gain stage at 200 Hz. The magnitude of the EMG signal was averaged over 10ms period and reported on an analog display device (Chattecx Corporation, Chattanooga, TN 37405).

EMG signals were calibrated with a 1 volt peak to peak output +/- 2%. Waveform calibration was less than .5% of sinewave distortion. Signal frequency was recorded at 170 Hz +/- 3%.

Skin surface was shaven to remove hair and cleaned with cotton pads saturated with 70% isopropyl alcohol prior to electrode placement to reduce lead artifact. Quinton (Quinton Instruments, Seattle, WA. 98121) 16mm silver/silver chloride surface electrodes were coupled to the skin with ab electrolyte gel. Electrode placement was selected utilizing standard anatomical reference points supplemented by palpitation and isolated isometric contraction. Recording electrodes for the quadriceps were placed parallel; one centimeter medial and lateral to the motor point of the rectus femoris muscle fibers with the ground lead secured over the patella. A video recording was made of each participant's performance. A potentiometer was interfaced with the computer and cam shaft to record the shaft angle changes. All variables were measured at each of the three consecutive testing sessions spaced 24 hours apart.

Instrumentation

Data Collection

Data was collected and processed for this EMG study utilizing Pulse Code Modulation (PCM) Technology through video tape and the Digital Audio File (DAF). A PC/AT computer with a set of programs to transfer, edit and scale data, along with the Digital Audio File allowed for processing of the archival data.

The one-inch cam-shaft of the leg-extension machine was drilled to accept a 1/4 inch diameter aluminum shaft extension, which was then bonded in place with two part epoxy resin to form an overall shaft reduction. The reduced shaft was then force-fit and epoxy bonded to a precision multi-turn potentiometer using a four-inch long, 3/4 inch hollow hard rubber extension allowing small displacements in shaft alignments to be absorbed over distance by the flexible extension.

A known regulated voltage reference from the digitizer subsystem was applied across the potentiometer, ground referenced, and the voltage at the wiper supplied to one channel of the two channel digitizer. The output was a voltage linearly proportional to leg-extension shaft angle, spanning about 1.5 volts to represent the full range of motion.

The range of voltage detected in quadriceps studies is maximally 600 mv, and in this study, the anticipated input range was scaled, at the output, to represent almost the full dynamic range of the digitizer, or 16-bits. Due to unknowns in the study, the headroom was set to about 30% of the anticipated reading.

Data Digitizing and Storage

The real-time sampling rate was 44.1 kilosamples/second: a sample consists of Channel A (shaft-angle) and Channel B (EMG), each of 16-bits resolution, yielding a bit-transfer rate in excess of 1.5 megabits/second or 176.4 kilobytes/second. To facilitate fast turnaround between the study participants, the digitized data was stored on video tape. Each participant's input data, acquired through the sensors, was digitized using a direct-coupled Sony PCM-601esD, producing a video output that was recorded on a conventional VHS HQ video tape recorder (Panasonic PV-4760) for convenience and ease of operation.

Computer Subsystem

The computer used in this study was a 16 MHz, zero-wait IntelPC/AT clone with an 80386 processor and 80287 numeric co-processor; the co-processor was not required by the operating program. A high performance disk controller handled a 380 MBESDI hard drive partitioned into eleven (11) logical disks under DOS 3.30.

Primary to the data acquisition system was the Digital Audio File (DAF) card-set. The card-set supports a jog/shuttle interface that allows an operator to treat the unit as a conventional audio reel-to-reel recorder, providing random access to a recording instead of sequential. Data is stored by the operating program as two binary 16-bit words in 2's complement format, low-byte first.

The DAF card-set is a high-speed transparent device that does not alter or distort data in any way (i.e. no compression). Disc storage space was limited to 380MB with over 12 billion bytes of raw data collected. The raw data was processed in 15 minute portions, or, one subject's test sequence from one day including the calibration data. This method used about half of the available disc space before editing.

Digitized data from the PCM-601 was stored on video tape (or DAT) and/or transferred to the DAF in the PC/AT for real-time monitoring and recording; the video tape, the hard-disk, and the digital audio data stream are synonymous, as they represent the same data format in differing media or transmission modes.

Operating Program

The DAF program was written using Laboratory Microsystems PC-Forth, conforming to the 83-standards set for the language. A real time oscillograph displays data at 1/8 of the sampling rate and accumulates these subsamples over the standard 192 frame blockrate of the format. These 2 (channel) by 24 (subsample) 16-bit values were then time-averaged over consecutive interrupt periods until the desired display rate, in multiples of the interrupt rate, was encountered. The samples are then scaled and formatted for display as an ascending absolute-value (full-wave rectified) bar-graph for channel A and descending for channel B. The two channels are separated by 1/2 second time-tic stamps which represent the time coded byte-sample data base inherent to this sampling process. For the purposes of this study, the data transferred from videotape was stored and accessed on the hard-disk as one desired event - one subject, one-complete study "day" representing one cam-shape.

Once the unedited data was uploaded, the operating program time-averaged samples over a period equivalent to 1/20 of one second. The program produced a set of DOS compatible files formatted as ASCII integers in three columns with space delimited. The sample interval was in column 1, with channel A and channel B values in columns 2 and 3. A separate calibration file was constructed from the calibration references stored on video tape and which had been taken before each exercise. Scaling values were determined by directly reading the calibration file with Easy Plot 1.0 and extracting the absolute binary values corresponding to the calibration parameters. These scaling values were incorporated into a batch file containing the information necessary to accurately scale data from a given subject and test and to edit out pre-test and post-test unwanted data. For each exercise series, such as 10 RM's, the edit file contained transition point references to delineate one rep from another by sample interval index. This batch file was then read by a reduction program (written in Turbo-BASIC) which extracted the editing information, deleted the unwanted data, scaled the resultant raw data, matrix averaged the results of like tests with different subjects, and extracted mean times of concentric and eccentric contractions for the angular displacement study. The entire process yielded 600 data points in the form of 15 files, which were plotted with Easy Plot 1.0. A quantitative list was produced to provide for cross-correlational study with parameters measured at the time of testing to check the integrity of the reduction program. These 15 files were then uploaded to the IBM mainframe at Old Dominion University for multiple analysis of variance (MANOVA).

Calibration and Setup

The calibration file extracted from the video tape raw data contained two parameters that were necessary for the mathematical transformation of straight binary numbers of no significance to values representing the study parameters: MIN/MAX cam-angle and GND/CAL EMG reference. Empirical values in degrees and millivolts were determined during the time of the study and they needed only to be applied against the corresponding raw data values of the same parameters to produce EMG and angle data with the correct units. Given these two points on the calibration curve, for which the real values are known, any other point's corresponding real-value were calculated by simple proportion. Offsets, were subtracted out before the multiplication factors were applied, yielding a final result scaled in degrees for shaft angle, and in millivolts for EMG activity.

In this study, cam angular displacement was measured and found to be 120 degrees, while the EMG provided references at 0 volts (ground) and 100 millivolts representative input (cal). When a subject test was begun, the calibration procedure required the investigator to rotate the leg-extension cam-shaft from full lower stop to full upper stop, knowing that this angle represented the 120 degree span. The shaft-angle encoder activity was thus recorded as the current representative values, in straight binary, of the minimum and maximum shaft angle. Similarly, the EMG was switched between the GND reference and the CAL reference to record these representative parameters as well. Once this procedure was completed, the EMG was switched to LEADS and the subject was instructed in the exercise. This calibration procedure was repeated each time a cam or subject changed to insure consistency of data when processed.

Procedures

Pre-Event Assessments

When the subject arrived for the assessment, he was asked to give written consent for participation in the study and further procedural clarification was provided by the examiner upon request. The Subject Consent Form was reviewed with each subject before it was signed and confidentiality of the information assured. Anthropometric measurements were taken and subjects were asked to name their dominant lower extremity. The examiner then instructed the subject to sit in the Eagle/Cybex Leg Extension Machine. The force pad was placed three (3) cm above the malleolus and distance measured from the bottom of the force pad to the bony protrusion of the lateral condyle of the femur. The back rest pad was adjusted so that the lateral and medial condyles of the femur extended approximately two (2) cm past the edge of the seat. All settings were recorded in writing to insure consistency of results during each testing session.

Strength measurements were taken for the participant's one repetition max (1RM) and ten repetition max (10RM). The 1RM and the 10RM were defined as the maximum amount of weight that the subject could lift with correct form throughout the entire range of motion, one (1) and ten (10) times respectively. The 10 RM was set to a taped cadence: ascending for two (2) seconds and descending for four (4). The participant was given as many trials as necessary to establish the lifting and lowering rhythm of the count. The subject was scheduled for his testing session appointments, asked to refrain from weight training the lower extremities, and released. All assessments were conducted by the investigator.

Testing Session

Testing was conducted on three consecutive days, each separated by a twenty-four hour rest period. Upon arrival at Norfolk State University Exercise Science Laboratory, subjects performed a generalized warmup period consisting of stretches and ten-minute stationary bicycle riding.

Subject preparation for the non-invasive EMG procedure included thorough skin cleaning at the location for the attachment of electrodes. Prior to attachment of the bipolar surface electrodes, the skin was mildly abraded with alcohol soaked cotton pads. Adhesive electrodes were placed over the muscles of interest, located by palpitation during isometric contractions. Two photographs of the dominant leg (anterior and medial or lateral) were taken after attachment of the electrodes to document placement and to insure site specific reattachment. The ground electrode was attached proximal to the knee. The raw EMG signals were preamplified at the electrode site. Further amplification, full-wave rectification and smoothing was performed by the EMG analog processor which then fed an analog to digital convertor contained within the PCM video processor. The final output was two channels of digitally represented analog data (one EMG, one shaft angle) in a form that was recorded on standard VHS video tape.

The subject was seated on the Eagle/Cybex Leg Extension Machine with force pad and back rest adjusted to fit. During the test session, the subject performed two 1RM contractions and a series of time-loaded submaximal contractions. A three (3) minute rest period followed each set of contractions. The submaximum contractions were patterned after the conventional DeLorme technique. The first set of 10 repetitions used 50% of the 10RM. The second set of 10 repetitions used 75% of the 10RM. The third set of 10 repetitions used 100% of the 10RM. Each of the three testing sessions followed the format of an initial 1RM followed by the series of 10RM at 50%, 75%, and 100%, and concluded with a second 1RM to determine the effects of muscular fatigue, if any.

Subjects received one of three counterbalanced cam treatments per testing session. The leg extension apparatus allowed for interchangeable cam profiles and had a partition to cover them from the subjects. EMG and angular displacement was measured for each counterbalanced cam treatment. Calibration of all apparatus was made before and after each trial to assure integrity. After the exercise bout, no post exercise assessments were conducted on the subjects upon completion of the three consecutive testing sessions.

Statistical Analysis

Data were analyzed using a multiple repeated measures analysis of variance (MANOVA) to compare the mean values of the cam profiles upon the variables of EMG activity and angular displacement. Specifically, the Multivariate Mixed Model (MMM) approach was used to analyze the three main effects studied. First was the cam effect, second was the lift effect, and third was the cam X lift effect. A Roy-Bargman stepdown F test was applied when significant F-ratios were determined at a probability level of 0.05 in the Wilk's lambda. Group mean values were obtained for each maximum and submaximum exercise for the cam effect, lift effect and marginals. Secondary one way analyses of variance concerning peak, concentric, and eccentric torque were conducted using derived data from Easy Plot 1.0 software. The formula used was T=Fd sine(degree), where T=torque, F=magnitude of one of the forces involved, d=length of moment arm, and degreeis the point where the force was applied.

Summary

In this chapter the methods of study were presented. The experimental procedures were also outlined, followed by a detailed description of the test sessions. Lastly, the data analyses procedures were explained.

CHAPTER 4

Results

The purpose of this investigation was to determine the force variations between three different cam profiles as measured by electromyographic activity and angular displacement. The following results will help analyze the optimal tension loads within the range of motion which may be applicable to strength training regimens and rehabilitation programs.

As a review, the electromyographic analysis was the electrical stimulus of the muscle during contraction as measured in millivolt activity through surface electrode attachment. The angular displacement for the analysis was the amount of rotation expressed in degrees and was a product of the angular velocity and time.

Subject Characteristics

Anthropometric measurements and overall strength assessments were completed on the participants one week prior to the project's testing sessions. Table 1 depicts the means and standard deviations for these data. The project's sample consisted of all males, ranging in age 18-24 years, height from 144.8 to 194.3 cm, and weight from 62.3 to 98.2 kg. One repetition maximum weights lifted from from 31.3 to 79.5 kg, whereas the 10 repetition sub maximum weights ranged from 19.9 to 51.1 kg. It is worth noting that subject two was noticeably

Table 1. Subject Characteristics for Height, Weight, Age, and Strengh Measures of 1 Rep Max and 10 Rep Submax Weights.

Subject (#)	Height (cm)	Weight (kg)	Age (yrs)	1 RM (kg)	10RM (kg)
1	176.5	86.8	22.0	79.5	39.8
2	144.8	64.3	21.0	31.3	19.9
3	176.5	68.2	24.0	42.6	28.4
4	171.5	79.5	22.0	54.0	36.9
5	188.0	98.2	22.0	68.2	51.1
6	188.0	90.5	20.0	62.5	45.5
7	168.9	72.3	22.0	51.1	34.1
8	185.4	80.5	21.0	48.3	34.1
9	194.3	90.0	19.0	62.5	51.1
10	189.2	87.7	18.0	68.2	45.5
Mean	178.31	81.8	21.1	56.82	38.64
SD	13.70	10.30	1.64	13.43	9.52

weaker than the others within the project and therefore possibly contributed to reducing the average results of the entire group.

Project Descriptive Data

Tables 2 and 3 present the means and standard deviations for the EMG Data and the Angular Displacement Data for each test of the study. In comparing the EMG raw mean values in Table 2, the consistant cam appeared to have the greatest mean of all three profiles, followed by the easy and the hard cams.In Table 3 where the Angle data is shown, the easy cam had the greatest total angular displacement in degrees, which was followed by the consistant and the hard cams. Figure 2 shows strength curves for EMG activity and Angular displacement for all three cams during a typical lift.

Multivariate Model Data Analyses

There were three main effects studied in the repeated measures multivariate model approach for the analysis of EMG activity and Angle displacement. Basically the cam effect was reported, the lift effect was reported also as a repeated measure, and then the interaction of the type of cam with the various lifts was reported. Figure 3 shows the EMG (mv) and angular displacement (degrees) for the Wilk's and stepdown tests.

EMG Results:

Examination of Table 4 reveals the results for the

Table 2. EMG Activity (mv) Data for the Easy, Hard, and Consistant Cams During All Five Lifts.

Test		EASY	HARD	CONSISTANT	MARGINALS BY LIFTS
1RM-Pre	Mean	179.64	191.12	198.31	189.69
	SD	50.22	80.04	53.66	61.31
10RM-50%	Mean	85.83	71.43	86.35	81.20
	SD	36.39	33.91	46.25	38.85
10RM-75%	Mean	125.83	107.20	135.92	122.98
	SD	45.73	40.20	43.49	43.14
10RM-100%	Mean	148.53	145.13	161.12	151.59
	SD	41.57	46.07	40.33	42.66
1RM-Post	Mean	184.00	190.39	209.07	194.49
	SD	46.81	62.94	36.77	48.94
Marginals by Cams	Mean	144.77	141.05	158.15	147.99
	SD	44.14	52.63	44.10	46.96

Table 3. Angular Displacement (degrees) Data for the Easy, Hard, and Consistant Cams During All Five Lifts.

Test		EASY	HARD	CONSISTANT	MARGINALS BY LIFTS
1RM-Pre	Mean	79.86	46.47	73.34	66.56
	SD	10.55	29.76	20.50	20.27
10RM-50%	Mean	88.22	71.40	71.11	76.91
	SD	13.65	24.96	20.23	19.61
10RM-75%	Mean	86.01	62.96	65.76	71.58
	SD	10.17	27.21	26.19	21.19
10RM-100%	Mean	86.29	42.17	52.07	60.17
	SD	7.99	30.21	23.06	20.42
1RM-Post	Mean	83.46	43.22	52.25	59.64
	SD	13.79	38.05	30.77	27.54
Marginals by Cams	Mean	84.77	53.24	62.90	66.97
	SD	11.23	30.04	24.15	21.81

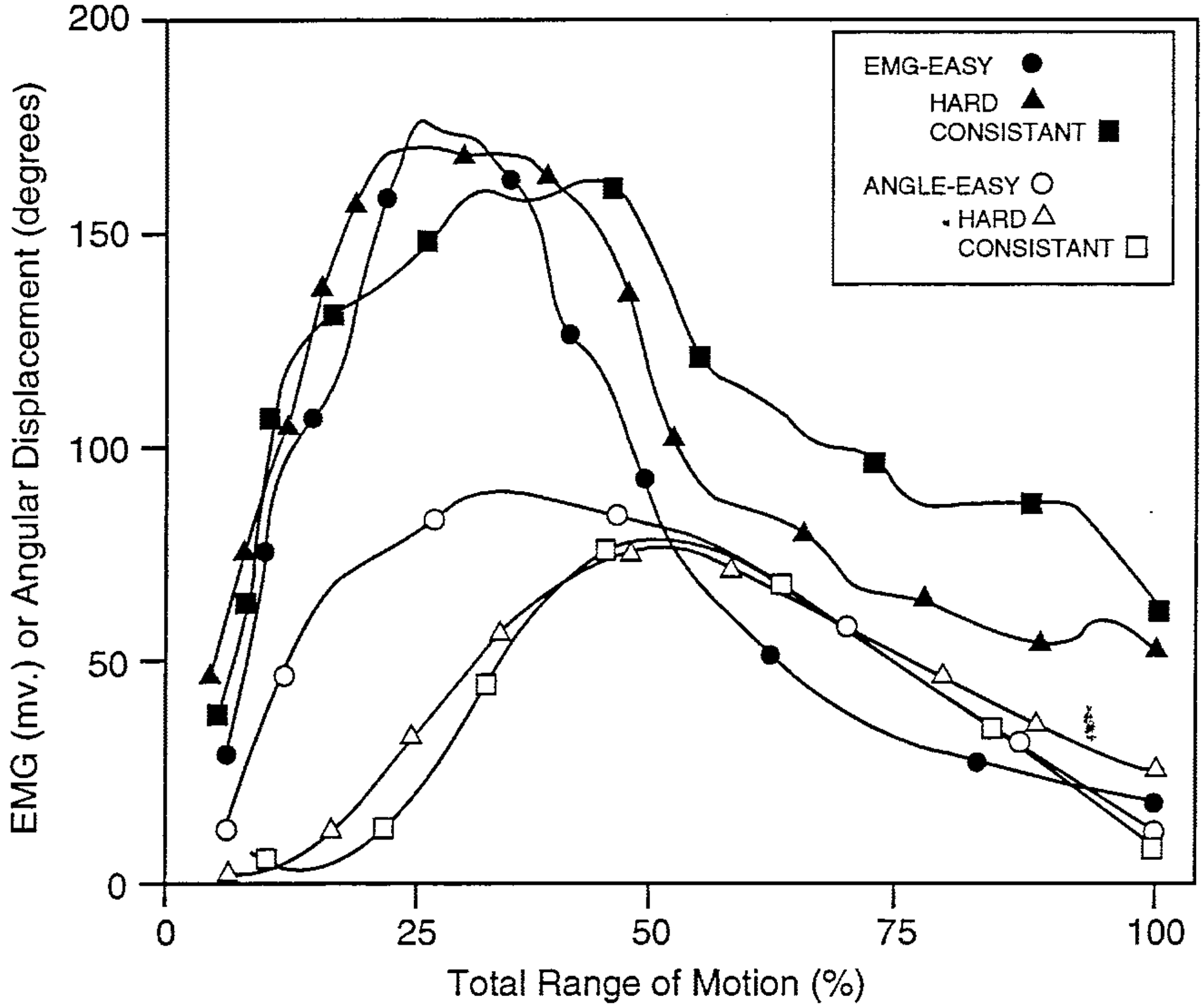


Figure 2. Contraction response pattern for the Easy, Hard and Consistent Cams during EMG (mv.) and Angular Displacement (degrees) for the 50% 10 Repetition Submax load.

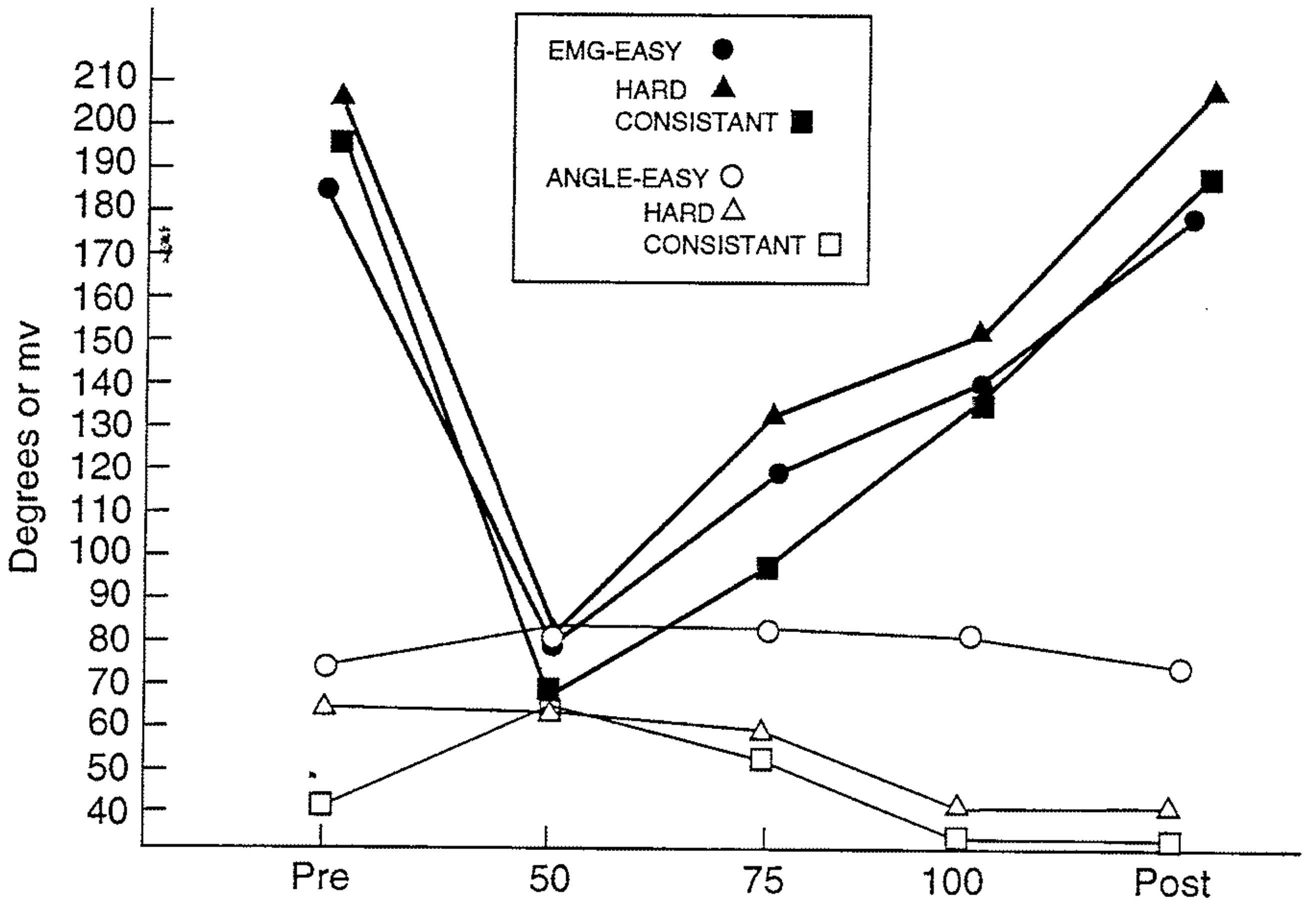


Figure 3. Interaction of CAM Shape, EMG Peak Activity (mv) and Angular Displacement (degrees) over all Five Lifting Conditions.

Table 4. EMG Data (mv) for Multivariate Tests of Significance for Cam Effect, Lift Effect, and Cam X Lift Effect.

Effect	Wilk's Value	DF	F	p
Cam	.1598	2/8	21.025	.001
Lift	.0948	4/6	14.316	.003
Cam X Lift	.0133	8/2	18.532	.052

EMG's Wilk's lambda multivariate tests of significance. Here the cam effect was significant with Wilk's = .1598 and p = .001. The lift effect was also significant with Wilk's = .0948 and p = .003. The cam X lift was not significant although the value of p = .052.

Follow-up contrasts and applicable stepdown tests for identifying signicant EMG activity differences are shown in Table 5. The consistant cam performed with more millivolt than the easy cam (F= 29.921; p = .000). No other cam contrasts were significant. Roy-Bargman stepdown comparisons for the repeated lifts indicated that the first test (pre vs 50%) was significant (F=29.577; p = .000) indicating the pre 1RM vs 50% max comparison was significant with the pre 1RM test highest in millivolts. No other EMG stepdown values were significant.

Angular Displacement Results:

Examination of Table 6 reveals the results for the Angular Displacement Wilk's lambda multivariate tests of significance. Here the cam effect was significant with the Wilk's=.3219 and p=.011. The lift effect was not significant (p=.213). Likewise, the cam X lift effect was nonsignificant with p=.297.

Follow-up contrasts for identifying significant angular displacement differences are shown in Table 7. The easy cam performed with more degrees of displacement than the hard cam (F=12.698; p=.006). No other cam contrasts were

Table 5. EMG Data (mv) Analyses by Contrasts and Roy-Bargman Stepdown F-Tests Showing Cam Effects and Lift Effects.

Effect	Comparison Variables	DF	F-Tests	P
Contrasts:				
Cam	Hard vs Consistant	1/9	29.921	.000
	Easy vs Consistant	1/9	3.573	.095
	Easy vs Hard	1/9	.548	.478
Roy-Bargman Stepdown Comparisons for Repeated Measures:				
Lift	Pre vs 50%	1/9	29.577	.000
	50% vs 75%	1/8	.531	.487
	75% vs 100%	1/7	4.738	.066
	100% vs Post	1/6	2.253	.184

Table 6. Angular Displacement (degrees) Data for Multivariate Tests of Significance for Cam Effect, Lift Effect, and Cam X Lift Effect.

Effect	Wilk's Value	DF	F	p
Cam	.3219	2/8	8.427	.011
Lift	.4280	4/6	2.005	.213
Cam X Lift	.0844	8/2	2.712	.297

Table 7. Angular Displacement Data (degrees) by Contrasts Dealing with Cam Effects.

Effect	Comparison Variables	DF	F-Tests	P
Cam	Easy vs Hard	1/9	12.698	.006
	Easy vs Consistant	1/9	3.238	.110
	Hard vs Consistant	1/9	2.309	.167

significant.

One Way Data Analyses

In addition to the multivariate analyses of EMG and AngleDisplacement data, secondary one-way analyses involved the calculation of torque diferences by the Easy Plot software from the collected data base. These analyses were not as powerful as the multivariate techniques, but in an exploratory study such reduced signficance effects might suggest meaningful trends in regards to the three cams.

Peak Torque:

In Table 8 the Peak Torque is first presented for the three cams and five lifts. None of the F-tests were significant athough on the 100% 10RM lift, the $p = .054$, in favor of the CAM-E.

Concentric Torque:

For the evaluation of Concentric Torque one significant F-test was determined, as seen in Table 8. This was at the 75% 10RM lift with $p = .045$, indicating that the CAM-C was significantly higher than CAM-E.

Eccentric Torque:

Finally, the Eccentric Torque results are also presented in Table 8. None of the F-tests even approached significance, which indicated no cam or lift differences.

Summary

In this chapter, the significant results of the study were reported with regards to the EMG activity (mv) and

Table 8. Peak, Concentric, and Eccentric Torque Analysis for Cams and Lifts.

Lift: Peak	Easy Cam	Hard Cam	Consistant Cam	P
Pre	210.19	180.30	208.70	.150
50%	61.15	60.36	61.16	.073
75%	110.05	110.78	111.30	.671
100%	149.65	147.10	144.16	.054
Post	210.94	149.64	171.24	.069
Concentric				
Pre	204.03	180.59	208.79	.222
50%	59.72	49.98	61.14	.142
75%	107.57	110.99	111.04	.045
100%	144.38	146.93	141.78	.279
Post	518.73	373.27	428.00	.106
Eccentric				
Pre	187.13	179.74	199.39	.512
50%	57.61	52.91	59.85	.327
75%	104.07	110.06	109.42	.145
100%	140.21	141.82	140.59	.807
Post	494.43	368.83	417.11	.217

angular displacement (degrees) illicited by three different cam profiles. For the EMG test, the consistant cam had the greatest individual and total mean millivolt activity within the cam effect. For the lift effect, the 1 rep max pre had the highest millivolt value. For the Angular Displacement test, the easy cam had the greatest degrees total mean displacement for the cam effect. No significance was found for either the lift effect or the cam X lift effect. Of the peak, concentric, and eccentric torque analysis, only the concentric torque showed statistical significance at the 75% 10RM. Implications of these significant results pertaining to the variations in muscle loading of cam controlled equipment will be discussed in Chapter 5.

CHAPTER 5

Discussion

Progressive resistance exercise is an accepted method to maximize strength gains during training and/or rehabilitation. A limitation arises when force generated by the muscles during a contraction is not maximum throughout all phases of the joint movement. To remedy this, various equipment manufacturers have devised variable resistance machines which utilize cams to accomodate the resistance in accordance with the lever characteristic of a particular joint movement. Unfortunately, little research exists specific to this type of cam controlled resistance exercise equipment. Each type of cam resistance machine proposes to produce strength curves representing maximum contraction at each angle of movement. Optimal contractions would theoretically result in greater and more rapid strength capacity and subsequent gains. Various common brands of this equipment include Nautilus, Eagle-Cybex, Paramount, and Polaris. The primary objective of the current study was to statistically analyze three different cam profiles for differences in EMG potential and angular displacement. A secondary objective was to measure torque characteristics.

The rationale for this study was regarding the differences in force tension at various angles throughout the arc of motion. Lack of scientific research regarding cam loaded variable resistance exercise machines demonstrated a need for controlled investigation in this area. Each type of machine proposes to produce strength curves representing maximum contraction at each angle of movement. Optimal contractions would theoretically result in greater and more rapid strength capacity and subsequent gains.

Due to the biomechanical arrangement of muscles within the bony levers of the skeletal system, the magnitude of muscular strength is dependent on the joint configuration (joint angle) at the time of measurement and varies throughout the range of movement (Kulig, Andrews, and Hay, 1984). Kulig further reports that strength gains resulting from overloading the muscle at all points throughout the range of motion are thought to be superior to strength gains resulting from a constant resistance that overloads the muscle only at a specific critical joint configuration. Furthermore, Graves, Pollock, Jones, and Colvin (1989) suggest that machine resistive torque of variable resistance exercise machines does not perfectly correspond to muscular torque capability. Current research support the concept that some variable resistance exercise machines can provide a uniform training stimulus (optimal load) throughout a full range of movement.

Patton and coworkers (1978) suggested that (isokinetic) fatigue patterns are functions of strength levels and follow a curvilinear form similar to other types of contractions. This study supported the suggestion, as it was designed to examine the effects of varying muscle loads by the different shaped cams. This experiment also examined muscle loading by using an adaptable resistance which followed the specific force angle relationship of the muscle. This principle of variable resistance may have the potential to create optimal conditions for high muscle activation throughout the entire joint movement (Hakkinen and Komi, 1986, Hakkinen, Komi, and Kauhanen, 1987).

The following discussion will review the significant results as they pertain to the hypotheses of force output as determined by EMG response (H1), angular displacement in regards to force variations in three different cam profiles (H2), and interaction between the EMG and Angle (H3).

Multivariate Analyses

EMG Response

The statistically significant findings for the cam effect of the EMG response were found between the hard and consistant cams in the Roy-Bargman stepdown test (p=.000). One possible explanation for the statistical difference in millivolt activity could be that the hard cam was too difficult a challenge for the muscle threshold of contraction. The cam overloaded the muscle in the beginning of the lift, which prevented stimulation of a significant amount of muscle fiber recruitment. The typical strength curves for the hard and consistant cams showed the consistant cam to produce the highest millivolt activity. The sharp drop in the hard cam indicates a quick ascent during the leg extension. As far as application to strength training is concerned, muscle fiber activity was only optimal throughout the latter part of the movement.

Statistical significance was found in the lift effect (Roy-Bargman) between the Pre and 50% levels. This is possible because the 50% level was too light in weight to produce the necessary fiber recruitment for a muscle overload. The Pre level was the minimum level needed to produce the overload and subsequent fiber stimulation of adequate amounts to produce strength gains.

To reemphasize the original problem of why various cam controlled equipments feels differently, this study shows that the individual cam has to be a certain shape to load the muscle effectively. Also, the load must be of a certain minimum weight to engage the muscle in an overload adaptation. It should be noted here that velocity relationships are operative in the lift. Muscle fiber recruitment is dependent on velocity of movement, such as at a slower velocity more fiber recruitment takes place. In each case, it was the cam shape that controlled the speed of movement, and not the limb by itself.

<u>Angle Response</u>

The only significant finding for the Angle response was found in the cam effect between the easy and hard cams (p=.006). The easy cam was lighter to lift and so moved through a large range of motion (greater degrees displacement) at a fast pace. The hard cam was difficult to lift in the initial portion of the ascent and so consequently produced the smallest displacement (degrees). The consistant cam had the greatest millivolt activity and degrees displacement over the longest range of movement than the other cams.

One Way Data Analyses

Torque Analysis

The secondary one-way analysis involving the calculation of torque differences in the peak, concentric, and eccentric analysis were not as powerful as the multivariate technique. Such reduced significant effects did not suggest meaningful trends in regards to the three cams.

Implications

1.This study supports the finding that the consistant cam is recommended for general strength training and rehabilitation. The muscle is loaded at more points in the range of motion and is able to maneuver throughout a greater arc in this same range.

2.The easy cam would be appropriate for rehabilitation purposes. It would appear from the results and review of the literature the lessened tension in the initial phase of the lift would allow some muscle stimulation during the range of movement. This exercise would allow slower strength gains over the time it takes for the recuperation process.

3.It seems that intuitively, the hard cam would be used in situations where rapid strength gains are desired possibly due to engaging the muscle in a greater overload response.

Conclusion

In conclusion, the results seem to indicated that the differences in the cam values were a function of the shape which controlled and influenced the speed of movement and limb position. This explanation supported the postulation that a cam shaped to control the tension uniformly throughout the range of movement would be the best for optimal muscle loading and strength training in normal circumstances. The easy and hard cams might br more beneficial in special populations. However, even though the preliminary data showed individual cam differences in speed of movement, there was no overall effect because the amount of work was the same.

Recommendations

Based on the results obtained in this study, the following research ideas are recommended.

1.Further investigation is needed in the area of cam loaded exercise equipment to test the effectiveness of the consistant cam in other exercises.

2.Research needs to be expanded to other areas of the body such as upper body movements to evaluate more than one muscle.

3.A female population needs to be studied to assess anatomical differences.

4.Increased number of subjects might increase chances of power, statistical corrolation, and interaction.

5.Integrate EMG and force platforms with new technology.

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APPENDIX 1

Patient Consent Form

The Effects of Various Types of CAM Profiles on Selected EMG Potentials and Angular Kinematics

Investigators: E. Grace A. Hood, B.S., Charles W. Jackson, DPE, Richard B. Kreider, Ph.D., Michael L. Woodhouse, Ph.D.

Description:

The purpose of this study is to statistically analyze three different CAM profiles for differences in EMG potential and angular kinematics.

Over a period of four (4) weeks, I will undertake a series of three (3) testing sessions and one (1) familiarization session. Each testing session will be separated by a one (1) week rest period. During each experimental session, I agree to perform a series of maximum and submaximum quadriceps contractions while seated on a leg extension apparatus. I agree to receive one of three counterbalanced CAM treatments per testing session. I understand that each CAM treatment will be analyzed for concentric and eccentric contractions, EMG activity, and angular kinematics by video analysis. I can expect each exercise testing session to take approximately two (2) hours to conduct. Prior to each testing session I agree to be prepared for testing by having two (2) electromyographic electrodes attached on my quadriceps of my favored extremity. I agree to have anterior and posterior photographs of my lower extremities taken after attachment of the electrodes. I agree to perform a general warm up period prior to the actual testing session. I realize that, during each exercise test, I will first perform a one repetition maximum contraction. I realize that video analysis will be made of my sub-maximum, maximum, eccentric, and concentric contractions. Following the completion of each testing session, I agree to observe a one (1) week rest period, during which I will refrain from exercising my lower extremity three (3) days prior to the next test. I realize that I am expected to give my best personal effort in each of the experiments.

Exclusionary Criteria:

I am not aware of any medical problems that would prohibit my participation on this study.

Risks and Benefits:

The exercise tests which I will perform may cause symptoms of muscular fatigue and soreness. Any dizziness or nausea would indicate to me that I should stop exercising. However, I understand that the series of contractions that I will perform will be similar to a heavy weight lifting workout and that I should expect my physiological responses to be similar to the physiological demands of training and/or performance. There does exist the very rare instance of a blackout I understand that there is a chance of abrasion at the site of electrode attachment. I also may be subject to other risks not yet identified.

I understand that the main benefit to accrue from this study is whether there is a difference in muscle compliance to different shaped CAMs, as measured by force-tension variables at various angles for concentric and eccentric contractions. I also understand that pertinent information relative to my muscular performance in the quadriceps contractions will be discussed with me by an investigator.

Alternative Treatments:

This is not a treatment program and, thus, I must continue to obtain treatment from my attending physician.

Costs and Payments:

I understand that my efforts in this study are voluntary and that no payment or reimbursement is expected.

New Information:

Any new information obtained during the course of this research that my be relative to my willingness to continue participation in this study will be provided to me.

Confidentiality:

I understand that any information obtained about me from this research, including questionnaires, medical history, laboratory findings, or physical examination will be kept strictly confidential. I also understand that the data derived from this study could be used in reports, presentations, and publications but that I will not be individually identified unless my consent is granted. I do understand however, that my records may be subpoenaed by court order or may be inspected by federal regulatory authorities. I understand that in order to ensure the Food and Drug Administration (FDA) regulations are being followed, it may be necessary for a representative of the FDA to review my medical records.

Withdrawal Privilege:

I understand that I am free to refuse to participate in this study or to withdraw at any time and that my decision to withdraw will not adversely affect my status at this institution or cause a loss of benefits to which I might be otherwise entitled. If I do decide to withdraw, I agree to undergo all trial evaluations necessary for my safety and well-being as determined by the Principal Investigator.

Compensation for Illness or Injury:

I understand that in the unlikely event of physical injury or physical illness resulting from the research protocol no monetary compensation will be made but any immediate emergency medical treatment which may be necessary will be available to me without charge by the investigators. I am advised that if any injury should result from my participation in this research project, Old Dominion University does not provide any insurance coverage, compensation plan, or free medical care planned to compensate me for such injuries. In the event that I believe that I have suffered injury as a result of my participation in the research program, I may contact Grace

A. Hood, (804) 683-4995, who will be glad to review the matter with me.

Voluntary Consent:

I certify that I have read the preceding or it has been read to me and that I understand the contents and that any questions I have pertaining to the research have been, or will be answered by Ms. E. Grace A. Hood, Dr. Charles Jackson, Dr. Richard Kreider, or Dr. Michael Woodhouse, whose phone numbers are (804) 683-4995. A copy of this consent form will be given to me. My signature below means that I have freely agreed to participate in this investigation.

Date	Signature
Date	Signature

I certify that I have explained to the above individual the nature and purpose of the potential benefits, and possible risks associated with participation in this study. I have answered any questions that have been raised and have witnessed the above signature. I have explained the above to the volunteer on the date stated on this consent form.

Date	Signature