

MUSCULAR FORCE-VELOCITY ALTERATIONS CONSEQUENT
TO SLOW AND FAST VELOCITY POWER TRAINING

by

Edward Francis Coyle

A Dissertation Submitted to the Faculty of the
COMMITTEE ON ANIMAL PHYSIOLOGY (GRADUATE)
In Partial Fulfillment of the Requirements
For the Degree of
DOCTOR OF PHILOSOPHY
In the Graduate College
THE UNIVERSITY OF ARIZONA

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The University of Arizona

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THE UNIVERSITY OF ARIZONA
GRADUATE COLLEGE

I hereby recommend that this dissertation prepared under my direction
by Edward Francis Coyle
entitled MUSCULAR FORCE-VELOCITY ALTERATIONS CONSEQUENT
TO SLOW AND FAST VELOCITY POWER TRAINING
be accepted as fulfilling the dissertation requirement for the Degree
of DOCTOR OF PHILOSOPHY.

Jack H. Wilmore
Dissertation Director

9 August 1979
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As members of the Final Examination Committee, we certify that we have
read this dissertation and agree that it may be presented for final
defense.

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August 9, 1979
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August 9, 1979
Date

Final approval and acceptance of this dissertation is contingent on the
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TABLE OF CONTENTS

	Page
LIST OF ILLUSTRATIONS	vii
LIST OF TABLES	viii
ABSTRACT	ix
1. INTRODUCTION	1
Review of Literature	3
Performance and Morphological Adaptation to Slow Training	6
Performance and Morphological Adaptations to Fast Training	10
Performance and Morphological Adaptation to Mixed Slow and Fast Training	11
Morphological Adaptation Resulting from Electrical Stimulation	12
Summary	12
Purpose	12
2. METHODOLOGY	14
Subjects	14
Isokinetic Equipment and Testing Protocol	15
Training Protocols	20
Histochemistry	25
Statistical Analysis	26
3. RESULTS	27
Learning Prior to Pre-Testing	27
Within Group Changes in MVC and MPT	27
Between Group Comparison of Changes in MVC and MPT	35
Vertical Jump	41
Morphological Adaptations to Training	43
4. DISCUSSION	45
5. SUMMARY	54

TABLE OF CONTENTS--Continued

	Page
APPENDIX A: CALIBRATION OF CYBEX II DYNAMOMETER	56
APPENDIX B: TESTING SCHEDULE PRE AND POST TRAINING	57
APPENDIX C: DETERMINATION OF WORK PERFORMED AT 60 AND 300°/SEC	58
APPENDIX D: TORQUE GENERATED THROUGH ELECTRICAL STIMULATION AND MEAN % MVC PRODUCED DURING TRAINING	61
REFERENCES	62

LIST OF ILLUSTRATIONS

Figure	Page
1. Force-velocity characteristics of skeletal muscle	2
2. CYBEX II isokinetic testing device	17
3. ORTHOTRON training device	22
4. CONTROL group alterations, \pm %, in torque-velocity with two legs simultaneously (A) and one leg individually (B)	28
5. PLACEBO group alterations, \pm %, in torque-velocity with two legs simultaneously (A) and one leg individually (B)	29
6. SLOW group alterations, \pm %, in torque-velocity with two legs simultaneously (A) and one leg individually (B)	30
7. FAST group alterations, \pm %, in torque-velocity with two legs simultaneously (A) and one leg individually (B)	31
8. MIXED group alterations, \pm %, in torque-velocity with two legs simultaneously (A) and one leg individually (B)	32
9. STIM group alterations, \pm %, in torque-velocity with two legs simultaneously (A) and one leg individually (B)	33
10. Mean (\pm SE) comparison of MVC changes	36
11. Mean (\pm SE) comparison of MPT/60 changes	37
12. Mean (\pm SE) comparison of MPT/180 changes	38
13. Mean (\pm SE) comparison of MPT/300 changes	39

LIST OF TABLES

Table	Page
1. Mean (\pm SE) Physical Characteristics of Groups Pre-Training	16
2. MVC and MPT Improvements Possessing a Significant Physiological Component	40
3. Vertical Jump Pre- and Post-Training	42
4. Mean (\pm SE _D) Morphological Adaptations to Training	44

ABSTRACT

The purpose of this investigation was to compare muscular force-velocity alterations consequent to slow and fast velocity power training. Active males trained the knee extensors of both legs simultaneously for six weeks, three times per week, by attempting to generate maximal peak torque (MPT) with each repetition at velocities of $60^{\circ}/\text{sec}$ (MPT/60), $300^{\circ}/\text{sec}$ (MPT/300), or both. The training regimens were designated SLOW ($n=4$), FAST ($n=4$), MIXED ($n=4$) respectively. A CONTROL group ($n=5$) was included, as was a PLACEBO treatment ($n=5$) in an attempt to separate the psychological influences of training from the physiological alterations, resulting from possible muscular or neurological adaptations. An additional group (STIM; $n=4$) had their quadriceps electrically stimulated to produce similar tension as the SLOW group, while not directly training their efferent nervous systems. Thus a direct comparison of the SLOW to STIM group might differentiate muscular from combined neuro-muscular adaptations.

Psychological effects, as determined from the PLACEBO group accounted for significant increases in MVC (+8%), MPT/180 (+5%) and vertical jump (+1.75 inches). SLOW training improved MVC (+23%), MPT/60 (+32%) and MPT/180 (+9%). Only the improvements in MPT/60 demonstrated a significant physiological component of adaptation. This physiological adaptation appears to be partly neurological as evidenced by the greater improvement in MPT/60 when testing specifically mimicked training.

FAST training significantly improved MPT uniformly (16-21%) at the training velocity as well as at slower velocities. Only the MPT/180 and MPT/300 improvements contained a significant physiological component of adaptation. Possible adaptations include either or both improved recruitment or synchronization of Type II fibers, and Type II fiber hypertrophy. No evidence for specificity of training was found subsequent to FAST training.

The mixing of slow and fast velocity training was not found to improve MPT/60 or MPT/300 anymore than that which can be attributed to the selective slow and fast velocity training. This observation challenges the common belief that slow velocity training hypertrophies muscle while fast training synchronizes its contraction, and when both are performed MPT/fast improves the most.

High tension producing contractions appear necessary to improve MPT/slow while fast training velocities must be employed to improve MPT/fast. FAST training improves MPT in the mid-velocities more effectively than does SLOW training. The training action should specifically mimic that encountered during performance, particularly if the performance occurs at slow velocities of contraction.

CHAPTER 1

INTRODUCTION

Success in many athletic activities is determined by the final velocity that can be imparted to an object or body segment, e.g., shot-putting, javelin throwing, jumping, sprinting. Thus, the most effective training regimen would be one which maximizes the velocity at which a given force can be moved (see A in Figure 1). As is noted in Figure 1, force and velocity are inversely related. Thus, events which measure success in terms of the quantity of force that can be generated, e.g., bench press and squats, typically are performed at slow velocities. The most effective training regimen in these instances would be one which maximizes the force which can be generated at these slow velocities (see B in Figure 1). All events which require a burst of maximal muscular effort, operate at some point along this force-velocity curve. The most effective training regimen would be one which maximally shifts the force-velocity relationship within the speed-specific range of a particular activity.

From the above, it becomes important to determine at what point or range in the force-velocity relationship should a training regimen be performed to maximize improvement. This requires an understanding of how maximal force is altered when training is performed at various points along its arc.

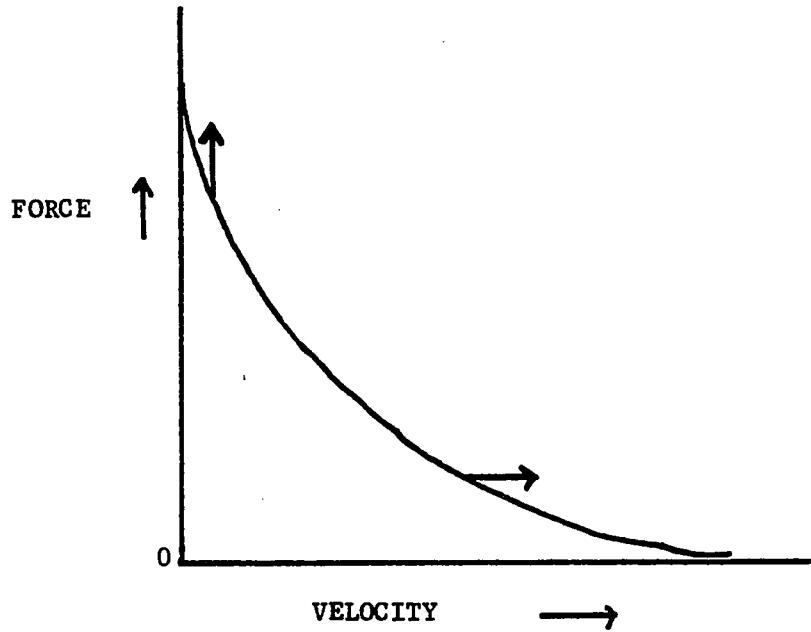


Figure 1. Force-velocity characteristics of skeletal muscle

Review of Literature

The size of a muscle, i.e., its contractile mass and its relative distribution of slow contracting (Type I) and fast contracting (Type IIa and IIb) fibers determine its force capabilities at various points along the force-velocity relationship. Type II fibers, because of their rapid ability to hydrolyze adenosine triphosphate (Barany, 1967; Close, 1972) can produce substantially more force than can Type I fibers, at fast contractile velocities, and at this time there are no known physiological differences between Type IIa and IIb fibers in humans (Halkjaer-Kristensen, 1978). Type I and Type II fibers appear to be similar in their force generating capabilities at slow contractile velocities (Close, 1972; Coyle, Costill, and Lesmes, 1979).

In vivo, during voluntary contractions, the nervous system regulates the number and type of motor units recruited, their frequency of activation, and synchrony of contraction. Therefore, the maximal peak force or tension a muscle can voluntarily produce at a particular velocity along the force-velocity curve (MPT/velocity) is a consequence of the interaction between the muscle's ability to produce tension and the nervous system's ability to activate the muscle.

Since MPT is determined by these neuromuscular interactions, any training-induced shift in the force-velocity relationship would have to be a result of either or both psychological influences on, or physiological adaptations within the muscle, i.e., muscle fiber size or type, fiber recruitment, and synchronization of recruitment. Those physiological adaptations within the muscle result, and may in fact differ with the stimuli specific to the form of training, e.g., training velocity.

If the stimuli evoked by fast speed training are somewhat different from those evoked through slow speed training, the adaptations should be different, and therefore the shifts in the force-velocity relationship should also differ.

A slow velocity contraction appears to provide a greater stimulus for muscular hypertrophy because of the associated high forces, since muscular force has been hypothesized to be the stimulus for hypertrophy (Goldberg et al., 1975). This ability to produce high force at slow contraction velocities appears to be the result of the recruitment of both Type I and Type II fibers (Lesmes et al., 1979; Gollnick, Karlsson, et al., 1974; Gollnick, Piehl, and Saltin, 1974) as well as the ability to reach peak tension in both fiber types. Although both fiber types are recruited during slow contractions, it is not clear if an individual has the ability to voluntarily recruit all of the fibers within a muscle, or whether only some undefined fraction of the total fiber population can be recruited. It is equally uncertain as to whether the nervous system allows fibers to most efficiently synchronize their contractions in an attempt to maximally summate their forces. Perrine and Edgerton (1978) suggest that the maximal voluntary contraction (MVC at zero velocity where force is highest) is less than what the muscle is innately capable of producing. Most probably, the nervous system inhibits the recruitment of all muscle fibers, or prevents their synchronous firing, or both.

Since MVC and MPT/slow may be less than what the muscle is capable of producing because of neural inhibition of either or both recruitment or synchronization the possible physiologic adaptation to training could involve overriding this inhibition. Yet, increases in MVC cannot

be attributed to pure physiological adaptations until possible psychological influences are factored out. Ikai and Steinhaus (1961) have noted MVC to acutely increase by as much as 20% through psychological treatments, i.e., hypnosis and shouting, which were theorized to disinhibit the nervous system's regulation of muscle function. From the above, slow contraction produce high forces within both muscle fiber types, and should, therefore, provide the stimulus for muscular hypertrophy. Since MVC and MPT/slow do increase with slow speed training (to be detailed in the following section), this increase could result from an increase in the number of fibers recruited or in the synchronization of recruitment. Therefore, the question must be asked, does slow volitional training exclusively provide the stimulus necessary to improve MPT/slow.

MPT/fast is more dependent upon the recruitment and synchronization of Type II muscle fibers. Type I fibers require approximately 100 msec to develop tension (Buchthal and Schmalbruch, 1970) and therefore cannot contribute significantly to force production during fast contractions. Type II fibers can reach peak tension in 40 msec, and have recently been found to be responsible for and related to MPT/fast (Lesmes et al., 1979). Thus, if MPT/fast does improve with training (this literature will be reviewed in a subsequent section), the physiological adaptation responsible for this improvement might include increasing either or both the number and size of Type II fibers, increasing Type II recruitment, or increasing the synchronization of Type II fiber contraction (Burke and Edgerton, 1975). The total force developed during fast speed contraction is small, and is mostly concentrated within Type II fibers. Therefore the stimuli for hypertrophy, if sufficient, may occur only within those

fibers. The adaptability of Type II fiber synchronization to training is, at present unknown.

The following sections will review the force-velocity adaptations resulting from slow, fast, and mixed slow and fast velocity training. Reference will be made when available as to the possible psychological as well as physiological mechanisms which could account for the noted adaptations.

Performance and Morphological Adaptation to Slow Training

Numerous studies report isometric training to improve MVC and isotonic training to improve I-RM (the maximal amount of free weight that can be lifted one time) by 10 to 50% of the initial values as a result of six to ten weeks of strength training (Clarke, 1978). Before discussing the physiological basis for these improvements, one must consider psychological factors which can improve MVC or MPT. Obviously a commitment to a training study designed to show improvement, places many expectations and experimenter "demand characteristics" upon the subject (Orne, 1974). No investigation has attempted to control those psychological factors which might be operational in such a situation by including a placebo treatment. Thus, the noted improvements must be interpreted in view of the 0 to 26% strength increases which have been observed to result from acute psychological manipulation (Ikai and Steinhaus, 1961).

Various morphological adaptations have been associated with improvements in MVC and MPT/slow. The muscle is capable of hypertrophy (Morpurgo, 1897; Siebert, 1960). Apparently, this compensatory growth is more specific to Type II fibers (Edgerton et al., 1972; Edgerton,

1976). Gollnick et al. (1972) and Prince, Hikida, and Hagerman (1976) have observed weight-lifters to possess enlarged Type II fibers in those muscle specifically trained, while the Type I fibers were of normal size or only slightly enlarged. It must be recognized, however, that the cross-sectional nature of these data do not account for the possibility that these athletes were genetically predisposed to large Type II fibers. The possibility of a genetic predisposition is discounted by the data of Coyle et al. (1978), who observed a world class shot-putter with Type II fibers three times as large as the Type I fibers in the deltoid muscle, while in the gastrocnemius muscle the Type I and Type II fibers were of equal size.

Although both fiber types are recruited during slow speed contraction, the resulting tension may promote hypertrophy to a greater extent within the Type II fibers (Edgerton, Simpson, and Gillespie, 1975; Edgerton, 1976). The specific mechanism or mechanisms by which tension stimulates myofibrillar growth has not yet been resolved (Goldberg et al., 1975), but apparently is quantitatively different in Type II muscle fibers.

External girth measurements, for the most part, remain unchanged even with dramatic increases in MPT/slow (Clarke, 1978). Neurological adaptations allowing the recruitment of more muscle fibers, or greater motor unit synchronization, or both, are possible explanations as previously discussed. Milner-Brown, Stein, and Lee (1975) have noted weight-lifters to have greater motor unit synchronization during voluntary contraction of the first dorsal interosseus muscle. The degree of synchronization was determined by comparing single motor unit electrical potentials to the total EMG of the muscle. A synchronous contraction

would be one during which the single motor units fire in synchrony, corresponding to the attainment of peak total EMG. Milner-Brown et al. (1975) observed a 20% increase in MVC among normal subjects following training, to be associated with a significantly greater level of synchronization. Thorstensson, Karlsson, et al. (1976) also observed increases in MVC and I-RM which was associated with a tendency for the integrated EMG to remain unchanged or decrease slightly. Komi et al. (1978) also suggest isometric strength can be enhanced by improving synchronization consequent to their observations of a decrease in the amount of fiber involvement (IEMG) needed to sustain a standardized submaximal contraction. Thus, data suggesting increased motor unit recruitment are lacking. Increased synchronization, however, is one likely mechanism which can be related to improved MVC, I-RM or MPT/slow.

The enlargement of the nucleolus in motor neurons provides a morphological indication that the nervous system does adapt with training (Gerchman, Edgerton, and Carrow, 1975). Neurological adaptations are one possible explanation for the observed cross-training effect, that is, exercised ipsilateral muscles have been observed to increase MVC by 26% while the unexercised contralateral muscles show significant increases of 11% (Davis, 1898; Rose, Radzynski, and Beatty, 1957; Logan and Lockhart, 1962). Other possible explanation for the contralateral increase in MVC include psychological influences or actual training of the contralateral muscles while attempting to stabilize the body, during contractions of the ipsilateral muscle.

Further evidence that the nervous system controls the muscle's expression of MVC is obtained in examining the literature relating

increases in isometric MVC to the specific angle at which isometric training occurred (Clarke, 1978; Boileau, 1962; Berger, 1962a; Belka, 1968). Gains are specific to the training angle in that improvements in MVC become increasingly smaller as the joint angle during testing moves successively farther away from the training angle. It is possible, although unproven, that the muscle must provide familiar proprioceptive feedback to the nervous system to enable it to enhance recruitment or synchronization at the specific angle of training. This specificity of proprioceptive feedback concept may also help explain the observation that a muscle is able to exert more force when tested in the specific manner it was trained. Rasch and Morehouse (1957) as well as Berger (1962a) have observed isometric training to improve MVC significantly more than isotonic training and conversely, isotonic training to improve I-RM significantly more than that which could be achieved through isometric training.

Slow speed training is obviously very effective in improving MVC and MPT/slow, yet conflicting data exists as to its efficacy for enhancing MPT/fast. Past investigations have used vertical jump almost exclusively as a measure of MPT/fast or power. The maximum velocity of knee extension during the vertical jump is $200^{\circ}/\text{sec}$, while the unloaded joint can move at $750^{\circ}/\text{sec}$ (Thorstensson, Grimby, and Karlsson, 1976). Thus, the vertical jump measures MPT at a velocity somewhat slower than the MPT/300 (300 referring to $300^{\circ}/\text{sec}$) isokinetic measure to be discussed later in the text. Ness and Sharos (1956), Berger (1963), Williams (1965) and Bangerter (1968) have all observed squat-type weight training to increase vertical jump (1-3 inches) and I-RM. Pipes and Wilmore (1975)

observed slow speed isokinetic training to increase vertical jump by one inch while Prins (1978) found no significant improvement.

Performance and Morphological Adaptations to Fast Training

Before the advent of isokinetic training devices it was difficult to train at high velocities unless natural movements were employed, e.g., jumping or throwing. Thus, the early literature references a few studies during which the subjects practiced vertical jumping. In two investigations this practice was found to be superior to weight training alone (Schultz, 1967; Prins, 1978), while Berger (1963) found weight training to produce significantly greater improvements in vertical jumping ability.

Lesmes et al. (1978) and Costill et al. (1979) recently reported MPT/180 knee extension and flexion training to improve MVC, MPT/60 and MPT/180 by 11, 14, and 14% respectively. MPT did not improve at velocities above those encountered during training. In addition, they found a 7% increase in Type II area, along with increases in total activity of key anaerobic enzymes.

Cross-sectional data have observed sprinters to possess a wide range (0.8-2.0) of Type II/Type I fiber area ratios (Costill et al., 1976; Thorstensson, Larsson, et al., 1977). As a group they appear to have slightly hypertrophied Type II fibers, but nothing comparable to the enlargement observed in weight-lifters. Adolescents who performed 5-second sprint training on a treadmill improved MVC by 10%, vertical jump by 9% and displayed a tendency although statistically insignificant, to enlarge both fiber types (Thorstensson, Sjodin, and Karlsson, 1975).

Generally, fast speed training results in an 8-12% improvement in MPT at slower speeds, while altering muscle morphology only slightly, if at all. The author is unaware of any data relating neurologic adaptations to high speed training.

Performance and Morphological Adaptation to Mixed Slow and Fast Training

A number of studies have incorporated both weight training (leg squats) and vertical jumping into their training regimens. Thorstensson's (1977; Thorstensson, Hulten, et al., 1976) observations are similar to those of Berger (1963) and Schultz (1967). After eight weeks, subjects improved 1-RM squat strength by 67%, vertical jump by 22%, MVC by 13% and Type II/Type I area by 14% (Thorstensson, Hulten, et al., 1976). One individual, who improved 25% in MVC and 10% in MPT/180, continued to train for five additional months, with no further improvement in MVC, while MPT/180 improved an additional 7%.

It is difficult to assess the efficacy of these mixed slow and fast training studies because direct comparisons were not made with individual slow and fast regimens. The performance-related interaction of slow and fast speed training would be of particular interest. Most power athletes, i.e., shot-putters and olympic-style weight lifters, perform both. They have also been observed to possess awesome power. World class shot-putters have a mean vertical jump of 32 inches (Coyle et al., 1978), which is significantly above normal age matched values of 20 inches (Prins, 1978).

Morphological Adaptation Resulting from Electrical Stimulation

Electrical stimulation has been shown to be an effective modality for promoting hypertrophy in animal muscle. Poortman and Taylor (1979) have recently reported a 20% atrophy of Type I fibers and a 9% hypertrophy of Type II fibers after ten successive days of Faradic current stimulation. Electrical stimulation places the muscle under tension, yet it does not require the neural control of recruitment. It may therefore be possible to separate the muscular aspects of improvement from the neurological aspects, by comparing slow speed high tension volitional contractions with high tension producing electrical stimulation.

Summary

Slow speed training improves MVC, 1-RM, MPT/slow and possibly vertical jump by promoting physiological adaptations either or both in the muscle or nervous system or both. Their relative contributions are unknown as are the influences of psychological factors on both slow and fast speed performance. The performance adaptations consequent to high speed training are not well defined. Empirical observations suggest mixed slow and fast training to be superior. Direct performance related comparisons of slow, fast and mixed training on slow and fast performance are lacking.

Purpose

The purpose of this investigation was to compare muscular force-velocity alterations consequent to slow and fast velocity power training. The psychological component of adaptation (placebo effect) was

elucidated, and thus alterations resulting from actual physiological adaptations were identified. Further attempts were made to distinguish between the possible muscular and neurological components of adaptation accounting for the physiological alterations within the force-velocity relationships. This was attempted by comparing volitional slow velocity training, which produces high muscular tension through the neurological recruitment of many muscle fibers, to a form of training which results in equally high tension, yet does not require the neurological recruitment of muscle fibers, i.e., electrical stimulation.

The common belief that slow velocity training promotes muscular adaptation while fast promotes neurological adaptation, and the two when combined result in the maximal force-velocity alterations, was examined. The specificity of training concept was examined through a range of velocities by comparing the force-velocity alteration observed in the training mode, i.e., two legs contracting simultaneously, to the alterations noted when each leg was tested individually.

CHAPTER 2

METHODOLOGY

Subjects

A population of physically active college age males, who had not been involved in any formal training during the previous two years volunteered to participate in this study. These volunteers were solicited from undergraduate and graduate physical education classes following a detailed explanation of the purpose of, potential benefits from, and risks associated with participation in this study. Those persons who indicated an initial interest met with the investigator to determine their qualifications as potential subjects. Qualified individuals included those not running more than ten miles weekly or lifting weights, and who exhibited less than a 10% difference in the strength of the right and left leg. One subject accepted into the study did not exactly meet this latter qualification. Those who met these qualifications and who expressed continued interest in participation, completed a schedule of those times, in one hour blocks, during which they would be available for training. Subsequently, each individual's free time was matched with that of all other responding individuals to determine common times which could be used to establish training groups. Thirty-four combinations of training groups and matching times were established. Six of these possible combinations were then selected based upon convenience and accessability of the training facilities. Finally, each of the six

groups were randomly assigned to one of the following training regimens: slow isokinetic (SLOW); fast isokinetic (FAST); mixed slow and fast isokinetic (MIXED); electrical stimulation on a Faradic stimulator (STIM); placebo (PLACEBO) and control (CONTROL). The specifics of each training regimen are discussed in a following section. The mean physical characteristics of the groups are presented in Table 1.

All subjects were informed of the potential physical risks involved as a participant in this study. All protocols had been previously approved by the University of Arizona Human Subjects Committee. A consent form detailing the subjects' involvement, was then signed and witnessed.

Isokinetic Equipment and Testing Protocol

A CYBEX II* isokinetic muscle testing system was used to evaluate the subject's muscular strength and power both pre- and post-training. The operational principles of this device have been discussed in detail by Hislop and Perrine (1967). The present system, as pictured in Figure 2, was modified slightly by, (1) mounting the dynamometer head to a concrete wall, and (2) extending the cross bar and supporting it with an additional bearing mounted to the bench. The fastening of the head to the concrete wall reduced the ballistic oscillations which commonly appear on the resulting torque recordings. By extending the cross bar and supporting it with a precisely situated bearing, it became possible to measure true torque at any point along the bar, thus allowing the assessment of either leg, or both legs simultaneously without altering

*Lumex, Inc., 100 Spence St., Bayshore, N. Y.

Table 1. Mean (\pm SE) Physical Characteristics of Groups Pre-Training

Group (n)	Age (yrs)	Height (cm)	Weight (kg)	Mid-thigh Circumference (cm)	Mid-thigh Skinfold (mm)	% Type I	% Type IIa	% Type IIb
SLOW (n=4)	25.1 (\pm 2.3)	177.7 (\pm 5.6)	74.0 (\pm 6.5)	51.4 (\pm 3.0)	12.1 (\pm 2.6)	32.2 (\pm 2.7)	45.9 (\pm 4.8)	21.9 (\pm 3.6)
FAST (n=4)	25.0 (\pm 1.9)	166.2 (\pm 8.1)	64.2 (\pm 3.2)	49.2 (\pm 3.1)	11.3 (\pm 2.2)	36.5 (\pm 2.5)	48.9 (\pm 1.1)	14.6 (\pm 1.6)
MIXED (n=4)	22.3 (\pm 1.6)	178.7 (\pm 4.3)	79.2 (\pm 3.0)	53.1 (\pm 0.7)	10.6 (\pm 0.8)	40.6 (\pm 4.9)	41.5 (\pm 3.2)	17.9 (\pm 4.5)
STIM (n=4)	24.7 (\pm 2.1)	179.7 (\pm 5.6)	82.3 (\pm 3.7)	55.1 (\pm 1.2)	14.6 (\pm 3.9)	37.4 (\pm 6.6)	41.5 (\pm 2.6)	21.2 (\pm 4.0)
PLACEBO (n=5)	21.4 (\pm 3.0)	180.2 (\pm 5.8)	80.0 (\pm 4.2)	52.6 (\pm 1.9)	11.2 (\pm 1.6)	38.5 (\pm 1.6)	39.1 (\pm 1.4)	22.4 (\pm 0.7)
CONTROL (n=6)	26.9 (\pm 3.1)	180.2 (\pm 4.9)	76.3 (\pm 4.7)	52.0 (\pm 2.9)	8.8 (\pm 2.9)	31.8 (\pm 7.9)	51.4 (\pm 5.2)	16.8 (\pm 2.8)

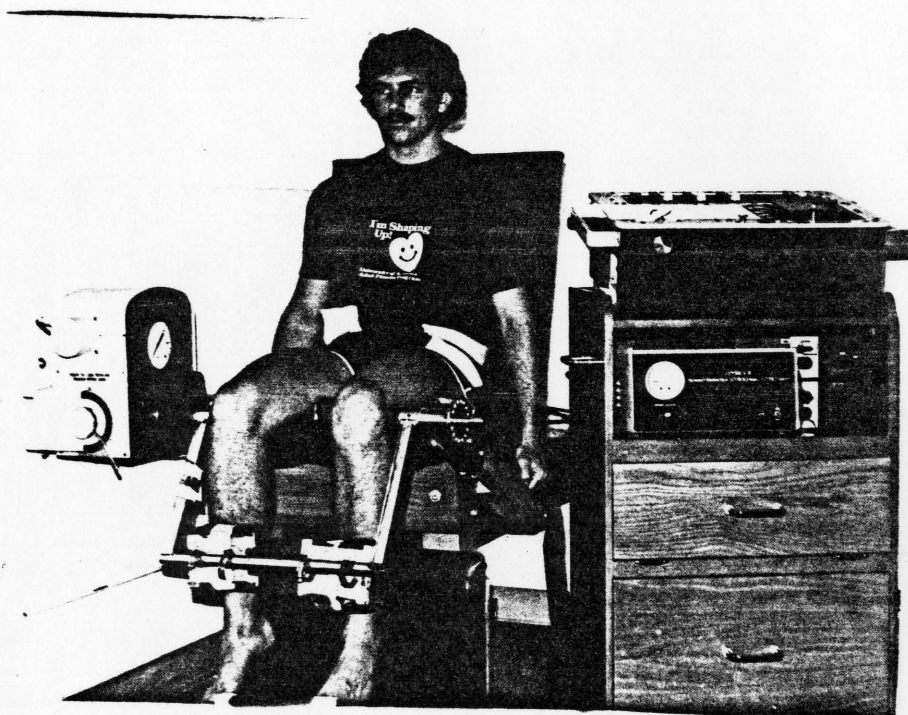


Figure 2. CYBEX II isokinetic testing device

either the position of the equipment or the subject. This was verified by the observation that a given force applied anywhere along the cross bar resulted in identical torque as measured at the dynamometer head.

Torque production was converted into a voltage by the dynamometer which was then displayed as a pen deflection on a Gilson 5 channel polygraph recorder. A sudden burst of torque applied to the dynamometer tends to cause a voltage surge and therefore results in a disproportionately high initial deflection of the recording pen. This overshoot was negated by placing a capacitor in the circuit so as to damp the signal according to CYBEX specifications (damp=2). The dynamometer was calibrated at 126 Nm by applying a known torque. Subsequent torques ranging from 0-400 Nm were applied so as to determine the linearity and accuracy of the instrument. The resulting calibration curve is shown in Appendix A. The reading accuracy was found to be ± 2 Nm, with a total instrument accuracy of ± 4 Nm, which assures an accuracy of 1 to 4% over the ranges tested. The CYBEX II system was calibrated immediately before and after each test conducted during the pre- and post-testing periods.

The subject was positioned in the isokinetic testing apparatus as depicted in Figure 2. Peak muscular torque of the quadriceps was evaluated by aligning the pivot axis of the knee with that of the CYBEX ii arm and subsequently measuring the maximal torque which could be generated at extension velocities of 60, 180 and 300^o/sec. To measure isometric muscular strength, i.e., 0^o/sec, the knee angle was fixed at an angle of 65^o (90^o corresponding to vertical and 0^o to complete extension). Measurements were made on the right and left legs individually as well as on both legs simultaneously. A padded seat belt stabilized

the subject securely in the chair, preventing movement at the hip joint. Additional stabilization was achieved by gripping padded handles on both sides of the chair.

The order of testing was as follows: $60^{\circ}/\text{sec}$, $180^{\circ}/\text{sec}$, $300^{\circ}/\text{sec}$ and isometric. The subject was instructed to become familiar with each speed by taking several submaximal practice trials followed by two practice trials at maximal effort. After a brief rest (30 seconds), during which the subject was encouraged by the investigator to give his best effort, the subject performed two additional trials. If the values for these final two trials did not agree within $\pm 5\%$ a third trial was performed. All tests were conducted by the investigator, who attempted to standardize the encouragement offered each subject. At the conclusion of each testing speed the subject was told he had done well, yet no quantitative reinforcement was provided.

The pre- and post-testing schedule is provided in Appendix B. It should be noted that prior to the beginning of pre-testing, the subjects familiarized themselves with the testing apparatus. Although Johnson and Siegel (1978) have reported a minimal learning influence and high reliability for multiple testing sessions, it was the author's feeling that the individual must psychologically gain confidence or familiarity with the specific testing devices. During this time the subject was allowed to experiment to determine which technique resulted in the best performance. This was particularly important for the isometric contraction, subjects were able to improve isometric strength by as much as 25% simply by shouting. This initial familiarization is critical in a training study during which time the subjects may learn

subtle techniques that may greatly improve performance independent of gains in strength.

The testing schedule (Appendix B) displays the point that the two weeks following the familiarization period were devoted to pre-testing while the two weeks following training were devoted to post-testing. Identical testing protocols were followed pre- and post-testing. The individual's right and left legs were tested on one occasion and both legs were tested simultaneously on another. At least 40 hours of rest was allowed between testing sessions. The entire test battery was then repeated to determine the reliability of test procedures, thus resulting in four pre-training and four post-training testing sessions. Additionally, most testing for any one individual was scheduled at approximately the same time of the day. The best performances on each of the two testing sessions were averaged to derive the respective pre- and post-training performances.

Vertical jumping ability was determined as described by Sargent (1921). Mid-thigh circumference and skinfold, using a Gulick tape and a Harpenden skinfold caliper respectively, were determined in duplicate as described by Behnke and Wilmore (1974).

Training Protocols

All members of each group trained together at their scheduled time period. This allowed a group comradery to develop, and helped ensure good adherence as evidenced by the perfect attendance of all groups. Sessions were supervised by the investigator.

The SLOW, FAST and MIXED groups trained isokinetically on a CYBEX ORTHOTRON*. This device was modified as shown in Figure 3, allowing both legs to be trained simultaneously. Two microswitches, placed 50° apart along the path of the lever arm, allowed the determination of the velocity of contraction with an accuracy of $\pm 5^\circ/\text{sec}$. Subjects were positioned in an identical manner as described in the testing protocol. Initial pilot work, as detailed in Appendix C, determined that approximately twice as much work was performed during a maximal contraction at 60°/sec as compared to a maximal contraction at 300°/sec. Thus, to equate work, the group training at 300°/sec (FAST) would have to perform two repetitions for every repetition performed by the group training at 60°/sec (SLOW). Using the work of Berger (1961, 1962b) isotonic training as a reference, it was decided that the SLOW group would perform five sets per day, with six repetitions per set. This dictated the following protocol for each of the isokinetic training groups.

	<u>Repetitions/set</u>	<u>Sets</u>	<u>Day/week</u>
SLOW	6/60°/sec	5	3
FAST	12/300°/sec	5	3
MIXED	6/60°/sec 12/300°/sec	2 or 3 2 or 3	3

It should be noted that the MIXED group performed half of their work at 60°/sec and the remaining half at 300°/sec. To accomplish this, they alternated between two sets at 60°/sec, and three sets at 300°/sec; and three at 60°/sec and two sets at 300°/sec on successive training days.

*Lumex, Inc., 100 Spence St., Bayshore, N. Y.

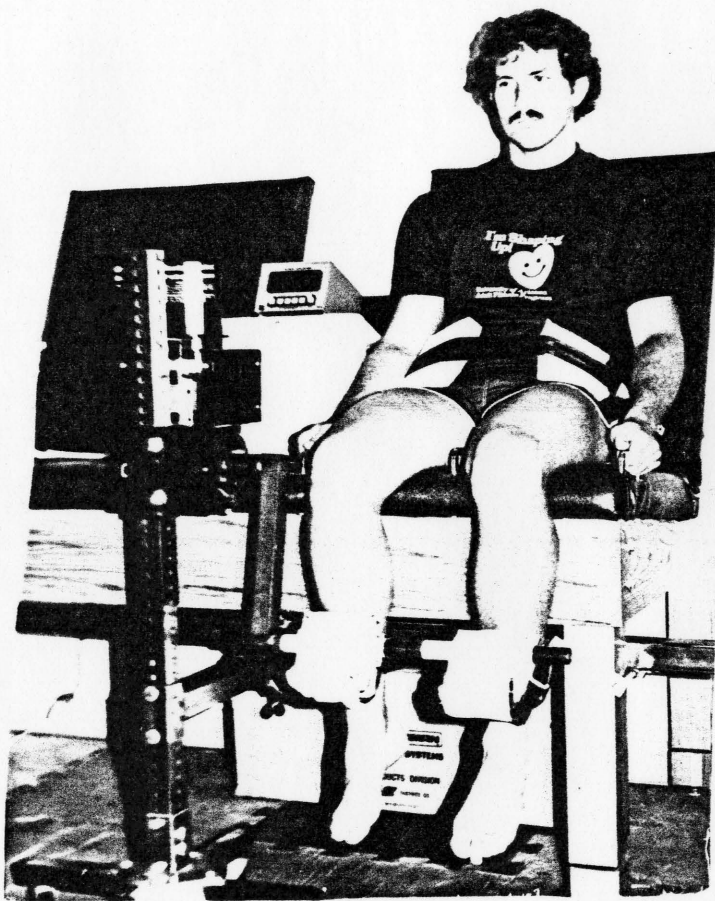


Figure 3. ORTHOTRON training device

This training was conducted three times per week for a total of six weeks.

During the training sessions each repetition was performed maximally. Subjects were instructed to concentrate fully on each contraction, exploding out of the starting position and exerting maximal force throughout the entire range of motion. Flexion occurred passively, followed by a pause to allow the subject to regain full concentration before initiating the next repetition. The subjects were allowed to monitor their performance during training by observing the amount of peak torque they generated, as displayed by the ORTHOTRON. This reinforcement encouraged them to work to their maximum. A five minute rest period intervened between sets.

Two of the groups (STIM and PLACEBO) were trained by use of a Faradic electrical stimulator. This device was developed by Dr. Kotz of the Soviet Union specifically for the muscular training of athletes. The frequency and duty cycle of the stimulator are such that it produces an anesthetizing effect (i.e., proprioception, tactile as well as pain sensation, is reduced with an increasing current of stimulation). Thus, the individual is able to tolerate the electrical current necessary to elicit tensions comparable to those produced during MVC.

Pilot work was conducted to determine the optimal placement of the 4-in Burdock conducting pads. One pad was placed proximal and lateral over the vastus laterals while the other was situated distal and medial over the vastus medialis. A moist cloth, saturated with conducting paste, was placed between the electrode and prepared skin.

The STIM group received current sufficient to result in a near-maximal isometric contraction. Appendix D details the individual's maximal voluntary torque capability as well as the maximal torque elicited through a given electrical current. On the average, the stimulator resulted in a contraction which was 86.5% of MVC. All electrical stimulation was performed at 65° of knee extension, training one leg at a time. The integrated time-tension of the STIM group was designed to be similar to that of the SLOW group. Peak torque corresponded to 79.3 and 86.5 of the % MVC respectively in the SLOW and STIM groups. The SLOW group, in performing six repetitions at 60°/sec through a 90° range of motion, required a total time of nine seconds. Thus, for the STIM group, the current was gradually increased to maximum, held briefly and gradually reduced, with the total duration lasting nine seconds.

Five sets were completed by the STIM group with a one minute rest interval between sets.

The subjects in the PLACEBO group were told that they were being trained on the electrical stimulator. They never came in contact with the STIM group and, thus, never suspected that anyone but themselves was using the stimulator. The placebo group members were prepared for the Faradic stimulator in an identical manner as the STIM group. The only difference was the amount of current applied, and therefore the strength of the contraction. For the placebo treatment to be effective, the group members had to experience a low level stimulus and a contraction sufficient to convince them that they were being trained. The anesthetic tingling sensation of the low level stimulation, and visualization of the quadriceps muscle group contracting spasmodically provided this

reinforcement. The current was set at 16 to 20 milliamps for the PLACEBO group compared to values ranging between 50 and 80 milliamps for the STIM group. The 16 to 20 milliamp range proved to be the threshold of excitability; the actual force produced being less than five percent of MVC and just sufficient to move the lower leg to the isometrically set position of 65° . This treatment proved effective as a placebo in that it provided no apparent physiological stimulus for adaptation, yet was perceived by the subjects as an effective training stimulus.

Histochemistry

The right vastus lateralis muscle was biopsied pre- and post-training, according to the needle technique described by Bergstrom (1962). Samples were aligned under a dissecting microscope to assure cross-sectional slicing, and then mounted in an imbedding matrix (OCT). Sections of ten microns thickness were stained for myofibrillar adenosine triphosphatase (M-ATPase) (Dubowitz and Brooke, 1973; Padykula and Herman, 1955) and nicotine adanine dinucleotide (NAD) (Novikoff, Shin, and Drucker, 1961). Multiple sections stained for M-ATPase were initially pre-incubated at pH values of 4.3, 4.45, 4.50, 4.55 and 4.60 to distinguish between Type I, IIa and IIb fibers. The percentage of the total population represented by each of the various fiber types was determined by counting Type I, IIa and IIb fibers from the M-ATPase stain and Type I and II from the NAD stain. The percentage of Type I fibers, determined from the two stains agreed within $\pm 2\%$. This close agreement provided assurance that Type IIb fibers were not incorrectly identified as Type I.

Statistical Analysis

Mean differences (i.e., post-pre) within groups were tested to determine if they were significantly different from zero through the use of student-t-ratios. Variances were pooled and a population mean square error was determined for each variable.

A one-way analysis of variance or covariance was performed to determine if the observed mean differences were statistically significant between various groups. Initially an analysis of covariance was performed to determine if pre values had a significant regression effect on the observed differences. If the covariate regression proved significant the mean differences adjusted for the covariate factor were compared. If the covariate regression proved not to be significant, the one-way analysis of variance was performed.

Actual mean difference between groups were compared for statistical difference by the Duncan procedure for unequal sample sizes (Winer, 1962). All comparisons were made at $p < .05$.

CHAPTER 3

RESULTS

Learning Prior to Pre-Testing

As mentioned in the previous chapter, a two week period was devoted to familiarizing the subjects with the testing protocol. MVC and MPT/60 were significantly improved in many of the subjects by teaching them how to shout and disinhibit. These improvements ranged from 3-16% of the initial familiarization values. MPT/180 and MPT/300 were found to be more stable and were not significantly influenced by various forms of disinhibition.

Within Group Changes in MVC and MPT

Figures 4 through 9 display the torque-velocity curves of each individual group pre- and post-training for both two legs (A) and the mean of the two single leg determinations (B). The CONTROL group did not vary significantly over the training period in that all post-training MVC and MPT values were within \pm 3% of the pre-training values (Figure 4A and B).

The PLACEBO group significantly improved MVC by 8 and 11% when measured with two legs and one leg respectively. A significant improvement of 5% was also observed in two legged MPT/180 (Figures 5A and B).

The SLOW group, which trained both legs simultaneously at 60°/sec, achieved a significant increase of 23, 32 and 9% in two legged MVC, MPT/160 and MPT/180 respectively (Figure 6A). MPT/300 remained unchanged

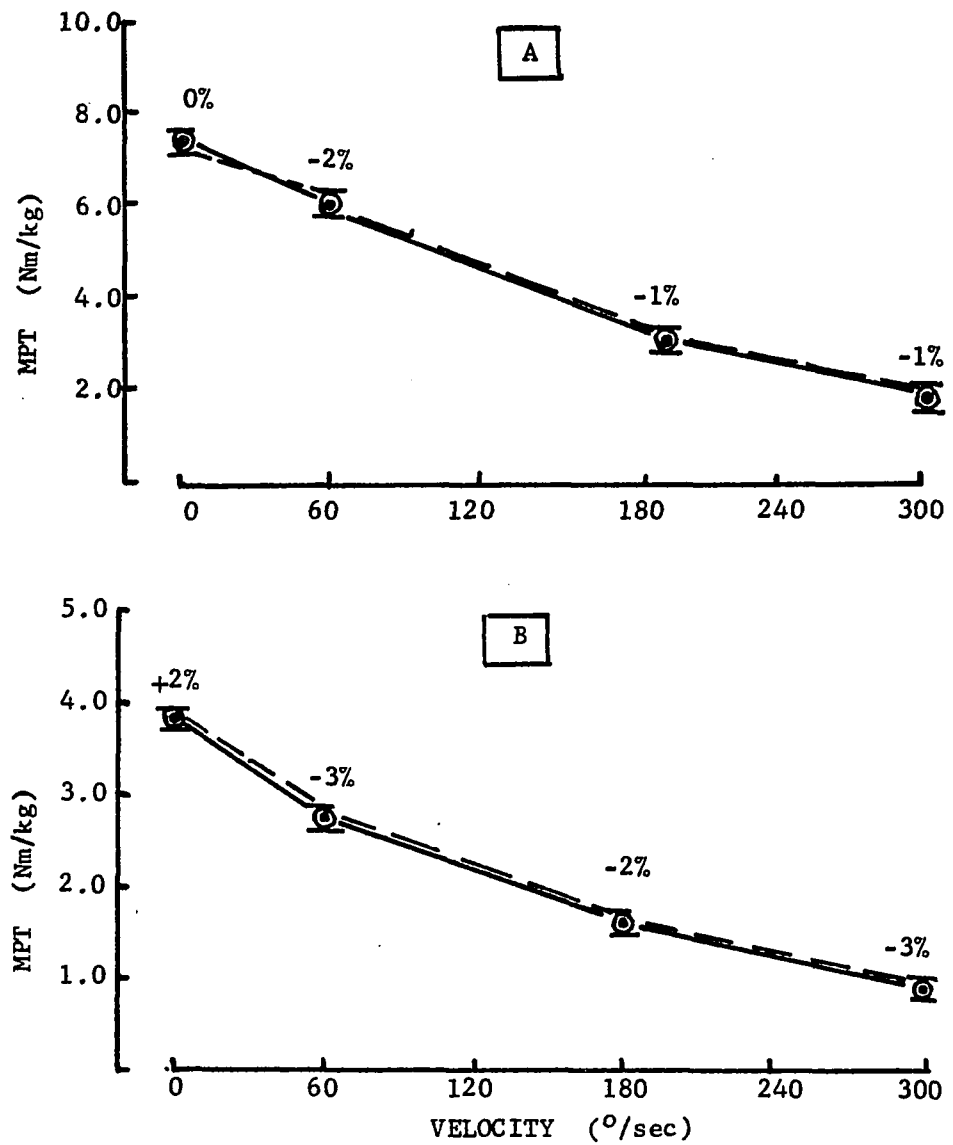


Figure 4. CONTROL group alterations, \pm %, in torque-velocity with two legs simultaneously (A) and one leg individually (B)

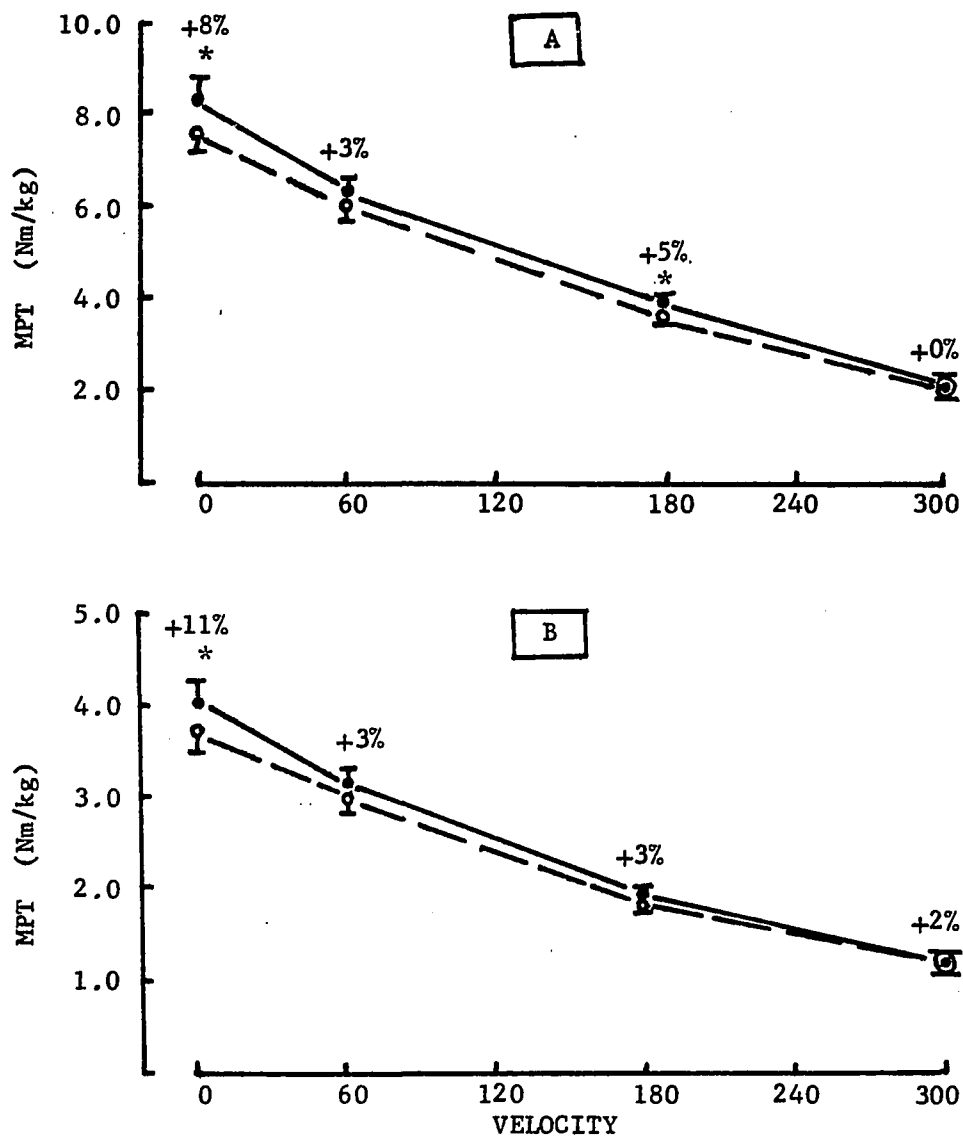


Figure 5. PLACEBO group alterations, \pm %, in torque-velocity with two legs simultaneously (A) and one leg individually (B)

* denotes significance $p < .05$

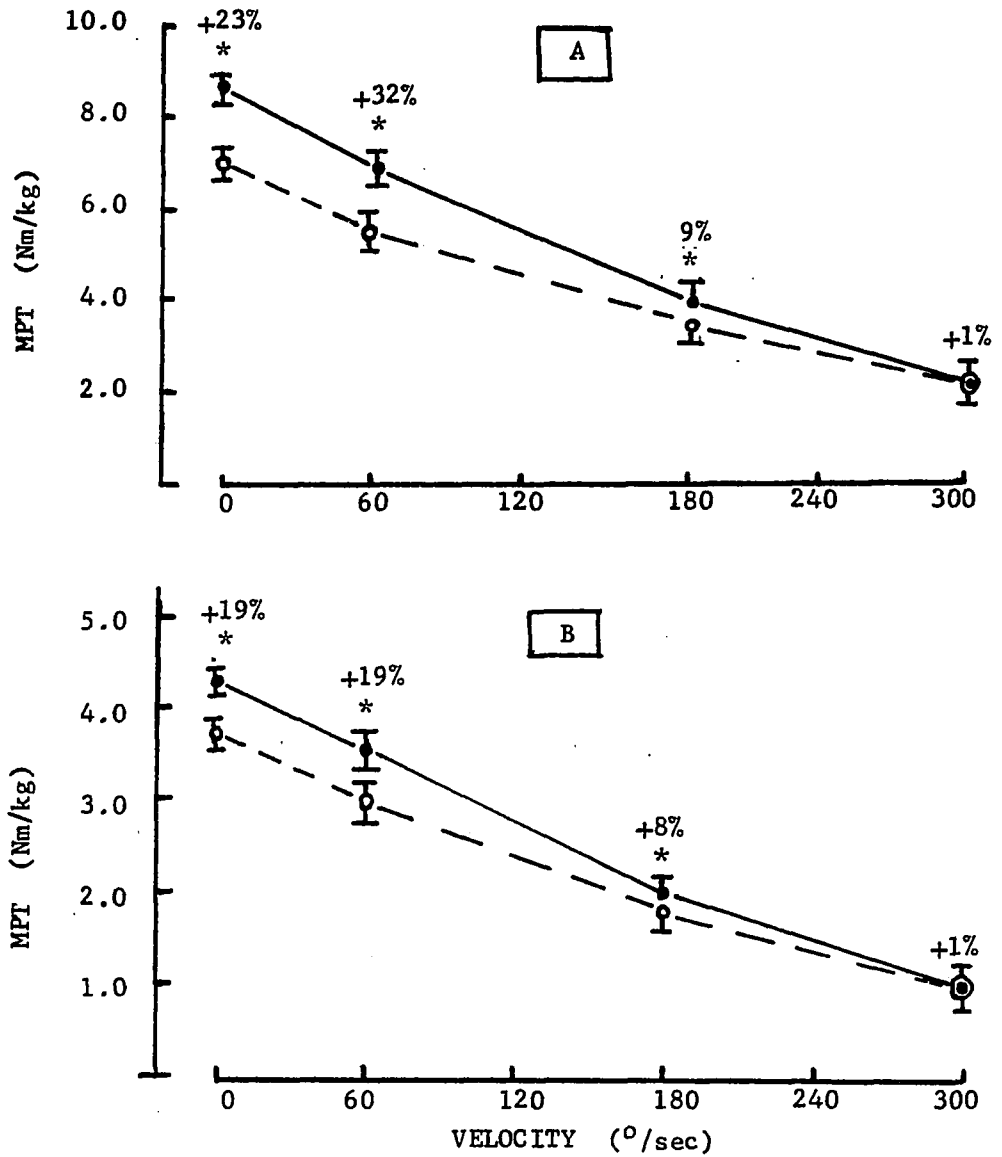


Figure 6. SLOW group alterations, \pm %, in torque-velocity with two legs simultaneously (A) and one leg individually (B)

* denotes significance $p < .05$

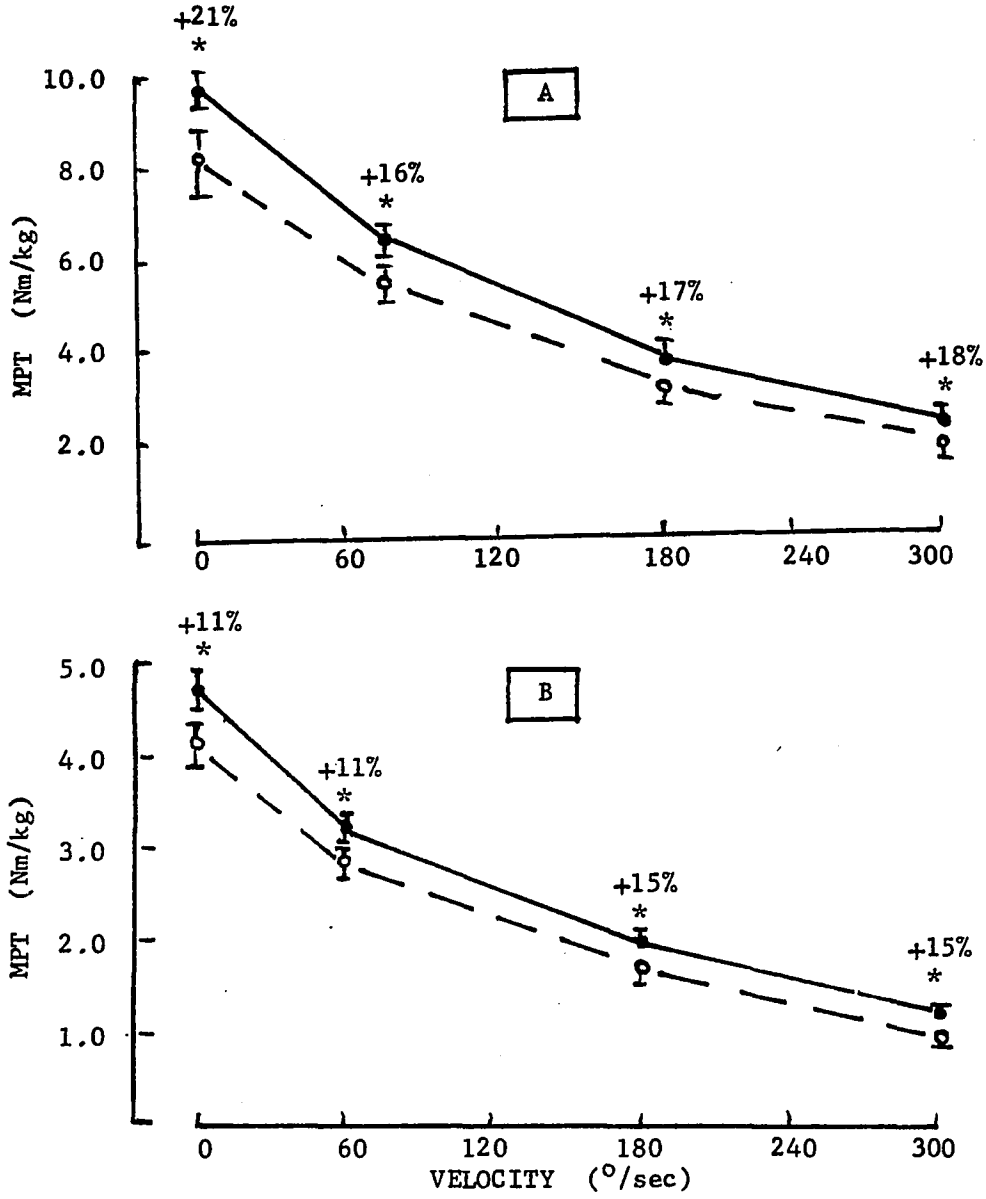


Figure 7. FAST group alterations, \pm %, in torque-velocity with two legs simultaneously (A) and one leg individually (B)

* denotes significance $p < .05$

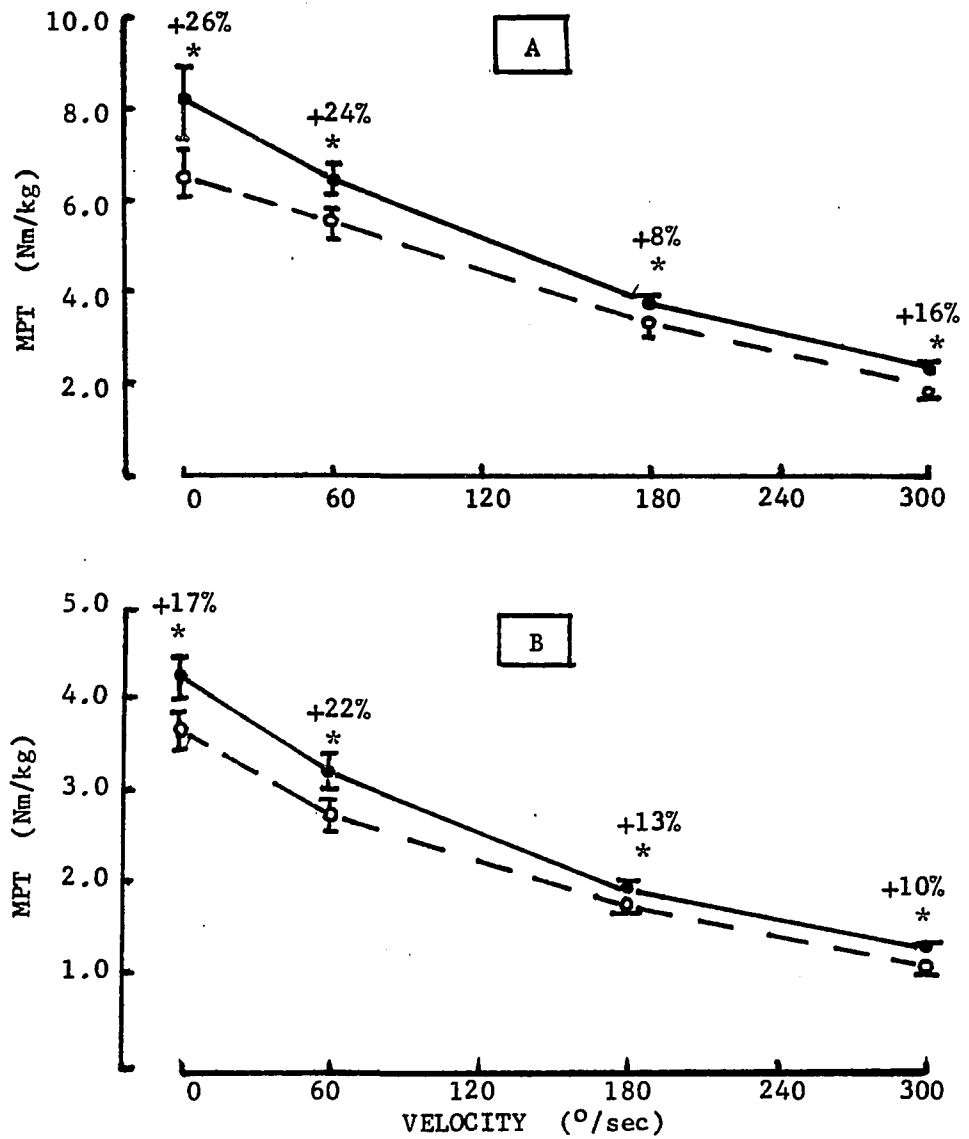


Figure 8. MIXED group alterations, \pm %, in torque-velocity with two legs simultaneously (A) and one leg individually (B)

* denotes significance $p < .05$

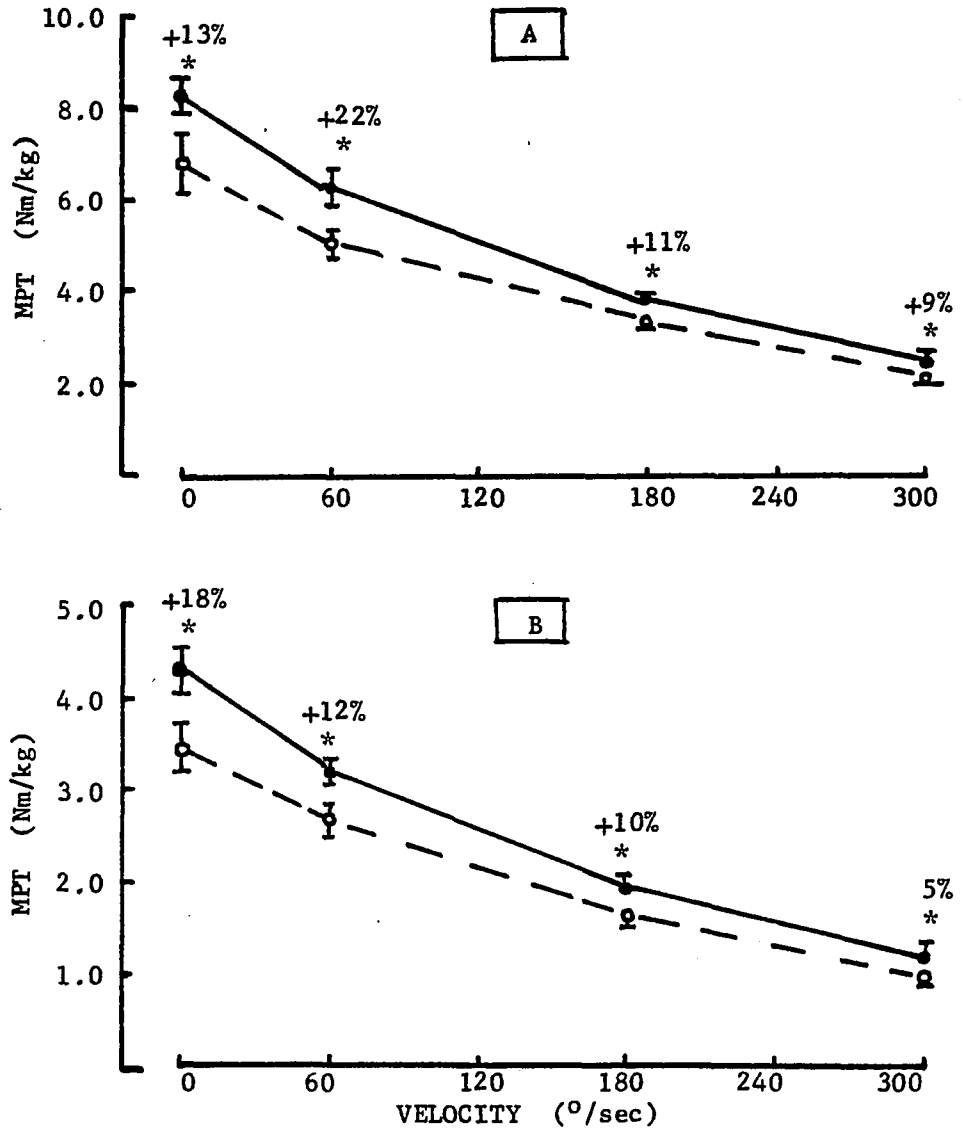


Figure 9. STIM group alterations, \pm %, in torque-velocity with two legs simultaneously (A) and one leg individually (B)

* denotes significance $p < .05$

when tested with both one and two legs. The one legged improvements in MVC, MPT/60 and MPT/180 were significant, yet tended to be of lesser magnitude (Figure 6). The two legged training of this SLOW group resulted in a significantly greater improvement in two legged MVC and MPT/60 as compared to those improvements noted when the legs were tested individually.

The FAST group improved significantly at all speeds during both two and one legged testing. The percentage increase at the various speeds were of comparable magnitude ranging from 16 to 21% with two legs, and 11 to 15% with one leg (Figure 7A and B).

The MIXED group, which trained at both slow and fast speeds, also achieved significant improvements at all speeds for testing on both one and two legs. The percentage increases ranged from 8 to 26% (Figure 8A and B).

The STIM group, which trained with one legged bouts of Faradic stimulation with the leg set isometrically, also achieved significant improvements at all speeds of testing for both one and two legs. Percentage increases ranged from 5 to 22%, as displayed in Figures 9A and B. The STIM training protocol was designed to provide similar muscular tensions to those encountered in the SLOW group. As mentioned, the SLOW groups' two legged training resulted in a significantly greater improvement in two legged MVC and MPT/60 as compared to the corresponding measurements on one leg at a time. The only other significant difference between the increases noted in one and two legged testing occurred in the STIM group. Their improvement of 18% in one legged MVC was significantly

greater than the 13% increase observed when the two legs were tested simultaneously.

Between Group Comparison of
Changes in MVC and MPT

Figures 10 through 13 compare the group changes observed in MVC, MPT/60, MPT/180 and MPT/300 respectively. Two legged and one legged comparisons were very similar so only the two legs are reported. The groups are ordered from highest to lowest with respect to their mean changes (Nm/kg). Groups that did not differ significantly in mean changes form a subset as depicted by the lower brackets in Figures 10 through 13.

All groups improved MVC significantly when compared to the control group (Figure 10). No differences in MVC improvement were observed, however, when comparing the remaining treatments, MVC was the only performance measure which showed a significant covariate regression effect regarding initial values. That is, the stronger individuals tended to improve less than did weaker individuals, both within and between groups.

Figure 11 compares the groups in changes observed at MTP/60. All groups except PLACEBO differed from CONTROL. The groups trained with high muscular tension (SLOW, MIXED, STIM) improved significantly more than did the PLACEBO. The improvements noted within the FAST group, however, could not be distinguished from those of the PLACEBO group, although they were similar to the changes observed in the high tension groups. These data suggest that SLOW, MIXED and STIM training result in significant improvements in MPT/60 which cannot be attributed to placebo effects (Table 2).

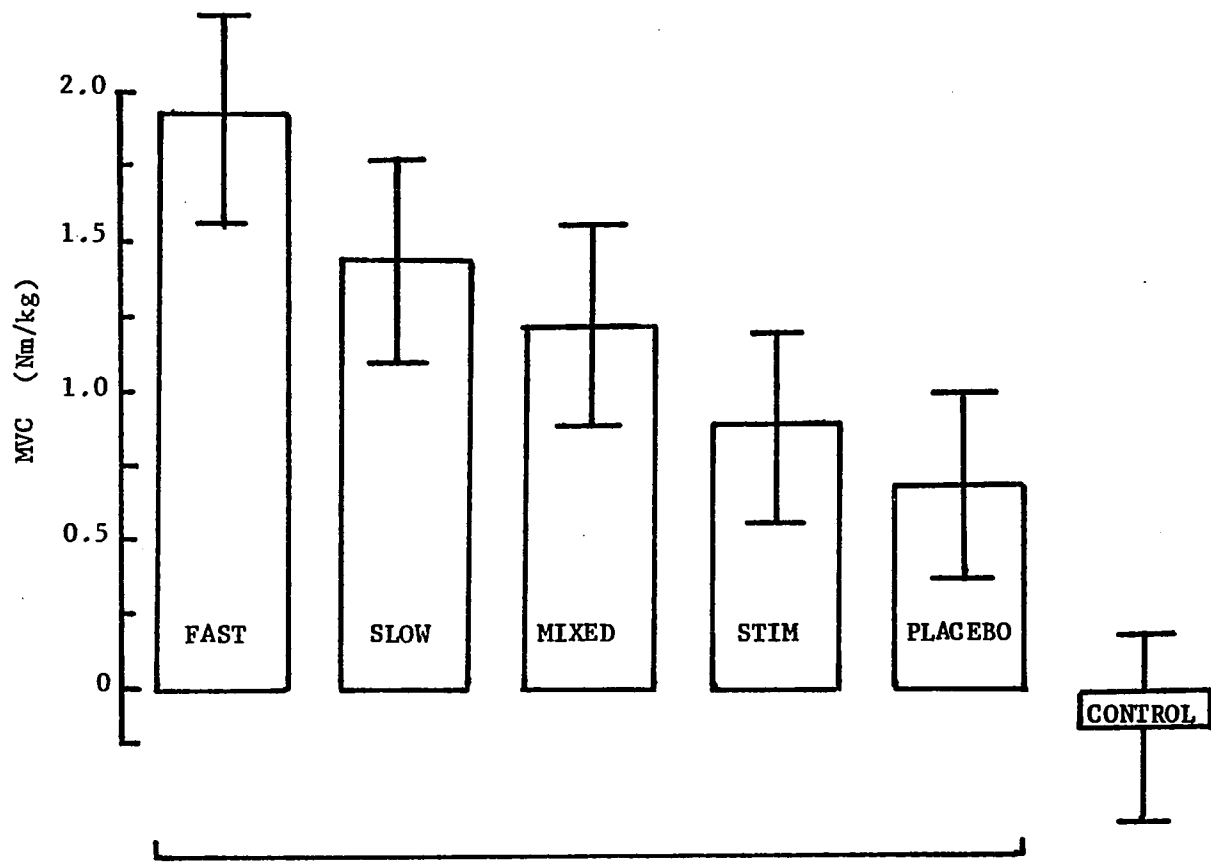


Figure 10. Mean (\pm SE) comparison of MVC changes


Lower bracket  forms subsets, with means not significantly different, $p < .05$



Figure 11. Mean (\pm SE) comparison of MPT/60 changes

Lower bracket — forms subsets with means not significantly different, $p < .05$

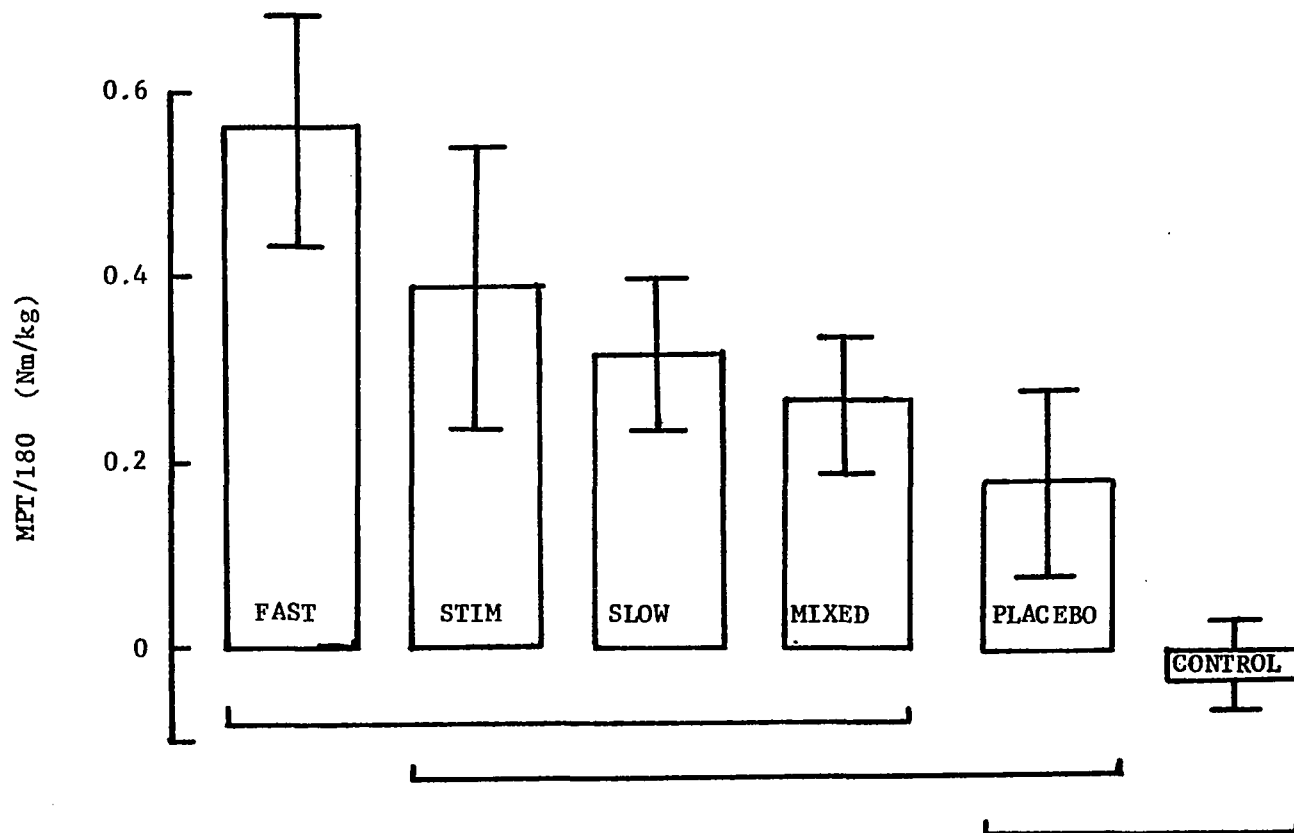


Figure 12. Mean (\pm SE) comparison of MPT/180 changes

Lower bracket
 $p < .05$

forms subsets with means not significantly different,

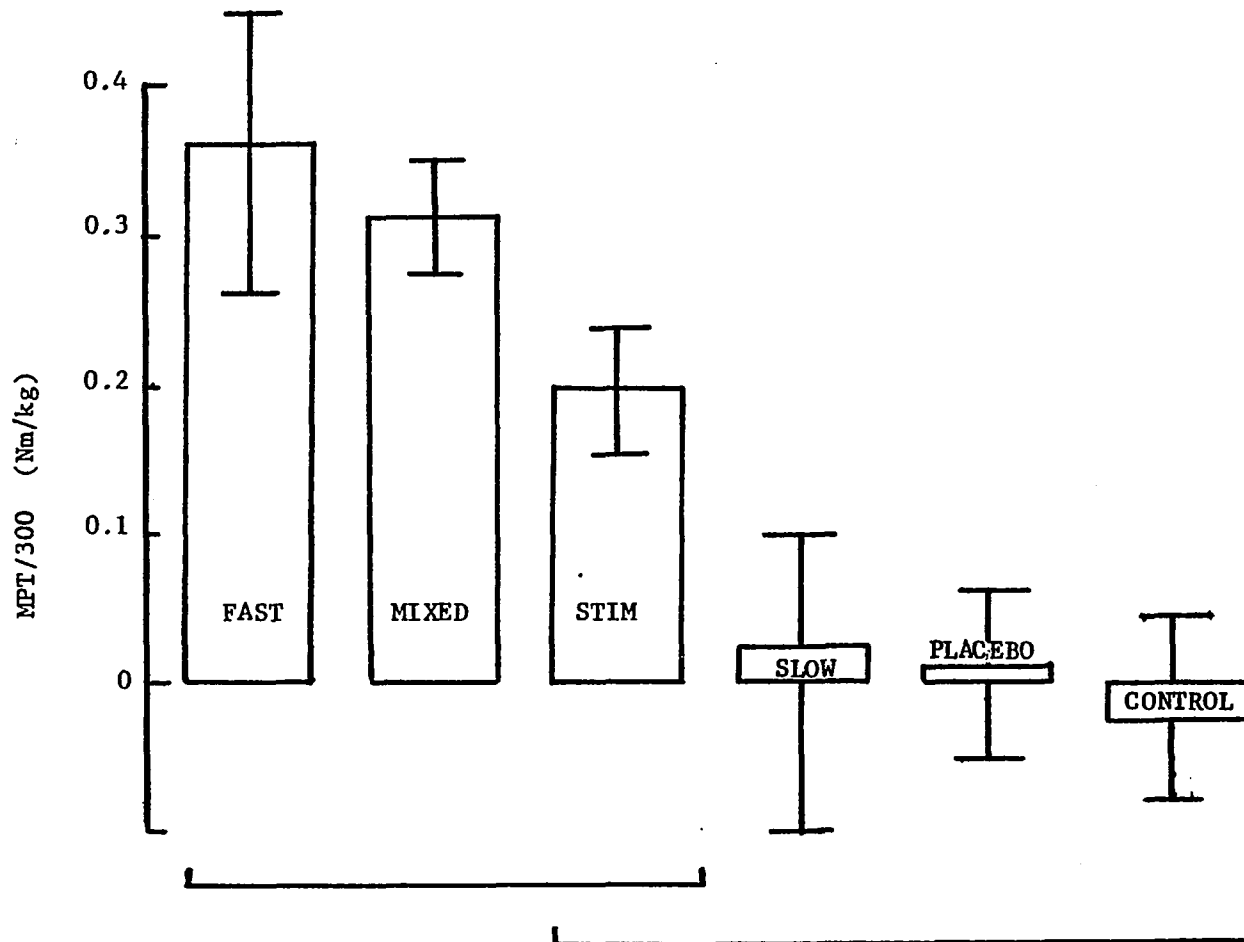


Figure 13. Mean (\pm SE) comparison of MPT/300 changes

Lower bracket forms subsets with means not significantly different, $p < .05$

Table 2. MVC and MPT Improvements Possessing a Significant Physiological Component

	Groups Displaying Improvements Which are Greater Than PLACEBO Effects	Improvements Which Could Not Be Distinguished From PLACEBO
MVC		FAST, SLOW, MIXED, STIM
MPT/60	SLOW, MIXED, STIM	FAST
MPT/180	FAST	STIM, SLOW, MIXED
MPT/300	FAST, MIXED	STIM, SLOW

Figure 12 compares the changes noted at 180°/sec. All groups except PLACEBO differed from CONTROL. The improvement of STIM, SLOW and MIXED, however, could not be distinguished from the PLACEBO improvements. Only the FAST group displayed significantly greater improvements in MPT/180 than could be attributed to placebo effects.

Figure 13 compares the changes noted at 300°/sec. The groups that trained at 300°/sec (FAST, MIXED) showed significantly greater improvements than did the CONTROL. The FAST and MIXED groups also distinguished themselves from the PLACEBO group. The improvement of the STIM group, although similar to those of FAST and MIXED groups, was not shown to be significantly different from SLOW, PLACEBO, or CONTROL. A statistical power analysis taking into account the mean differences and variances indicate that a sample population of seven would have been required to establish a difference between STIM and SLOW or PLACEBO, if indeed a difference does exist (Cohen, 1954). Therefore, the FAST and MIXED groups showed significant improvements in MPT/300, more than could be attributed to placebo effects.

Table 2 summarizes the observed improvements in MVC and MPT, distinguishing the groups that differed from PLACEBO from those that did not differ from PLACEBO.

Vertical Jump

Table 3 displays the groups mean vertical jump pre- and post-training as well as the observed change. The SLOW group demonstrated a significant increase of 1.15 inches. Surprisingly, the PLACEBO group also displayed a 1.75 inch significant increase in vertical jump.

Table 3. Vertical Jump Pre- and Post-Training

	Pre (in)	Post (in)	(in)	%
SLOW	21.17 (±0.77)	23.32 (±1.11)	+ 1.15* (±0.62)	+ 5.4%*
FAST	19.30 (±0.78)	19.92 (±1.07)	+ 0.62 (±0.47)	+ 3.2%
MIXED	22.35 (±0.96)	22.92 (±0.89)	+ 0.57 (±0.50)	+ 2.5%
STIM	20.52 (±1.85)	21.37 (±1.31)	+ ±0.85 (±0.61)	+ 4.1%
PLACEBO	19.75 (±0.76)	21.50 (±0.85)	+ 1.75* (±0.66)	+ 8.9%*
CONTROL	21.50 (±0.50)	20.86 (±0.82)	- 0.64 (±0.39)	- 3.0%

* Denotes statistical significance $p < .05$

Morphological Adaptations to Training

Table 4 displays the morphological adaptations to training. The body weights did not display any significant changes. External signs of muscular hypertrophy were not found as evidenced by the statistically unchanged mid-thigh circumference measures. There was a tendency for the training groups to reduce the amount of sub-cutaneous fat over the quadriceps muscle group. The SLOW group was the only group, however, to show a significant decrease (i.e., 2.86 mm or 23%).

The percentages of Type I, IIa and IIb fibers were not altered within the CONTROL, PLACEBO, SLOW or STIM groups (Table 4). The groups which performed fast contractions in training, i.e., FAST and MIXED, did show some significant alterations in percent composition. These changes did not follow a logical pattern. In the FAST group there was an observed increase in % Type I and decrease in % Type IIa. The MIXED group displayed a reduction in the % Type IIb.

Table 4. Mean (\pm SE_D) Morphological Adaptations to Training

	Weight (kg)	Mid-thigh Circumference (cm)	Mid-thigh Skinfold (mm)	% Type I	% Type IIa	% Type IIb
SLOW	-0.30 (\pm .27)	+ .187 (\pm .546)	- 2.86* (\pm 1.53)	- 3.5 (\pm 6.3)	+ 3.7 (\pm 5.1)	- 0.2 (\pm 5.9)
FAST	-0.52 (\pm .25)	+ .6625 (\pm .513)	- 0.57 (\pm 0.38)	+ 5.2* (\pm 1.8)	- 7.8* (\pm 1.6)	+ 2.6 (\pm 1.2)
MIXED	-0.80 (\pm .41)	+ .3625 (.2258)	- 0.12 (\pm 0.15)	+ 3.2 (\pm 1.8)	+ 0.4 (\pm 1.9)	- 3.6* (\pm 1.2)
STIM	-0.95 (\pm 1.36)	+ .220 (\pm .540)	- 1.06 (\pm 0.81)	- 1.9 (\pm 1.6)	+ 4.7 (\pm 4.2)	+ 2.8 (\pm 3.1)
PLACEBO	+0.30 (\pm .39)	+ .590 (\pm .351)	- 0.30 (\pm 0.671)	- 3.1 (\pm 2.5)	+ 0.5 (\pm 2.7)	+ 3.6 (\pm 2.1)
CONTROL	+2.1* (\pm 1.37)	+ 1.02 (.340)	+ 1.06 (\pm 1.42)	+ 7.2 (\pm 5.4)	- 6.4 (\pm 4.3)	- 0.8 (\pm 1.2)

* Denotes significant change $p < .05$

CHAPTER 4

DISCUSSION

The most effective training regimens for improving MVC and MPT at the slow velocity end of the force-velocity relationship (Figure 1), have been elucidated through research spanning the previous two decades (Clarke, 1978). Athletic events, requiring bursts of maximal muscular exertion however, are typically performed at relatively high velocities. This investigation has attempted to determine how slow and fast velocities of training alter the force-velocity relationship of muscle, which will allow delineation of the most effective training regimen for improving slow and fast velocity MPT.

In dealing with the above question, it is first necessary to exercise appropriate controls. Physiological research which measures alterations in maximal performance, and assumes these alterations to result from an imposed form of physical training, must contend with psychological factors which may alter performance irrespective of physiologic adaptations. This investigation has observed a significant placebo effect which can account for a significant portion of the observed improvements in MVC, MPT/180 and vertical jump (Figure 5). In fact, the placebo effect was so large at MVC, i.e., 8% two legs and + 11% one leg (Figure 5), and this isometric measure so variable (both within and between subjects), that no training group showed improvements

in MVC greater than that which could be accounted for by the placebo effect (Figure 10).

These data agree with the observations of Ikai and Steinhaus (1961) who noted that the suggestion of improved strength during hypnosis was capable of increasing MVC by as much as 26%. Therefore, the many investigations which have reported improvements in MVC and vertical jump, consequent to training, must be carefully interpreted regarding the actual physiological basis for such improvement. This does not suggest that previously observed improvements were all physiological in nature, but merely indicate a significant portion may have been the result of placebo effects.

The physiological mechanism by which the placebo treatment improved MVC most probably involves the nervous system. It is possible that more motor units are recruited, or that contraction becomes more synchronous, or both. This placebo effect was not found to improve MPT/300. Observations made during the familiarization period of this investigation suggest that shouting improves MVC. Shouting is presumed to disinhibit the nervous system, i.e., to reduce inhibitory postsynaptic potentials within the cell body of the motor neuron (Ikai and Steinhaus, 1961). Shouting had no effect on MPT/300. The neurological mechanisms of psychologically-induced increases in MVC may not be effective at MPT/300 because of the fast nature of the movement. This results in a relatively short time for the specific neurologic mechanisms to manifest itself in an augmented MPT/300.

The slow group displayed large significant improvements in MVC (+ 23%) and MPT/60 (+ 32%), a modest yet significant improvement in

MPT/180 (+ 9%), and no change in MPT/300 (Figure 6A). These observations are similar to those of Thortensson, Karlsson, et al. (1976) who noted slow isotonic weight training to improve MVC by 13% and MPT/180 by 10% (Thortensson, 1977). However, only the improvement of MPT/60 was significantly different from PLACEBO (Table 2) and thus can be considered to contain a significant physiological component. These data suggest, although they provide no conclusive evidence, that part of the physiological adaptation was neurological in nature. This suggestion is based upon the observed significantly greater improvement in MPT/60 when testing mimicked the training mode. That is, the two legged MPT/60 increase of 31% was significantly greater than the observed improvement of + 19% at MPT/60 when each leg was tested individually. If the physiological basis for improvement was solely muscular hypertrophy, the two legged and sum of the one legged improvements should not differ.

With SLOW training, it generally appears that improvements diminish as testing conditions, i.e., velocity and the number of legs used, move farther away from the training conditions. The specificity of training, or familiarity in testing, has been classically observed as a consequence of isometric and isotonic training (Boileau, 1962; Belka, 1968). It is possible that training provides specific afferent proprioceptive information to the central nervous system, which acts as a stimulus for promoting adaptation through neurological pathways. Yet, for these adaptations to manifest themselves, and thus for muscular output to improve, the proper proprioceptive feedback must be provided, i.e., training velocity, joint angle, number of legs used.

Milner-Brown et al. (1975) provide evidence that one neurological mechanism for improved MVC is increased Type I muscle fiber synchronization. If improved MPT were a result of more synchronous Type I muscle fiber action, the magnitude of improvement in MPT would be expected to decrease with increases in velocity. This is the result of the relatively long time it takes, i.e., 100 msec, for Type I fibers to develop peak tension (Buchthal and Schmalbruch, 1970), and thus, their contribution to total tension would become increasingly less as velocity increases and time for contraction decreases (Coyle et al., 1979). Therefore, increased Type I synchronization would not be expected to increase MPT/300, which is reached in 80 msec.

The evidence relating improved MPT/60 to possible muscular adaptations is contradictory. The SLOW group did not show any significant changes in the percentage of Types I, IIa, or IIb muscle fibers. If the improved MPT/300 were consequent to fiber hypertrophy, it would appear that hypertrophy would be selective to Type I fibers. Type II hypertrophy would most likely manifest itself as improved MPT/300, unless their action is suppressed by some neurological mechanism. Selective Type I growth contradicts previous observations which suggest high tension training, although recruiting both fiber types results in selective hypertrophy of the Type II muscle fibers (Edgerton, 1976; Gollnick et al., 1972; Prince et al., 1976).

The inclusion of the STIM group provided an additional attempt to factor out the neurological from the muscular adaptations. The STIM group trained with the same muscular tension as did the SLOW group, and thus received similar total stimuli for hypertrophy (Goldberg et al.,

1975). Yet, their muscles were activated electrically, thus disassociating motor unit recruitment and synchronization, and the subsequent adaptations. If, however, the improvement of motor unit recruitment or synchronization does not require direct practice, but relies on proprioceptive feedback, then the STIM group may have actually received stimuli from the electrical stimulation of afferent nerves.

If the assumption is made that no neurological stimuli were received, however, the differences between the improvement of the SLOW and STIM groups in MPT might indicate the degree of involvement of the nervous system in MPT adaptations. The improvements of the STIM group in MVC, MPT/60 and MPT/180 were similar to those of the SLOW group (Figures 11, 12 and 13). At MPT/300, the STIM group displayed a significant increase of 9% (Figure 9), yet this was not significantly different from the very small changes noted among the SLOW and PLACEBO groups (Figure 13). Therefore, the role of the nervous system in MPT could not be distinguished from the combined psychological, muscular and neurological effects of SLOW training. As mentioned in the Results (Chapter 3), a larger sample population would be needed to find differences if they do indeed exist. Nonetheless, the STIM treatment was as effective as voluntary training in improving MPT, and may prove to be valuable clinically for muscular rehabilitation.

In summary, SLOW training improved MVC, MPT/60 and MPT/180. Only the improvements in MPT/60 demonstrated significant physiological component of adaptation. This physiological adaptation appears to be partly neurological as evidenced by the greater improvement in MPT/60 when testing specifically mimicked training.

The FAST group displayed significant and uniform increases of 16 to 21% at each point along the force-velocity curve (Figure 7A). The increases in MVC and MPT/60, however, could not be separated from the improvement exhibited by the PLACEBO group and therefore only the MPT/180 and MPT/300 were considered to have a significant physiological basis (Table 2). Two legged MPT improvements were similar to the one legged improvements (Figure 7A and B), which suggests that the specificity of training concept may not apply when high training velocities are employed. If the specificity of training results from Type I synchronization as previously discussed, it would not manifest itself during contractions at high velocities, during which the contribution of Type I fibers is relatively small. It should be noted that these discussed mechanisms are only theoretical possibilities based upon observed improvements in MPT.

The increased MPT/180 and MPT/300 could result from muscular hypertrophy. Although the tension during MPT/300 is only 30% of MVC (Figure 4), it is more specific to the Type II fibers (Lesmes et al., 1979; Coyle et al., 1979), which hypertrophy more readily than Type I fibers (Edgerton, 1976). Hypertrophy of Type II fibers could contribute to the uniform increases in MPT/180 and MPT/300 during one and two legged conditions, since Type II fibers are recruited and contribute to MPT at all velocities.

Fast training (FAST and MIXED) resulted in significant alterations in muscle fiber composition. These alterations, however, did not appear advantageous for increasing MPT/fast.

Whatever the physiological mechanism accounting for the improvements from fast speed training, it appears to improve MPT at all velocities slower than those experienced during training. In agreement with this, Lesmes et al. (1978) observed MPT/180 training to improve MVC, MPT/60, MPT/120 and MPT/180, but not MPT/240 and MPT/300.

In summary, fast speed training significantly improves MPT at the training velocity and at slower velocities. Only the MPT/180 and MPT/300 improvements contained a significant physiological component of adaptation. Possible adaptations include either or both an improved recruitment or synchronization of Type II fibers and Type II fiber hypertrophy. No evidence for specificity of training was found subsequent to FAST speed training, possibly because the mechanisms involved do not contribute to MPT/fast, i.e., Type I muscle fiber synchronization.

The MIXED group was included to examine the interaction of slow and fast velocity training on the force-velocity relationship. It was hypothesized that if slow velocity training specifically promoted muscular hypertrophy while fast velocity training promotes neurological adaptation, i.e., improved recruitment and synchronization, then when the two were mixed MPT improvements would be greater than those achieved with either SLOW or FAST training. MPT/60 and MPT/300 improvements in the MIXED group was similar to those observed in the SLOW and FAST group respectively, and thus the hypothesized adaptation did not occur (Figures 11 and 13). If slow training does indeed promote neurological adaptations, i.e., Type I synchronization, it would not improve upon MPT/300 (as noted in Figure 6). Thus, the interaction of slow and fast velocity training should not improve MPT/300 to any greater degree than

simple FAST velocity training (Figure 7). The interactive effect of slow and fast velocity training on MPT/60 is difficult to interpret since the MIXED group performed only half the volume of high tension work that was encountered during SLOW training (Figures 6 and 8).

The MIXED group did not demonstrate a significant physiological increase in MPT/180 (Table 2). Either the quantity of fast velocity training was not sufficient to carry over to the slower speeds, or the slow velocity training inhibits faster performance.

In summary, MIXED training was not found to improve MPT/60 or MPT/300 any more than that which can be attributed to the selective SLOW and FAST velocity training. This observation challenges the common belief that slow velocity training hypertrophies muscle while fast velocity training synchronizes its contraction, and when both are performed MPT/fast improves the most.

Collectively, these data provide practical information for recommending velocities of training relative to the velocity of performance. Figure 11 suggests that MPT/slow is most effectively enhanced by placing high tension demands upon the muscle (SLOW, MIXED, STIM). Tension appears critical, whether it be for promoting neurological adaptation or muscular hypertrophy. The training action should also specifically mimic that encountered during performance.

MPT/fast is most effectively enhanced by training at fast velocities. Fast velocity training can significantly improve moderately fast actions, i.e., MPT/180, but it appears that this improvement may be dependent upon the completion of a sufficient quantity of work. MIXED training resulted in an improved MPT/60 and MPT/300, yet it was not more

effective in improving MPT/60 than SLOW velocity training alone, or in improving MPT/300 than FAST velocity training alone. Adaptations appear specific to the muscle groups involved as evidenced by the physiologically insignificant increase in vertical jump among all training regimens.

CHAPTER 5

SUMMARY

Psychological effects, as determined from the PLACEBO group accounted for significant increases in MVC (+8%), MPT/180 (+5%) and vertical jump (+1.75 inches). SLOW training improved MVC (+23%), MPT/60 (+32%) and MPT/180 (+9%). Only the improvements in MPT/60 demonstrated a significant physiological component of adaptation. This physiological adaptation appears to be partly neurological as evidenced by the greater improvement in MPT/60 when testing specifically mimicked training.

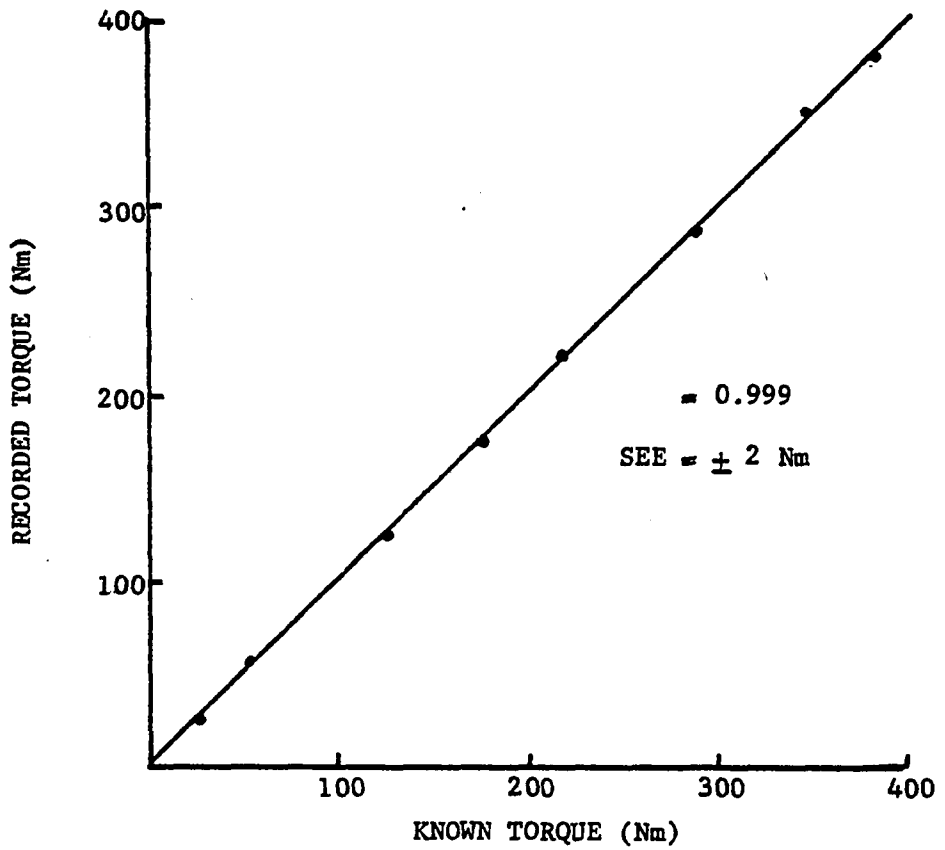
FAST training significantly improved MPT uniformly (16-21%) at the training velocity as well as at slower velocities. Only the MPT/180 and MPT/300 improvements contained a significant physiological component of adaptation. Possible adaptations include either or both improved recruitment or synchronization of Type II fibers, and Type II fiber hypertrophy. No evidence for specificity of training was found subsequent to FAST training.

The mixing of slow and fast velocity training was not found to improve MPT/60 or MPT/300 any more than that which can be attributed to the selective slow and fast velocity training. This observation challenges the common belief that slow velocity training hypertrophies muscle while fast training synchronizes its contraction, and when both are performed MPT/fast improves the most.

High tension producing contractions appear necessary to improve MPT/slow while fast training velocities must be employed to improve MPT/fast. FAST training improves MPT in the mid-velocities more effectively than does SLOW training. The training action should specifically mimic that encountered during performance, particularly if the performance occurs at slow velocities of contraction.

APPENDIX A

CALIBRATION OF CYBEX II DYNAMOMETER



Reading Accuracy = ± 2 Nm
Standard Error of Estimate = ± 2 Nm
Instrument Accuracy = ± 4 Nm

APPENDIX B .

TESTING SCHEDULE PRE AND POST TRAINING

<u>Week A</u>	Pre	Monday	- Orientation to isokinetics and Cybex II
<u>Week H</u>	Post	Wednesday	- One leg familiarization to Cybex II
		Friday	- Two leg familiarization to Cybex II
<u>Week B</u>	Pre	Monday	- Familiarization with isometric cable tension,
<u>Week I</u>	Post		practice vertical jump
		Wednesday	- One leg practice on Cybex II
			- Two leg practice on Cybex II
		Friday	- Anthropometry
<u>Week C</u>	Pre	Monday	- Cybex one leg pre-test 1
<u>Week J</u>	Post	Wednesday	- Cybex two leg pre-test 1
		Friday	- Vertical jump, isometric cable tension
<u>Week D</u>	Pre	Monday	- Cybex one leg pre-test 2
<u>Week K</u>	Post	Wednesday	- Cybex two leg pre-test 2
		Friday	- Vertical jump, isometric cable tension
<u>Week E</u>	Pre	Monday - Friday	- Muscle biopsy
<u>Week L</u>	Post		
<u>Week F</u>	Pre		Spring Break
<u>Week G</u>	Pre		Begin Training

APPENDIX C

DETERMINATION OF WORK PERFORMED AT 60 AND 300°/SEC

By physical definition, Work = Force x Distance. In angular terms Work = Torque (Γ) x Angular Distance (Θ). Thus to determine the work (joules) performed during a maximal isokinetic knee extension one must integrate the torque reading \int (nm) and multiply this by the angular distance Θ (rad) over which it is exerted. Since the CYBEX II system only measures torque once the desired angular velocity is reached, the work done in accelerating the lower leg must also be considered.

A pilot study was conducted on twelve physical education majors to quantify the work performed during a single maximal knee extension at velocities of 60°/sec (1.05 rad/sec) and 300°/sec (5.24 rad/sec). Measurements included Θ to constant velocity, $\int \Gamma$ from constant velocity to complete knee extension, and thus Θ over which $\int \Gamma$ was exerted.

$\int \Gamma$ was derived by planimetry, measuring the area under the torque curve and comparing it to a known area (or quantity of work). The individual amounts of work performed were as follows:

Subject (number)	Work at 60°/sec (joules)	Work at 300°/sec (joules)	Ratio($\frac{\text{Work at 60°/sec}}{\text{Work at 300°/sec}}$)
1	137.5	74.8	1.83
2	115.0	58.1	1.98
3	153.8	91.4	1.68
4	218.6	124.6	1.75
5	178.1	83.1	2.14
6	127.9	62.3	2.05
7	115.0	49.9	2.35
8	121.0	62.3	1.94
9	176.5	83.1	2.12
10	153.0	78.9	1.94
11	184.6	95.6	1.92
12	145.8	75.0	1.93
\bar{X}	152.1	78.2	1.97

Work must also be performed in moving the lower leg to the angle where constant velocity is reached and thus resistance is encountered. This angular distance averaged .053 and .26 radians respectively at 60 and 300°/sec.

The mean torque required to move the lower leg was derived based upon the following:

$$\begin{aligned} \text{Torque} &= \text{Mass Lower Leg} \times \text{Distance (from pivot to center of gravity)} \\ \text{Torque} &= 54.9 \text{ newtons} \times 0.33 \text{ meters} \\ \text{Torque} &= 18.12 \text{ newton-meters} \end{aligned}$$

(The mass and center of gravity of the lower leg were estimated using the equations derived by Katch and Katch, 1974).

Thus:

	(to constant velocity)	(nm)	Work (joules)
60°/sec	.053	18.1	.96
300°/sec	.26	18.1	4.70

Therefore the total amounts of work performed are:

$$\begin{array}{rclcl} 60^\circ/\text{sec} & 155.0 \text{ joules} & + & 0.96 \text{ joules} & = & 156 \text{ joules} \\ 300^\circ/\text{sec} & 78.2 \text{ joules} & + & 4.70 \text{ joules} & = & 83 \text{ joules} \\ \text{Ratio} & = & & & & 1.88 \end{array}$$

Accordingly, 6.0 maximal repetitions at $60^\circ/\text{sec}$ and 11.3 repetitions at $300^\circ/\text{sec}$ are equal in work output.

APPENDIX D

TORQUE GENERATED THROUGH ELECTRICAL
STIMULATION AND MEAN % MVC
PRODUCED DURING TRAINING

Subject	#	MVC isometric (Nm)	Electrical Stimulation (Nm)	Current (ma)	% Electrical MVC
STIM	#1	388	377	60	97.2
STIM	#2*	289	296	50	102.4
STIM	#3	308	277	70	90.0
STIM	#4	351	304	70	86.6

<u>\bar{X} % MVC</u>		
STIM #1	=	87.0%
STIM #2	=	86.0%
STIM #3	=	87.5%
STIM #4	=	85.5%
\bar{X}	=	86.5%

* Individual right and left legs very different

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