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EFFECT OF ISOKINETIC TRAINING ON FORCE-VELOCITY RELATIONSHIP AND MAXIMAL POWER OF THE CONTRALATERAL FOREARM FLEXORS

by

(C) WILLIAM F. LUKE

A THESIS

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled EFFECT OF ISOKINETIC TRAINING ON FORCE-VELOCITY RELATIONSHIP AND MAXIMAL POWER OF THE CONTRALATERAL FOREARM FLEXORS submitted by WILLIAM F. LUKE in partial fulfilment of the requirements for the degree of MASTER OF SCIENCE in PHYSICAL EDUCATION.

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ABSTRACT

The purpose of this study was to investigate the effects of ipsilateral isokinetic training on the force-velocity-power curves of the contralateral forearm flexors.

Forty-two female volunteers from the University of Alberta underwent a pre test period measuring forces exerted at 15, 25, 34, 45 and 50 RPM's, maximum isometric force at 100, 120, 140 and 160 degrees from horizontal, maximum mechanical power output, and force exerted at peak power. From the pre test forces exerted at peak power, subjects were grouped as High force and Low force. Within each group of High and Low force, subjects were assigned to a group training at 30% of maximal isometric force, 60% of maximal isometric force or a control group which received no training. An isokinetic ipsilateral training period was undertaken for a five week period and immediately following a post test period was conducted with duplicate measures as pre test procedure.

Three-way analysis of variance showed significant pre test to post test differences for maximum isometric force, maximum mechanical power and force-velocity relationships at the five pre set velocities. Further significance with force exerted at peak power was not found. Between and within group significance was also not established.

The results of this study indicate that transfer of training from ipsilateral forearm flexors to contralateral forearm flexors was produced following the five week isokinetic training period.

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W.F.L.

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CHAPTER I

STATEMENT OF THE PROBLEM

Introduction

The force-velocity relationship has revealed one of the most important dynamic properties of contracting muscle. When a muscle or muscle group is made to perform a series of single maximal voluntary contractions against a series of increasing loads, the maximal force exerted increases while the maximal velocity of contraction decreases (42). The converse relationship is also true. When the load on the muscle is decreased, the maximal force exerted decreases while the maximal velocity of contraction increases.

Hill (16) as early as 1922 stated, from evidence derived in his research on human arm movements, that the reason for the decrease in maximal exerted force as the velocity of contraction increased was that more energy was being used to overcome the increased viscosity of the muscles at the higher velocities of contraction. Many researchers investigated the force-velocity relationship along the lines of viscosity (8, 10, 11, 15) but it was not until Fenn and Marsh (7) concluded that the inverse relationship between the maximal exerted force and the maximal velocity of contraction was exponential rather than linear, was viscosity eliminated as being solely responsible. Hill (15) reaffirmed this conclusion and produced a characteristic equation to describe the hyperbolic nature of the force-velocity relationship of contracting muscle.

It is now believed that the diminution of force as velocity of contraction is allowed to increase is related to a property of the cross-bridges of the muscle myofilaments. As the actin filaments are allowed to move faster they are less capable of making the cross-bridge connections with the globular heads of the heavy meromyosin molecules which are presumed to be the sites of force generation in muscular contraction (15).

Recently, research has indicated that force-velocity curves for intact human muscle can be displaced to the right which results in an improvement in maximal mechanical power output (mmpo) (24). Presumably, interindividual variation in performance is reflected by existing differences in the relative position of the force-velocity curve and maximal mechanical power. Consequently, there are strong implications for the study of the force-velocity relationship and maximal mechanical power in the area of physical education.

The aspect of bilateral training derived from unilateral exercise has been researched as far back as 1898 when Scripture, as cited (32), found that the contralateral arm significantly increased its physical performance after isotonic training trials on the ipsilateral arm. There has been very little quality research done pertaining to transfer of training and its immediate effects on the alteration of the force-velocity curve and maximal mechanical power as demonstrated by Kawahatsu (21) as being displaced to the right in the ipsilateral arm under training trials. The question still has not been unequivocally answered as to how or why such transfer of training results, if in fact it does result. Nielson (30) stated:

"The planning which precedes the execution of volitional motor acts requiring mediation via the cerebral hemispheres has a unilateral representation capable of bilateral co-ordination. In fact the conceptual motor plan can be formed on either side of the hemispheres which retain control, yet actual stimulation can be limited to one extremity."

Researchers (11, 12, 13, 37, 43) have been delving into neurological explanations for the occurrence of transfer of training. Wissler and Richardson (43) suggested there is a diffusion of motor impulses to the contralateral musculature. Hellebrandt et al (13) postulated that transfer results from the wide spread synergistic fixation of the contralateral musculature. Slater-Hammel (37), however, hypothesized that during strenuous and systematic exercise of one group of muscles, an individual probably learns to ignore or tolerate feelings of muscular fatigue for an increased length of time, thereby allowing transfer to occur and, as a consequence, the other muscle groups are influenced. Zane, as cited (37), stated the results he obtained for research related to transfer of training to the contralateral limb and ipsilateral musculature (co-contraction) are possibly augmented by motivational factors both conscious and subconscious. Hellebrandt (14) and Shaver (32) found that the appearance of transfer of strength and endurance to the contralateral extremity is significantly higher when the work has been performed according to the overload principle. Conversely, Carlson (1) reported that increases in strength and endurance as a result of training are not simultaneous and may be unrelated processes in both the ipsilateral and contralateral musculature.

Meyers (26) contradicted earlier studies of the occurrence of cross-education when he reported that no measurable increase in the contralateral limb strength was found following isometric training on the ipsilateral extremity.

The most widely reported basis for transfer of training results from the diffusion of motor impulses being initiated in the cortico-spinal system in conjunction with the retinacular activating system; specific muscular contractions can be propogated not only through the ipsilateral limb but also the contralateral extremity.

Sage (31) reported that retinacular formation excitation may cause enough spinal facilitation to result in contraction in the contralateral muscular system. Further, the tonic responses of the body designed to maintain proper postural alignment when muscular activity is taking place could produce sufficient muscular contraction in the contralateral limb to develop a training effect.

The irradiation of motor impulses along efferent pathways may be of sufficient intensity to reach the significant level; whereby training of the contralateral musculature could result. Irradiation of motor impulses, following an ipsi[illegible]ral musculature contraction to maintain proper postural alignment, may be of sufficient intensity to prod[illegible] a contralateral training e[illegible] ([illegible]).

When a motor movement is [illegible]g made, the remaining body musculature reacts in some way to preserve the proper body positioning which facilitates the most efficient bodily function. The relationship between body parts again appears to have a determining effect upon the amount of transfer of training which is produced by ipsilateral muscular contractions. Slater-Hammel (37) stated that symmetrical body parts appear to offer a more favourable medium for the propogation of neurological impulses diffusing from the ipsilateral to contralateral extremity.

The Problem

The primary purpose was to ascertain and evaluate the effects of two different training interactions on alteration of the force-velocity relationship and peak power in human forearm flexor muscles of the contralateral arm as a result of isokinetic training of the ipsilateral forearm flexors. The data available seems to indicate that both the maximal training force exerted by the muscle (21) and its maximal training velocity of contraction (27) must be considered for all round alteration of force-velocity curves. The research also points toward the fact that there is an optimal training level for development of the maximal force of a muscle and its maximal velocity of contraction which is needed to provide the most effective alteration of the curve and consequently the greatest improvement in maximal mechanical power. In addition, there is some evidence which indicates that the change in maximal power is mainly due to the alteration of the maximal exerted force factor at peak power with little increase in the maximal velocity of contraction (21) rather than a concomitant increase in both factors (19). Related to this, the possibility exists that the optimal training interaction may need to be modified for individuals who possess different initial levels of maximal exerted force at peak power in order to describe the improvement of either the force or velocity factor under loaded conditions. A sub-purpose of this study therefore, was to evaluate the effects of the two different training interactions on the maximal force exerted at peak power of the nonexercised contralateral arm in individuals who possess different initial levels of maximal force at peak power.

The research measurements for this investigation applied to the unexercised, contralateral forearm flexor muscles. However, the training methodology for the ipsilateral forearm flexor muscles must be described to give insight into the transfer of training conditions that were measured. Both force-velocity training interactions were administered to two different groups based upon their ability to exhibit maximal force at peak power. The high force group was divided such that one sub-group trained the forearm flexor muscles of the ipsilateral arm at a maximal velocity of movement of the forearm corresponding to 30% of the maximal isometric force (P_o), while their counterpart trained the ipsilateral arm at a maximal velocity corresponding to 60% maximal isometric force. The control groups (high and low force) were not trained.

Time and velocity of movement of the forearm were independent variables as the velocity of movement of the forearm were controlled by means of an isokinetic dynamometer.

Delimitations of the Study

1. The study was limited to a sample of 42 female volunteers registered

as students at the University of Alberta. Their ages ranged from 17 to 27 years.

Limitations of the Study

1. Familiarization to the Cybex II apparatus and experimental procedure for all subjects was limited to one session prior to the pre test. The learning effect involved in initial training periods should be considered as a limitation of this study.
2. Training was conducted Monday, Wednesday and Friday, of each training week, between the hours of 12:00 and 2:00 P.M.
3. Accuracy of the Cybex II apparatus at the higher velocities of testing should be considered within manufacturers specifications.
4. Individual variation in athletic experience, degree of gross and fine motor skill coordination and maximal force generation should be considered. Subjects within this study were volunteers and as such activity background and experience were not investigated.

Definition of Terms

Maximal Isometric Force (P_o). The maximal force (Kg) exerted by a single muscular contraction in which length of the muscle does not change appreciably.

Maximal Velocity of Contraction (V Max). The maximal angular velocity of movement (degrees/sec) of the forearm produced by the contracting forearm flexor muscles, converted to a linear equivalent (meters/sec), without any external load on the muscle.

Degrees per second. A direct measure of velocity of contraction in which the forearm flexors move in an arc about a fixed point represented by the lever arm of the Cybex II isokinetic apparatus. Measurement varies on the Cybex apparatus from 0 to 300 degrees per second.

Maximal Mechanical Power Output (mmpo). The maximal mechanical power output (KgM/Sec) as calculated from the product of force (Kg) multiplied by the maximal velocity of contraction (M/Sec) obtained from the "best fit" force-velocity curves.

Isokinetic Exercise. Maximal force production of a muscle or group of muscles throughout the entire range of motion at a controlled speed of contraction.

Non-preferred or Contralateral Arm. The left forearm which is not subject to direct exercise.

Preferred or Ipsilateral Arm. The right forearm which is subject to direct exercise for the five week period.

Transfer of Training. The measured increase in force and power of the contralateral forearm flexors as an outcome of isokinetic training of the ipsilateral forearm flexors.

CHAPTER II

REVIEW OF LITERATURE

The literature relating to the force-velocity relationship and transfer of training has been reviewed as separate entities: (1) force velocity of isolated striated muscle and intact human muscle and (2) transfer of training.

The Force-Velocity Relationship

The purpose of the literature relative to the force-velocity relationships is presented to give background of the area so that the aspect of transfer of training has an adequate reference point for study. The research being undertaken specifically concerns the varying degrees of transferability that occur at different force-velocity interactions. But as stated previously, an understanding of the basic force-velocity relationship is necessary so that the varying degrees of transfer of training can be held in perspective with the training interactions.

Gasser and Hill (8), in their research dealing with isolated striated muscle and the effect of the speed of shortening of the muscle to force developed, concluded that the greater the speed of contraction the less the force exerted at any length. Gasser and Hill stated "the dependence of force exerted on the speed of shortening was the result merely of the viscosity of the muscle".

Stevens and Snodgrass (39) used the gastrocnemius muscle of the decerebrate cat to determine the speed of shortening of the muscle, the force developed, the work done and the power expended during each 0.001 second of the contraction cycle. With the method employed, both the tension and length of the muscle was allowed to vary concomitantly during the same contraction against an inertia system. It was thus possible to determine accurately the entire range of tension and corresponding length changes throughout the same contraction cycle. The results presented were the averages of eleven records obtained from the same animal during the experiment. They were selected as representative of a series in which twenty animals were used. The curve relating the force developed to the velocity of muscle shortening revealed that as the speed of contraction increased, once the muscle had developed maximal tension, the force diminished. They concluded that some of the loss of force was due to the viscosity of the muscle. Further that the inverse relationship between velocity of contraction and force depended upon the fact that constant power was exerted by the muscle at this time.

Fenn and Marsh (7) used the sartorius muscle of Rana pipiens, except for a few experiments on the gastrocnemius, to show the relationship between the force exerted by the muscle and its speed of contraction. The velocity of contraction was always measured near the beginning of shortening where the slope of the tracing was constant and maximal. No attempt was made to calculate the magnitude of inertia. It was reasoned that s[illegible]here was no change in velocity, the tension in the muscle wou[illegible] equal to the load. The force was calculated per cm^2 cros[illegible] area of the muscle. In most experiments, the muscle was stimulated [illegible]eries of loads increasing in steps from minimum to maximum and the[illegible]easing in the reverse order. The maximum speed of shortening was measured for the series of different loads, the measurement being made always at approximately the same muscle length. When the force or load was plotted against the velocity of shortening, the curve was not linear, but rather logarithmic in shape. They concluded that as the speed of shortening increased the force decreased, not in a linear fashion as would be expected if viscosity alone was concerned, but rather in an exponented fashion. Fenn stated that "this exponential relation was concerned in some way with the processes of developing extra energy for work of shortening".

Hill (15) developed a more exact and rapid technique for heat measurement so that a more consistent picture might emerge of the energy relations of muscle shortening (or lengthening) and doing positive (or negative) work. Hill showed that if a frog sartorius muscle, mounted on a thermopile, was stimulated isometrically and then suddenly released under a small load, it shortened rapidly and during the shortening the galvonometer gave a quick extra deflection. To Hill the extra deflection implied a sudden increase in the rate of heat production of the muscle. Hill postulated that when a muscle shortened extra heat was liberated. Experimentally, Hill found the rate of energy liberation was a rather exact linear function of the load; increasing as the load diminished and being zero when the load was equal to the maximal isometric force. Hill put forth an equation which related the rate of energy liberation to the load. The equation was:

$$(p + a)v = b(P_o - p) \qquad (11)$$

where p = the load on the muscle;

a = a constant with the dimension of force;

v = the velocity of shortening;

b = a constant defining the absolute rate of energy liberation; and

P_o = the maximal isometric force.

This equation was also written as:

$$(p + a)\ (P_o + a)b = \text{constant} \qquad (11\text{-}1)$$

which related the velocity of contraction and the force in isotonic shortening. In this equation:

p = the load on the muscles;

a = a constant with the dimension of force;

v = the velocity of contraction;

b = a constant with the dimension of velocity; and

P_o = the maximal isometric force.

Hill (14), in further experiments, showed that when a contracting muscle was made to lengthen gradually by applying a load rather greater than isometric tension, there appeared to be a negative heat of lengthening and the total energy given out by the muscle was less than in an isometric contraction. These experiments on heat and lengthening made it impossible any longer for Hill to regard viscosity as the primary cause of the effects observed in active muscle. He stated:

> "if viscosity were the chief reason for a decrease in force as the velocity of contraction increased, the lengthening of the muscle should produce greater heat production and certainly not less than isometric tension."

Further, Hill (15) deduced from the force velocity curves of a number of other experiments that the greatest rate of doing external work (power) should occur with a load equal to about 30% of the isometric tension.

Hill (16) and Lupton (25) conducted experiments on intact human muscle and concluded that the greater the equivalent mass, the greater the work done and the greater the duration of shortening, the greater the work done. Hill hypothesized that a muscle, when stimulated, produced potential energy which in any actual contraction was employed partly in doing external work and partly in overcoming the viscous resistance of the muscle to its change of form. Lupton's results were in agreement with those of Hill, that the external work was diminished through the viscosity by an amount depending upon the velocity of shortening.

Fenn (6) illustrated a new method of demonstrating muscle viscosity in sprint running. The subject sat on a table with one leg hanging over the edge and arrangements were made for recording variations in the angle of the knee with time as the lower leg moved. A curve was traced by a pointer on a revolving drum as the lower leg moved which indicated angle of the knee plotted against time. The slope of the curve represented the angular velocity. If the angular velocity measurements were plotted as a function of time, the slope of the resulting graph presented the angular acceleration. The results indicated how quickly the force decreased following a quick release of the lower leg. Fenn suggested that the failure to develop force while shortening may be due partly to a reflex cessation of stimulation on a reflex inhibition. He also suggested that the loss of force may be due to some characteristic of the muscle itself. He stated that:

> "the delay in development of tension might equally well be in some chemical reaction involving the mobilization of a necessary energy for contraction. In such a case, the term viscosity would be inappropriate."

Ikai (19) has tried to approach the problem of training of muscular power by considering the force-velocity curve of muscle. He measured individual force-velocity curves of the forearm flexor muscles for thirteen male and fifteen female adults. The maximum power produced was found when the force and velocity were about 35% of the maximum values in both sexes. A power training study was conducted in twelve male adults to see the effect on the force-velocity relationship of the forearm flexor muscles. The load used for training was 0, 30, sixty, or 100% of the maximum isometric strength. The training consisted of ten maximal voluntary contractions of the elbow flexor once a day lifting the load specific to the group. The results indicated that a greater displacement of the force-velocity curve, and consequently better all around improvement in maximal muscular power, was obtained with the subjects that used the 30 and 60% training loads. He concluded that for all-round power training a load from 30 to 60% of the maximum strength should be used.

Moffroid (27) used isokinetic exercise to evaluate the effects of two different training speeds 36 and 108 degrees per second) on muscular endurance (average power) and on muscular force. Peak torque at different velocities of contractions (3, 6, 9, 12, 15, 18 revolutions per minute) was measured for the quadriceps and for the hamstring muscle group. She found that lower power (low speed, high load) exercise produce increases in muscular force only at slow speeds. On the other hand, high power (high speed, low load) exercise produced increases in muscular force at all speeds of contraction at and below the training speed of 108 degree/second. She concluded that high power exercise increases muscular endurance (average power) at high speeds more than does low power exercise increase muscular endurance at slow speeds.

Transfer of Training

Research in the area of transfer of training or cross education surfaced as early as 1894 when Scripture, as cited, introduced the term "cross-education" (32,33). He had found that exercise of one hand on a dynanometer resulted in increased muscular performance of the contralateral hand. Then, as now, a complete understanding of why or how such a training transfer occurs or does not occur is lacking.

Wissher and Richardson (43) found that daily exercise using a dynanometer with one arm increased muscular performance in the contralateral limb which was presumably not directly involved in the muscular contraction. They hypothesized that diffusion of motor impulses from the exercised to the non-exercised limb could be responsible for the transfer effect, while adding "it must not be claimed that muscles do not receive cross-exercise until more refined methods of observation are used than heretofore available in such experiments".

Presently the physiological basis of cross-training is not clearly understood, or at least agreed upon. Although most researchers do in fact report the measurable presence of transfer of training as an outgrowth of their experiments (12, 13, 14, 32, 33); Krause (23) found that no significant increase of strength or endurance appeared in the contralateral limb after controlled exercise. His experiment consisted of 60 male university students trained on an isometric machine for 2, 3, 4 and 5 weeks depending upon which experimental group they belonged to. Although significant increases in muscular strength and endurance were measured in the exercised arm, no significant transfer of training to the contralateral limb was found.

Slater-Hammel (37) conducted a study of the bilateral effects of simple flexion and extension of the right forearm. The testing and training was done with no knowledge by the subject what in fact was being measured. By this approach he hoped to avoid any confounding psychological variables that could influence the outcomes. His results showed a systematic exercise program involving the flexion and extension of one arm resulted in positive and significant improvement in the muscular performance of the contralateral limb. In addition, he stated that because the bilateral gains were rapidly lost after cessation of training, the gains must have been primarily attributable to the exercise training trials.

Shaver's 1970 (33) study of 40 "right-handed" male volunteers under a condition of a 6 week progressive resistance was designed to test the increase of muscular endurance and strength in the ipsilateral and contralateral limbs, "demonstrating the phenomena of cross transfer of static strength and endurance". Although Shaver was sure the results indicated the existence of cross-education, he was not decided as to why such a phenomenon persisted ..."the present findings might be attributable to bio-chemical as well as biophysical and neuromuscular factors".

Lawrence et al (24) found through nineteen days of isotonic training of knee extension, the contralateral quadriceps showed strength increases of 65-100% of the measured increase of the exercised limb.

Walters (41) tested 13 females between the ages of 23 and 53 for transf of motor skill as indicated by a controlled administration of the Minnesota Rage of Manipulation Test which consisted of placing cylindrical blocks in the appropriate holes while under an overload principle facilitated by a metronome pacer. He stated "the greatest transfer effects were obtained in practice of overload". Walters also concluded from his study that as much transfer of skill could be gained by indirect practice subject to conditions of overload as direct training subject to submaximal training.

The areas of retention and loss of training on the ipsilateral and contralateral limbs were investigated by Shaver (32) in his study of 60 male university students. The participants in the experiment underwent six weeks of isotonic training at various levels of strength, i.e. 10, 15, 20 and 25% of maximum as predetermined by a maximal isometric strength recording. Muscular endurance was measured by the total number of times the subject could perform the prescribed task throughout the entire range of motion. Following the six week training period the experimental groups were again tested for strength and endurance followed by differing periods of inactivity, i.e. 1, 3 and 5 weeks. Shaver's findings showed that all three experimental groups retained their newly acquired strength and endurance to a significant level in both the ipsilateral and contralateral limbs following the appropriate inactivity period. He reported the following statistics that were produced by his investigation (i.e. the amount of strength lost by differing periods of inactivity):

> "(a) 0.5 percent in the exercised limb; 1 percent in the unexercised limb following 1 week of detraining,
> (b) 1.5 percent in the exercised limb and 1.0 percent in the unexercised limb following 3 weeks of detraining,
> (c) 2.5 percent in the exercised limb and 1.5 percent in the unexercised limb following 5 weeks of detraining."

It was found the greatest endurance loss occurred at high loads, i.e. 25% of maximum static strength, while the least loss was recorded at 10% of maximum static strength regardless of the period of detraining.

Hellebrandt's 1951 study (13) measured the bilateral influence of unilateral practise of standardized activities requiring manual dexterity. She concluded that cross-education appears somewhat greater for the left to right than the right to left training complex. In addition, she stated:

> "Cross education appears to occur with equal facility whether the exercise performed demands the development of maximal contractile force by large muscle groups or the execution of highly skilled and agile digital movements. The cross education occurs so readily

> that it may not be more than the normal resultant of simultaneous discharge of identical efferent impulses over bilateral pathways, differing only in volume."

She felt that the reaction of normal individuals to volitional exercises suggests the efferent patterns of discharge may take a bilateral course with the major flow going to the contralateral side and a smaller but identical flow travelling ipsilaterally. Hellebrandt was unsure whether the behavior had its origin in bilateral representation of the musculature in the motor cortex or because ideational motor planning involves a bilateral visualization of the body scheme as a whole.

Carlson (1) by use of isometric training stated:

> "that static pressure of force applied to one side of the body can have an effect on structures located elsewhere in the body. Demonstrated cross-transfer increases as the distance of the muscle group from the central nervous system decreases."

In addition, Carlson felt it was feasible that a muscle, whether it be flaccid or spastic, could be affected by force or contraction applied to appropriate contralateral structures.

One the most exhaustive research ventures investigating cross-transfer by use of electromyographic techniques was conducted by Gregg and associates (9). Recordings of the subjects were taken as they performed repetitive, resistance exercise with the preferred limb. The electromyographic tracing, while utilizing a ten pound weight, indicated electrical activity appeared simultaneously in the right biceps and triceps at the instant flexion started (co-contraction). Evidence of of the overflow to the unexercised, contralateral muscles was not observed during simple, non-resistance exercise, nor isometric contraction of the biceps brachii. Recordings of electrical activity in the contralateral limb were only observed after the load or number of repetitions was increased. A two minute rest after cross-overflow had been recorded resulted, on resumption, in a temporary almost complete loss of overflow. The tracings also pointed to a complete loss of overflow during isometric contraction against a super-maximal load; while disappearance of the manifested overflow after two minutes evidenced a relationship between the appearance of overflow, movement of a heavy load and fatigue.

Hellebrandt (12) investigated the principle of indirect learning in relation to the effect of unimanual exercise on related muscle groups of the same and opposite side. The testing design consisted of half the experimental group exercising their wrist flexors while the remaining half of the experimental group trained the wrist extensors. She found that duration of training was less important than frequency or magnitude of the training in relation to the indirect learning that resulted. The best results, measured by the highest increase of strength and endurance of the muscle groups, were obtained when practise was scheduled daily and the resistance imposed was compatible with full wrist mobilization.

> "This form of training program virtually doubled the functional capacity of the antagonists in 8 days and had an outstanding influence on the ipsilateral antagonist and same muscle groups of the opposite limb" (contralateral transfer).

As stated by Hellebrandt, the most conspicuous change in muscle functional capacity was exhibited by the muscle group subject to direct practise. Observation alone appeared to have a measurable influence on performance. She further concluded that daily practise and resistance compatible with full mobilization of the joint being exercised, yields the best training results, i.e. increased strength and endurance and the corresponding transfer to the antagonist and ipsilateral muscles.

Sills (34) found that action potentials were recorded in the exercised as well as unexercised arms at simultaneous times. He recorded the varying potentials by adding 4 1/2 pound weights to the training routines until the subjects were unable to lift the weight through the full range of motion. Sills found the microvoltage recorded increased as resistance increased; 70% of maximum isometric contraction in the ipsilateral limb produced a 10 m.v. recording which he stated was the least activity that could be an indication of an action potential. He stated that a strong individual may elicit a response in the contralateral arm by using a smaller percent of the total muscular strength of the exercised arm, but a greater amount of absolute strength. Sills could not find substantial evidence to prove or disprove two questions that remained as his study came to a close: (1) maybe more microvolts (i.e. larger action potential) may be developed by active non-resistance exercise (muscle setting) than heavy resistance exercise; (2) relaxation of unused musculature may affect microvolts recorded as indicative of an action potential.

Coleman (3) conducted a study consisting of isometric and isotonic contractions and the effects upon the contralateral limb. His research involved 41 college men divided into isometric and isotonic experimental groups who exercised for twelve weeks. Results of the comparison of pre and post tests showed that both isometric and isotonic groups improved dynamic and static strength in both the ipsilateral and contralateral limbs subject to sub-maximal exercise. In addition, Coleman found that: (1) isotonic exercise greatly increased dynamic strength, i.e. ipsilateral musculature, (2) isometric exercise trials increased dynamic and static strength, i.e. ipsilateral and contralateral musculature.

Meyers (26) was concerned with isometric training and the manifested effects upon strength, size and endurance of the exercised and non-exercised limbs. The study consisted of two experimental groups and a control group which did not receive any training bouts.

Group I - preferred arm 3 x/week; maximum pulls on elbow flexion for three 6 second bouts at thirty second intervals.

Group II - preferred arm 3 x/week; maximum pulls on elbow flexion for twenty 6 second bouts at thirty second intervals.

The isometric contractions for both experimental groups were performed at 70 and 90 degree of arm extension.

Analysis of the results showed no significant transfer of training in strength, size or endurance of the contralateral limb as a result of the isometric training.

Hellebrandt (13) stated that whenever unilateral exercise of large muscle groups is performed against heavy resistance, widespread postural re-adjustment takes place. The re-adjustment utilizes synergistic co-contraction of muscles of the ipsilateral and contralateral extremities. She suggests that the neurological component in cross-education may be as important as the involuntary training of peripheral effector organs.

Wissher and Richardson (43), in attempting to explain the occurrence of cross-education, stated:

> "any attempt to explain the transference of practise from one part of the body to another must consider the muscle, nerve and center as a unit ... A diffusion of the motor current in the arm, and it follows out an order corresponding to anatomical and functional relations such as would occur in an irradiation of the current in the cells of the cortex or in the spinal cord ... it also follows the line of anatomical and functional development."

In summary, it can be stated that the research findings and conclusions drawn from these findings are contradictory and inconclusive. Researchers such as Hellebrandt (12, 13, 14); Shaver (32, 33) and Sills (34) feel adamantly that there is a transfer of training yet are not in total agreement as to the reasons or reason for such a physiological appearance. On the other hand, researchers Myers (25) and Krause (24) found no significant transfer of training when utilizing isometric and isotonic training trials. The majority of the meager literature in this area of cross-education, was as stated, inconclusive and at the present time there still is not total agreement in this area as to the neurological, biochemical or psychological basis for cross-education.

CHAPTER III

METHODS AND PROCEDURES

Subjects

Forty-two female volunteers, ranging in age from 17 to 27 years, underwent a five-week isokinetic training program involving the ipsilateral forearm flexors. Prior to, and immediately following the five week training period, all subjects underwent a testing period measuring force at five preset lever arm velocities and maximal isometric force at four preset angles for the contralateral and ipsilateral forearms.

Anthropometrical Data

Anthropometrical data from each subject was collected to represent: age (years); weight (Kg) and length of forearm (cm). See Appendix C.

The Cybex II System

The recent developments of isokinetic rehabilitative apparatus have provided new tools that allow the study of mechanical properties of intact human muscles under conditions of constant velocity. The concept of isokinetic exercise has been discussed by several researchers (2, 4, 17, 28, 38, 40). The Cybex II Isokinetic system consists of three components:

(1) The Cybex II Dynamometer which measures torque inputs up to 360 foot-pounds. The resistance supplied via the input attachment varies automatically to accommodate the fluctuating force applied by the subject. Any force against the input shaft is measured as torque on the input shaft and displayed on a front

guage dial. Because of the accommodating resistance mechanism in the apparatus, the velocity of an exercising limb cannot be accelerated. Instead, as more force is exerted against the lever arm of the apparatus, more resistance is encountered by the limb and movement occurs only at a predetermined velocity of contraction.

(2) The speed selector, which can be preset to obtain a constant speed of rotation of the lever arm from 0 to 300 degrees/second. Once a speed is selected, the lever arm cannot be accelerated beyond that speed regardless of the input torque applied below 360 pounds.

(3) The fast response recorder and heated stylus which simultaneously produces and displays a permanent written record of the applied torque.

The Cybex II Isokinetic System is shown in Figure I.

Pre-Training Test

The pre-training test involved two measures of maximal isometric force (P_o) of the forearm flexor muscles of the contralateral forearm at the elbow angle of 100, 120, 140 and 160 degrees (180 degrees being horizontal). To complete the pre-training test, two measurements were obtained for the maximal force exerted by the forearm flexor muscles at five preset lever velocities of 15, 25, 35, 45 and 50 revolutions per minute.

FIGURE 1

Cybex II Training Apparatus and Subject in Experimental Position

Determination of Maximal Force Exerted at Peak mmpo

From the pre-training test results, an individual force-velocity-power curve was obtained for each individual at an elbow angle corresponding to maximal force production at 100, 120, 140 and 160 degrees from horizontal. Utilizing the force-velocity-power curves obtained at an elbow angle of maximal force production, the maximal force exerted at peak mmpo was determined. This is shown in Figure 2.

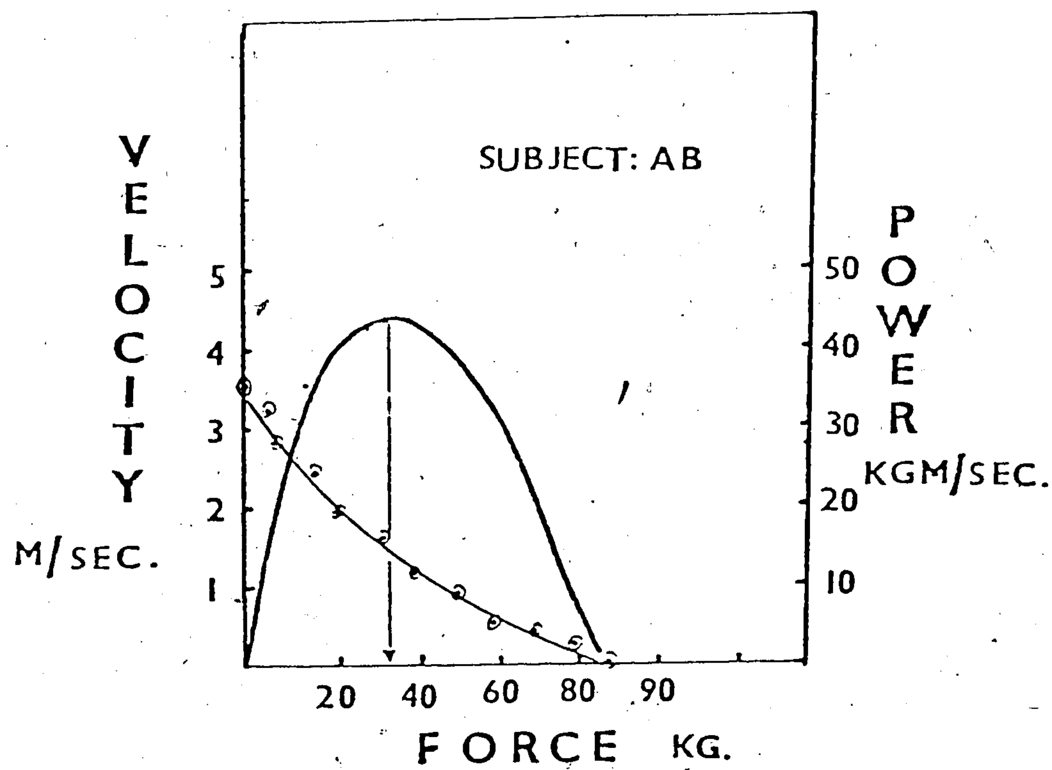

FIGURE 2

Determination of maximal force exerted at peak MMPO from individual force-velocity curves

Determination of Maximal Isometric Force (P_o)

The lever arm of the Cybex Dynamometer was rigidly fixed at each angle of 100, 120, 140 and 160 degrees with respect to the horizontal. Two maximal voluntary contractions of the contralateral forearm flexors were made at each angle with a one minute rest period between each trial. The highest force value attained by the contralateral limb was used as the experimental P_o on the force-velocity curves. (See Appendix B for conversion.)

Determination of Maximal Force Exerted Under Loaded Conditions

In the experimental starting position of 180 degrees, two maximal voluntary contractions of the contralateral forearm flexor muscles were obtained for a preset maximal velocity of contraction with a one minute rest period between each trial. Five maximal velocities of contraction corresponding to 90, 150, 210, 270 and 300 degrees/second were used. The highest recorded force produced with its corresponding maximal velocity of contraction were utilized to draw the force-velocity curves.

The order of testing for all subjects progressed from 90 to 300 degrees per second with the one minute rest period between each preset velocity of the Cybex II lever arm.

Subjects trained three days per week for a period of five weeks at their respective training velocity corresponding to 30 or 60% of their maximal isometric force. The training program can be seen in Table I.

Table 1

Training Program to be Followed for Five Weeks

Group		(Week)	(Session/Week)	x (Repetitions)	=	(Total)
I	(30% P_o)	1	3	10	=	30
I	(60% P_o)	1	3	10	=	30
II	(30% P_o)	1	3	10	=	30
II	(60% P_o)	1	3	10	=	30
I	(30% P_o)	2	3	10	=	30
I	(60% P_o)	2	3	10	=	30
II	(30% P_o)	2	3	10	=	30
II	(60% P_o)	2	3	10	=	30
I	(30% P_o)	3	3	15	=	45
I	(60% P_o)	3	3	15	=	45
II	(30% P_o)	3	3	15	=	45
II	(60% P_o)	3	3	15	=	45
I	(30% P_o)	4	3	15	=	45
I	(60% P_o)	4	3	15	=	45
II	(30% P_o)	4	3	15	=	45
II	(60% P_o)	4	3	15	=	45
I	(30% P_o)	5	3	20	=	60
I	(60% P_o)	5	3	20	=	60
II	(30% P_o)	5	3	20	=	60
II	(60% P_o)	5	3	20	=	60

Statistical Procedures and Experimental Design

The Design (for diagrammatical display, see Appendix E)

The experimental design was a 2 x 3 x 2 factorial design (fixed model) with repeated measures on factor C.

The two levels of factor A (classification) were the two blocks into which the subjects were assigned according to their maximal force exerted at peak MMPO. These were established as:

(a_1) high maximal force pretraining scores at peak MMPO; and

(a_2) low maximal force pretraining scores at peak MMPO.

The three levels of factor B (treatments) were:

(b_1) a maximal training velocity corresponding to 30% of an individual's maximal isometric force (P_o);

(b_2) a maximal training velocity corresponding to 60% of an individual's maximal isometric force (P_o); and

(b_3) a control group that received no training stimulus.

The two levels of factor C were:

(c_1) pre-training test scores; and

(c_2) post-training test scores.

Statistical Analysis

The data on each parameter was analyzed by a three way analysis of variance with repeated measures on factor C. More specifically, the analysis was carried out on the dependent variables of P_o, maximal force exerted at five preset velocities of contraction and MMPO as an index of the overall alteration of the force velocity relationship and

MMPO of the contralateral arm.

Post-Training Test

The post-training test involved duplicate measures as made for the pre-training test. (See Page 25.)

Assignment of Subjects to the Training Groups

From the pre-training values of maximal force exerted at peak MMPO, of the ipsilateral forearm flexors, the subjects were ranked and classified into two blocks of twenty-one individuals designated as Group I (high force) and Group II (low force). The twenty-one subjects in each block were then assigned to one of three training groups by assigning the first seven subjects to the 30% training group, second group of seven subjects to the 60% training group and the third group of seven subjects to the control group, irrespective of peak MMPO values that each subject obtained on the pre-test measures.

The three groups to which subjects were assigned were:

(a) Training Group (30% P_o) N = 7. Trained the forearm flexor muscles of the ipsilateral arm at a maximal velocity of movement corresponding to 30% of the maximal isometric force (P_o), as determined from the individual force-velocity curves; (see Figure 3).

(b) Training Group II (60% P_o) N = 7. Trained the forearm flexor muscles of the ipsilateral limb at a maximal velocity of movement corresponding to 60% of the maximal isometric force (P_o); (see Figure 3).

(c) Control Group (C) N = 7. Were asked to maintain their normal activity pattern during the five week training period which the 30 and 60 percent subjects received.

Therefore, there were four training groups (N = 7 subjects/group), one designated as Group IA (30% P_o), one designated as Group IB (60% P_o), one designated as Group IIA (30% P_o) and one designated as Group IIB (60% P_o). In addition, the control groups from each block were designated as Group IC and Group IIC (N = 7 subjects/group).

The individual maximal training velocities were determined for the four training groups as shown in Figure 3.

Determination of Composite Force-Velocity-MMPO Curves

Composite pre and post test training force-velocity-mmpo curves were drawn for the four training groups and two control groups utilizing mean values obtained from individual force-velocity data for the respective groups.

Relationship of Contralateral to Ipsilateral Measurements

The five week training period was only done by the ipsilateral forearm flexors. The contralateral forearm flexors were subject only to a pre test and post test measuring the force (Kg) produced at 15, 25, 35, 45, and 50 revolutions per minute, and maximal isometric force (P_o) at 100, 120, 140 and 160 degrees from horizontal following the ipsilateral five week training period. The duplicate methodology and similar measurements and determinations as earlier described were followed. (See page 27.)

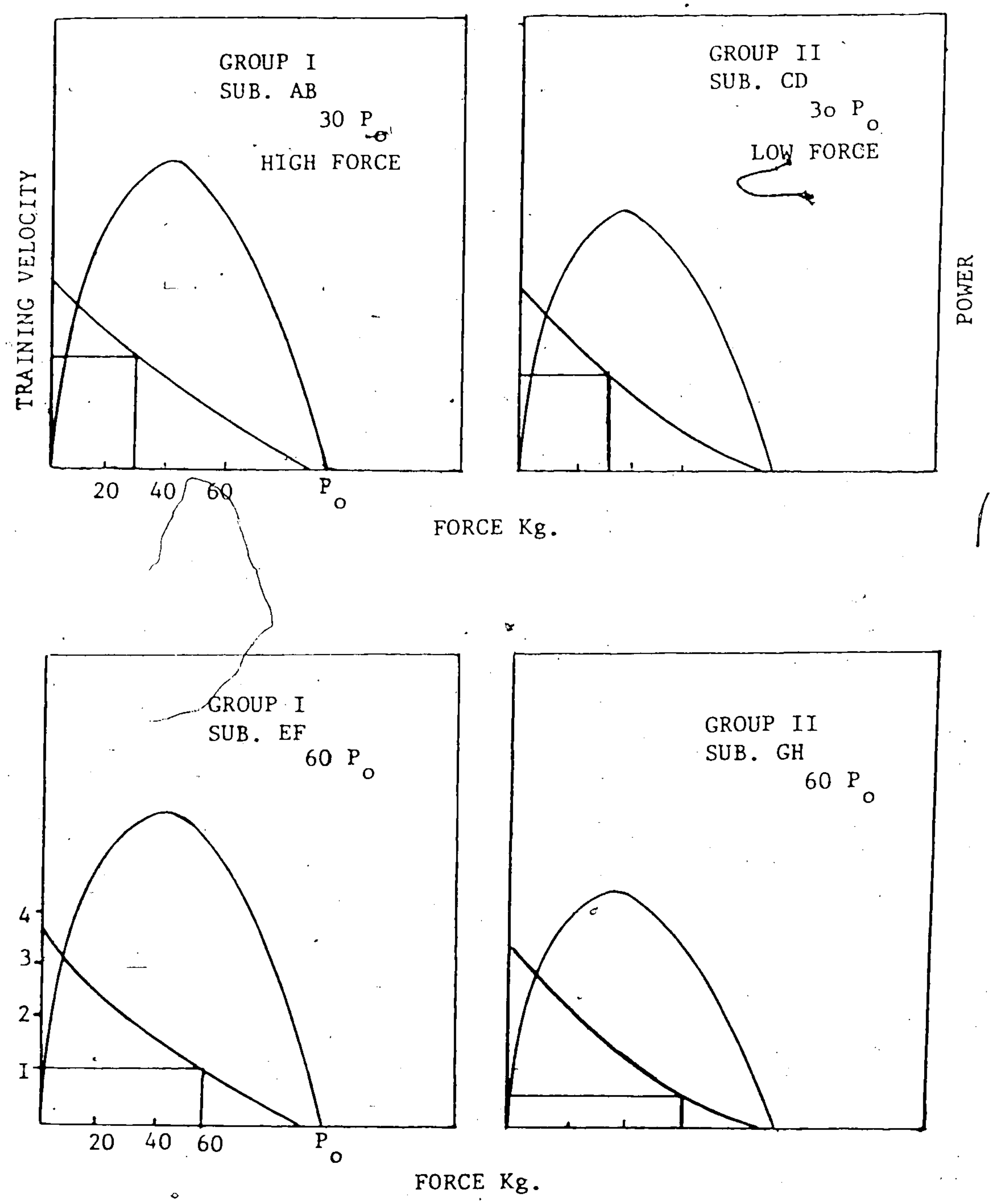

FIGURE 3

Determination of Individual Maximal Training Velocities Corresponding to 30 and 60% for Subjects in the Training Groups

Contralateral Limb Analysis

Percentage differences in the force-velocity-power curves, maximal isometric force (P_o) and force at peak power (mmpo) from pre to post test were established.

The percentage differences between pre and post test were found at the five preset level velocities of 15, 25, 35, 45, and 50 revolutions/minute to establish the force-velocity interaction following the ipsilateral training period.

Percentage differences from pre to post test were established for measures of maximal isometric force (P_o) at the angle which in the pre test had shown the greatest force produced. This angle was one of 100, 120, 140 and 160 degrees from horizontal.

Percentage differences from pre to post test for force at peak power, as realized from the force-velocity-power curves, were established for the contralateral forearm flexors following the five week ipsilateral forearm flexor training period.

CHAPTER IV

Results

The research investigated the transfer effects of isokinetic ipsilateral training, utilizing the Cybex II apparatus, on the force-velocity power curves, maximal mechanical power output (mmpo), and maximal isometric force produced by contralateral forearm flexors. The initial determination of experimental groups: Group I - High force; Group II - Low force, was based upon forces produced by the ipsilateral forearm flexors in pre test measures. Subjects were then assigned to one of six experimental groups: I-60%, I-30%, I-control; II-60%, II-30% or II-control. Figure 4 represents the composite force-velocity-power curve for the forty-two subjects. Figure 5 and 6 are representative of the force-velocity-power curves of the High and Low force groups based upon ipsilateral measurements.

The data was statistically studied by three-way analysis of variance with regapeted measures on factor C. Specifically, force-velocity, maximal isometric force (P_o), mmpo, and force at peak power were studied. Analysis of variance showed a significant factor C (pre-post test) for the three variables of: force-velocity, Max. P_o and mmpo, with force at peak power showing a non-significant factor C.

Group Performance

The Group I (High force) subjects who trained at a velocity corresponding to 30% Max. P_o showed significant pre test to post test differences in Max. P_o, mmpo and force-velocity relationships. Maximal isometric force production measures from pre to post test, showed significant

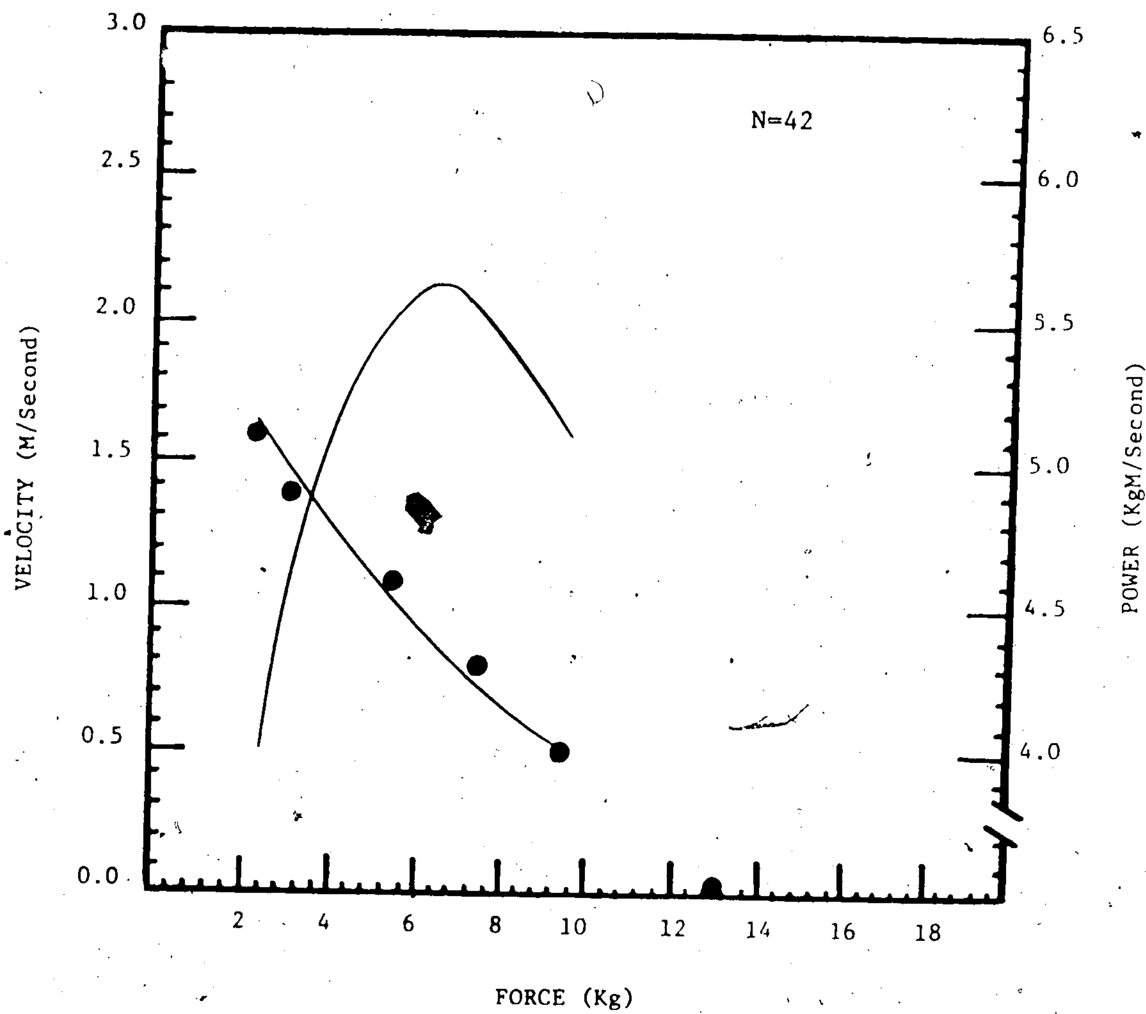

FIGURE 4

Ipsilateral Pre-test: Composite and
Force-Velocity-Power Curves

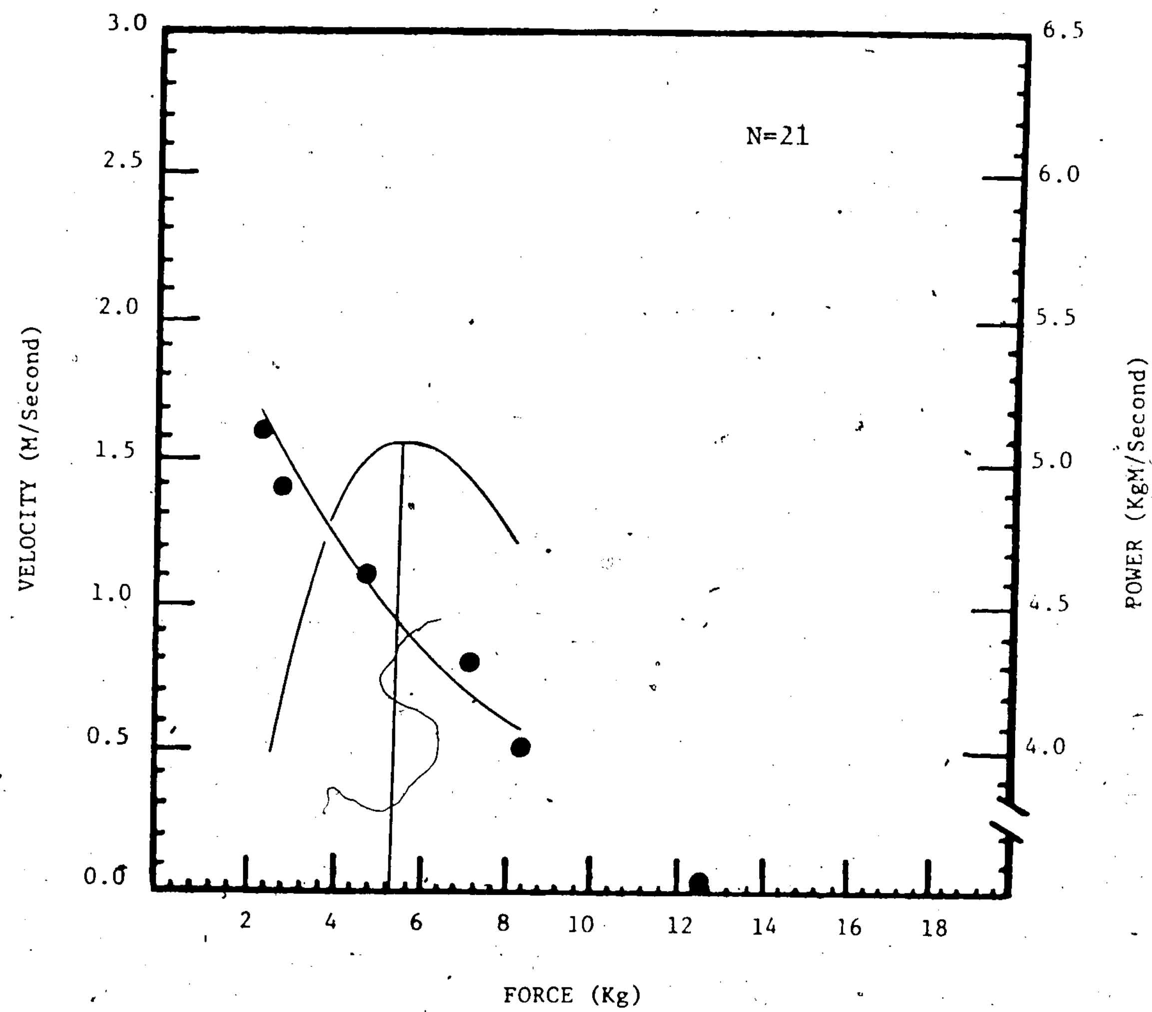

FIGURE 5

Group II - Ipsilateral Pre-test
Force-Velocity-Power Curves

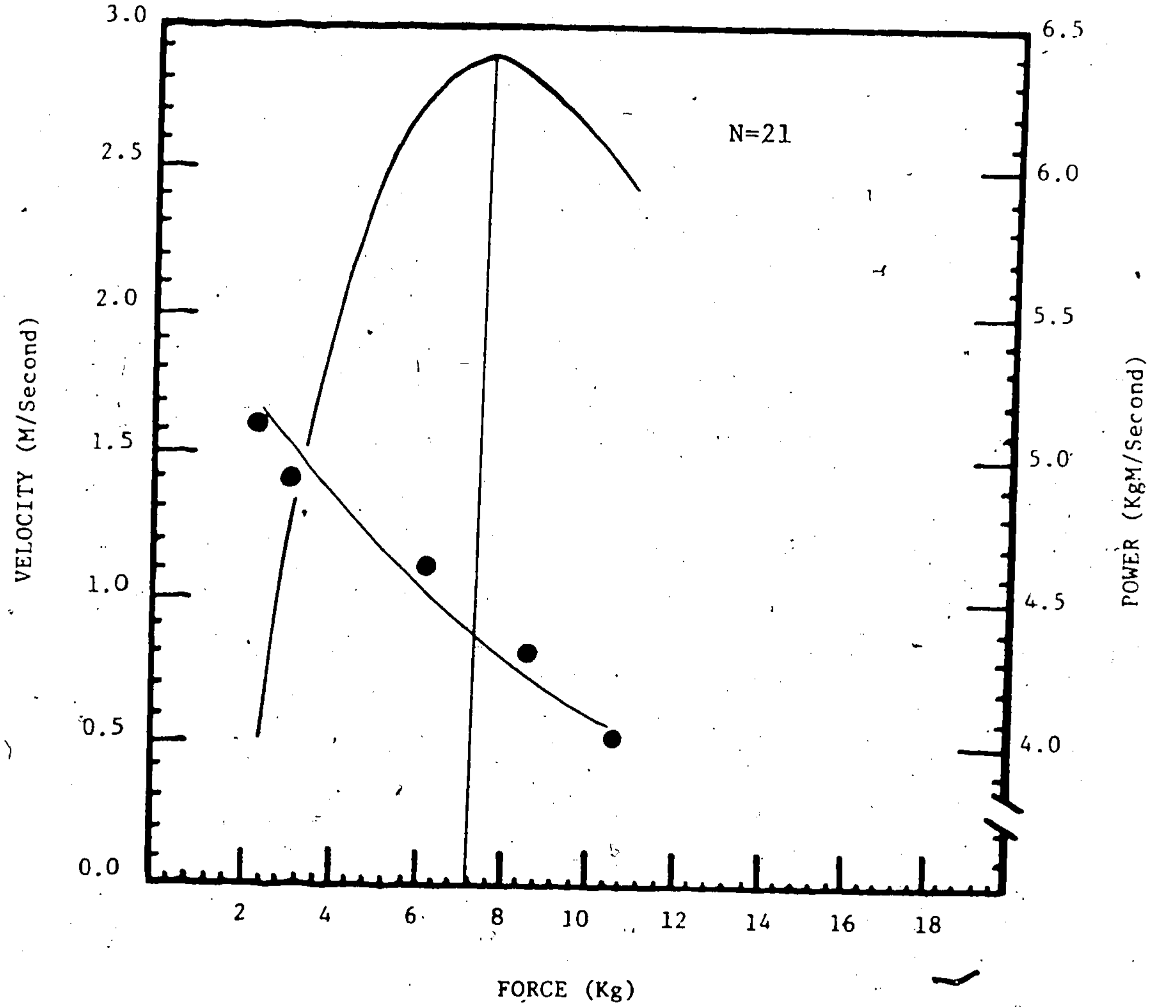

FIGURE 6

Group I - Ipsilateral Pre-test
Force-Velocity-Power Curves

percentage increase in the maximum force produced for the 60% training group (+ 17.9%) (see Table 2). Alteration of the maximum mechanical power output (mmpo), from pre to post test, produced a vertical shift in the power curve with peak power occurring at a higher velocity. Overall, Group II produced a percentage increase of + 12.8% in mmpo. Specifically, Group IIA (30%) illustrated a + 8.7% pre to post test difference and Group IIB (60%) realized a + 21.2% pre-post test difference in mmpo (see Table 3).

Force-velocity relationships for Group II indicated a greater pre-post test difference as the velocities of measurement increased from 90-300 degrees/second (see Table 4). Group IIA (30%) showed a - 1.3% difference at 90 degrees/second while measurement at 300 degrees/second illustrated a + 51.6% increase from pre to post test. Group IIB (60%) showed the same basic pattern with measurement at 90 degrees/second realizing a + 12.8% pre-post test difference and 300 degrees/second showing a + 38.1% increase from pre to post test (see Table 4).

Group I showed significant pre-post test differences for Max. P_o, MMPO and force-velocity relationships. Maximal isometric force production for Group I overall, illustrated a + 8.20% increase from pre to post test measures. Specifically, Group IB (60%) produced a pre-post test percentage difference of + 8.40% with Group IA (30%) realizing a + 1.40% difference following the five week training period (see Table 2).

Maximum mechanical power output difference from pre to post test showed a 12.3% increase in production. Specifically, Group IB (60%) realized a + 21.7% difference from pre to post test and Group IA (30%) achieved a + 19.8% increase in MMPO (see Table 3).

TABLE 2

MAXIMAL ISOMETRIC FORCE (Kg)

		Pre-test	S.D.	Post-test	S.D.	% Difference
Group I	30%	12.45	1.40	12.62	1.30	+ 1.40
I	60%	13.09	2.10	14.21	1.76	+ 8.40
I	TOTAL	12.32		13.34		+ 8.20
Group II	30%	11.37	.89	11.37	1.28	0.0
II	60%	13.56	2.34	15.99	3.57	+ 17.9
II	TOTAL	12.31		13.56		+ 10.0

TABLE 3

MAXIMAL MECHANICAL POWER OUTPUT (Kg)

		Pre-test	S.D.	Post-Test	S.D.	% Difference
Group I	30%	4.58	1.52	5.49	1.17	+ 19.8
I	60%	5.61	1.84	6.82	1.81	+ 21.7
I	TOTAL	5.35		6.01		+ 12.3
Group II	30%	4.79	1.54	5.21	.90	+ 8.7
II	60%	5.09	1.63	6.17	1.60	+ 21.2
II	TOTAL	4.73		5.34		+ 12.8

TABLE 4

GROUP II - FORCE-VELOCITY-POWER

PRE AND POST TEST

Group		90^{o}/sec	150^{o}/sec	210^{o}/sec	270^{o}/sec	300^{o}/sec	$MaxP_o$	MMPO	F at Peak Power (Kg)
II 30%	Pre-Test	8.15	6.14	4.04	2.16	1.84	11.37	4.79	5.50
	S.D.	1.65	1.54	1.92	1.76	1.66	.89	1.54	.48
	Post-Test	8.04	6.66	4.85	3.23	2.79	11.37	5.21	4.65
	S.D.	.75	.83	.56	.53	.70	1.28	.90	.65
	% Dif.	-1.3	+8.4	+16.7	+54.1	+51.6	0.0	+8.7	-18.2
II 60%	Pre-Test	8.56	6.67	4.04	2.59	1.96	13.56	5.09	6.07
	S.D.	1.83	1.94	2.34	2.06	1.77	2.34	1.63	1.17
	Post-Test	9.66	7.54	5.62	3.81	2.92	15.99	6.17	5.77
	S.D.	1.29	1.45	1.39	1.58	1.75	3.57	1.60	1.13
	% Dif.	+12.8	+13.0	+39.0	+47.1	+38.1	+17.9	+21.2	-5.1

TABLE 5

GROUP I - FORCE-VELOCITY-POWER

PRE AND POST TEST

Group		90^o/sec	150^o/sec	210^o/sec	270^o/sec	300^o/sec	$MaxP_o$	MMPO	F at Peak Power (Kg)
I 30%	Pre-Test	8.72	6.31	4.07	1.84	1.50	12.45	4.58	6.50
	S.D.	1.86	2.35	2.49	1.64	2.32	1.40	1.52	1.25
	Post-Test	9.03	7.05	5.32	3.55	2.93	12.62	5.49	5.03
	S.D.	1.22	1.18	1.37	1.05	.94	1.30	1.17	.97
	% Dif.	+3.5	+21.6	+30.7	+92.7	+95.5	+ 1.40	+ 19.8	-22.6
I 60%	Pre-Test	9.51	7.64	4.75	2.29	1.84	13.09	5.61	7.03
	S.D.	1.91	1.81	2.17	2.11	1.86	2.10	1.84	1.30
	Post-Test	10.99	8.69	6.69	4.48	3.28	14.21	6.82	6.48
	S.D.	2.70	1.74	1.71	1.60	1.51	1.76	1.81	1.72
	% Dif.	+15	+13.7	+40.9	+95.6	+70.8	+8.4	+21.7	-7.9

Force-velocity relationships for Group I (High Force) showed significant pre test to post test differences although differentiation of the velocities of measurement was non-significant. Overall, however, Group I illustrated an increase in percentage force production from pre to post test as the velocity of measurement progressed from 90 to 300 degrees/second. Specifically, Group IA (30%) showed a percentage difference of + 3.5% at 90 degrees/second and progressed to + 95.5% at 300 degrees/second. Group IB (60%) also showed a gradual increase in percentage pre test to post test difference from 90 to 300 degrees/second. At 90 degrees/second a + 15.5% difference was realized while at 300 degrees/second a percentage difference of + 70.8 was attained (see Table 5).

Group I and II, whether training at a velocity corresponding to 30% or 60% of Max. P_o, produced non-significant pre test to post test differences in the measurement of force produced at peak power (see Tables 4 and 5).

Group I and II control groups realized non-significant pre test to post test differences for Max. P_o, MMPO, force-velocity relationships and force produced at peak power (see Tables 4 and 5).

CHAPTER V

Discussion

Transfer of Training

The overall result of the study conducted indicated a transfer of training from the isolinetic training period of the ipsilateral forearm flexors to the contralateral forearm flexors of the experimentally trained subjects. The transfer was indicated not only on pre to post test measures of the force-velocity relationship, but also in the values obtained for maximal isometric force and MMPO.

Maximal Isometric Force

Within Group II (Low Force) the 60% training group showed the greatest percentage pre to post test differences of +17.9% in maximal isometric force produced (Table 2).

Group I (High Force), although not showing as great a percentage pre-post difference as Group II, + 8.20% as compared to + 10.0%, did show increase in isometric force produced following the ipsilateral training period (see Figure 8). Within Group I, it was the 60% training velocity which did show the largest percentage pre to post test difference with a measured increase of 8.40%. Little research could be found to substantiate or disprove the results which surfaced relative to contralateral increase in maximal isometric force following ipsilateral isokinetic training. Indications are, from this research, that it is entirely possible to produce an increase in isometric force production through ipsilateral dymanic training and in particular by subjects who were determined to be of low force production as grouped from initial pre testing procedures.

Between groups I and II it was the low force (Group II) subje who realized the largest percentage pre to post test difference with force production values of +8.2% and +10.0% respectively. However, within these two groups, it was the 60% training subjects who realized the largest percentage increases from pre to post test.

Although it is only conjecture at this point, direct isometric training of the ipsilateral forearm flexors could possibly have produced the greatest pre-post test differences when bilateral measurements are being made of unilateral training.

Maximal Mechanical Power Output

The maximal mechanical power produced by the contralateral forearm flexors following ipsilateral training was found to show the greatest percentage difference from pre to post test within the Group I-60%

The high force subjects (Group I and II) who trained at a velocity corresponding to 60% of their maximal isometric force showed the largest percentage difference in pre to post test power production by the contralateral forearm flexors. Group I 60% and II 60% realized percentage increases of 21.7 and 21.2 respectively following the post test measures (Table 3). These results are in partial agreement with the findings of Ikai (19) who conducted a power study utilizing training velocities corresponding to 0, 30, 60 and 100% of the maximal isometric force produced. He found the greatest displacement of the force-velocity-power curves to be with subjects who trained at 30 and 60% velocities. Within this study, greatest power increases were found to be with the

60% training group.

Within Group II (Low Force) the subjects who trained at 60% velocity, again produced the greatest pre to post test differences in maximal mechanical power output (see Table 5).

In this study it was illustrated that those subjects trained at a 60% level, produced the most readily observable transfer effects in MMPO, and thereby, greatest alteration of the power curve.

Each subject who trained in the 30% group, whether high or low force, showed a measureable pre-post percentage difference in maximal mechanical power production.

Velocities of training were based upon individual force production in the pre-test measure of maximal isometric force. Subjects were not required to train at a pre-determined velocity that might have been nearer maximal isometric force production for themselves than for one of the other subjects. In this manner, the increases or decreases realized from pre to post test measures of power output were based upon individual training regimes.

Group II (Low Force) overall, produced a pre-post test difference of +12.8% in the maximal mechanical power output (mmpo), with force at peak power occurring at a higher velocity than realized in the pre test measures.

For all training groups, non-significant pre-post test differences were found for the measure of force at peak power (Tables 4, 5, 6).

Force-Velocity

Analysis of the contralateral force-velocity relationship, following the ipsilateral training period, showed non-significant pre to post test interaction between groups and within groups. Percentage increases within Group I 60% and II 60% were found to be greater in comparison to the 30% training groups. Research of Ikai (19) also indicates a similar pattern. The nearer a subject trained at a velocity corresponding to maximal force production, the greater the pre to post test differences. Without further statistical significance it is difficult to compare the training differen[illegible]ation between High and Low force groups (I and II).

Overall, Group I illustrated the greatest percentage increase in force production from pre to post test at the higher velocities of measurement (210, 270 and 300 degrees/second) (see Table 3). A similar pattern was followed by Group II with the largest pre to post test percentage differences produced at the higher velocities of measurement (210, 270, 300 degrees/second).

The percentage differences from pre to post test should be considered in light of certain considerations. At the higher velocities of testing, a very small increase in force production could result in a very large percentage difference from pre to post test. It was noted that many subjects had, on first exposure to the Cybex II apparatus, problems in exerting force at higher velocities or in "catching up to the lever arm". F[illegible]ng the ipsilateral training period, it was found that all [illegible] the training groups were able to exert measureable forces [illegible] ocities [illegible] esting.

Considered within the limitations of this study, the forces exerted by the contralateral forearm flexors can be attributed to training transfer derived from the overload training regime that was established for the ipsilateral forearm flexors.

Moffroid's (27) research offers partial support for the findings which were established in this research. She found that subjects who trained at low power settings (low speed, high load) produced muscular strength increases only at low speed movements. Conversely, she found high power training (high speed, low load) produced increases in muscular force at all speeds at and below the training velocity. Although these findings were related to direct training of the ipsilateral forearm flexors opposed to contralateral training as within this study, the subjects who trained at the higher velocities did show pre to post test differences at and below the higher velocities of testing. Those subjects who trained at low power velocities did show parallel increases in force production primarily at the low velocity measurements. Overall, however, the greatest pre to post test percentage differences were found at the higher velocities of measurement.

The greatest alteration of the force-velocity curve from pre to post test was realized by the 60% training group whether High or Low force, although statistical significance was not found between groups.

The statistical analysis of the low force experimental Group II showed a significant pre to post test factor C. However, as with the High force training group (Group I), non-significance was found between subjects, and group interaction. Possible reasons for lack of further significance between and within groups must be considered within limitations of this study, although further elaboration is deserving. Possibly a longer period of ipsilateral training would have resulted in a larger differentiation between groups; although this is only conjecture at this point. Further, it is possible that any contralateral strength developed was not substantial enough to produce significant differentiation between subjects and within groups. Moore (29) found that a 10% muscular contraction level was required to maintain tonus but not sufficient to produce a strength increase.

Certain subjects may have had a history of coordinated, complex motor skill practice and therefore the degree of familiarity with which subject would approach the movement would vary between subjects and increase or decrease the favourable conditions which were needed for differentiation between subjects and within groups (5, 35).

Individuals who were familiar with producing maximal muscle contractions could possibly have facilitated development of overload throughout the training. Despite the fact that a familiarization period, prior to beginning the actual testing and training, was conducted, individual variation in degree of muscular contraction and hence impulse propogation intensity must be considered as reported by Cratty (5) and Singer (35) in their research.

The possibility exists that some of the subjects in the four training groups did not exert maximally and as such did not produce significant differentiation between subjects and within groups.

Although the appearance of contralateral training is statistically significant, the fact remains that fatigue of the subjects could have reduced the amount of transfer and hence the degree of differentiation within groups and between groups. The reduction in impulse intensity as fatigue increases would not facilitate contralateral transfer of muscle strength from an ipsilateral training period.

Analysis for High and Low force control groups showed non-significance for all factors of pre test to post test measures: Max. P_o, MMPO, force at peak power and force-velocity relationships. These subjects received no training of the ipsilateral forearm flexors.

CHAPTER VI

Summary and Conclusions

Summary

Forty-two female subjects were assigned to a High force or Low force experimental group based upon pre test measures of $MaxP_o$, MMPO and force exerted at velocities of 15, 25, 35, 45, and 50 RPMs by the ipsilateral forearm flexors. Subjects were then assigned to a training group with a velocity corresponding to 30 or 60% of maximal isometric force exerted, or a control group which received no training. The training groups for High and Low force subjects were subject to five weeks of isokinetic training on the Cybex II isokinetic apparatus. Following completion of the training period, all subjects were again retested on the ipsilateral and contralateral forearm flexors. Force-velocity-power curves and maximal isometric forces were determined for pre and post test measures of the contralateral forearm flexors.

The contralateral effects of ipsilateral isokinetic training were investigated with specific analysis of alteration of the force-velocity-power curves, $MaxP_o$, MMPO and force at peak power from pre to post test (factor C).

The difference in percent transfer of training for the High and Low force groups trained at 30 or 60% velocities was also studied.

An analysis of variance of data, showed a significant factor C pre to post test for MMPO, Max. P_o, and force-velocity, but non-significant interaction within and between groups.

The analysis completed showed the only significant difference established was between pre and post test scores of the trained subjects irrespective of their High or Low force grouping.

Conclusions

Generalizations drawn from this research must be considered in light of the limitations of this study.

Within this study, one basic conclusion can be drawn: Transfer of training from the ipsilateral to contralateral forearm flexors was produced by isokinetic training of ipsilateral forearm flexors.

Suggestions for Further Study

1. The area of bilateral training through unilateral exercise may still have some areas of inconsistancy and controversy. This research indicated that there is a measureable transfer effect from ipsilateral to contralateral musculature. Possible future studies utilizing muscle biopsies and fiber typing could be conducted to show if an actual increase in contralateral fiber size results.
2. Use of a longer training period could possibly show an effect on transfer measured.
3. These results indicate there is a need for future research in this area with implications projecting into actual strength training and rehabilitative areas.

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APPENDIX A

(Conversion of Angular Velocity to Linear Velocity)

Since the lever arm of the Cybex Dynamometer moves at a predetermined maximal angular velocity (degrees/second), the maximal linear velocity can be represented by the following equation:

$$V = \frac{1.571}{(A/B)} \times (R/100)$$

where: V = the maximal linear velocity (m./sec.);

1.571 = the radian measurement for 90 degrees;

A = the total angular displacement (90 degrees);

B = the maximal angular velocity (deg./sec.);

R = the radius of rotation (c.m.); and

100 = the conversion to meters/sec.

For V max, the above equation must be modified so that:

$$V_{max} = \frac{C}{(A/B)} \times (R/100)$$

where: V_{max} = the maximal velocity of contraction under unloaded conditions (m./sec.);

C = the radian measure corresponding to the angular displacement (A) at which V_{max} occurs;

B = the maximal angular velocity (deg./sec.);

R = the radius of rotation (c.m.); and

100 = a conversion to meters/sec.

APPENDIX B

(Conversion of Torque to Force)

TABLE 6

GROUP I - TRAINING VELOCITY AND FORCE

Group	Training Velocity		Training Force (Kg)
I 30%	degrees/second	RPM	
Subject 1	296	49.3	3.29
2	202	33.6	4.62
3	184	30.6	3.54
4	264	44.0	3.44
5	212	35.3	3.47
6	296	49.3	4.15
7	296	49.3	3.88
I 60%	degrees/second	RPM	
Subject 1	142	23.6	9.33
2	123	20.5	6.98
3	184	30.6	7.99
4	135	22.5	7.48
5	154	25.6	7.89
6	118	19.6	7.23
7	165	27.5	11.12

TABLE 7

GROUP II - TRAINING VELOCITY AND FORCE

Group	Training Velocity		Training Force (Kg)
II 30%	degrees/second	RPM	
Subject 1	216	36.0	3.77
2	218	36.3	3.12
3	250	41.6	5.04
4	300	50.0	3.19
5	222	37.0	4.02
6	144	24.0	3.59
7	216	36.0	3.0
II 60%			
	degrees/second	RPM	
Subject 1	90	15.0	9.41
2	112	18.6	8.96
3	152	25.3	7.05
4	107	17.8	7.34
5	110	18.3	8.44
6	111	18.5	8.73
7	81	13.5	6.29

The torque on the input shaft as measured by the Cybex Dynamometer is the product of force (lbs.) times the radius of rotation (ft.) measured perpendicular to the direction of force between the point of force application and the center of the input shaft. A simple equation can describe the torque as:

$$T = F \times R$$

where: T = the maximal torque (ft. lbs.);

F = the maximal exerted force (lbs.); and

R = the radius of rotation.

Thus:

The maximal torque (ft. lbs.) can be converted to the maximal force (kg.) by:

$$F = \left(\frac{T}{7.233}\right)/R$$

where: F = the maximal exerted force (kg.);

T = the maximal torque (ft. lbs.);

7.233 = the number of ft. lbs. in 1 kilogram-meter; and

R = the radius of rotation (meters)

APPENDIX C

(Anthropometric Data)

TABLE 8

Anthropometric Data

Subject	Age (Yrs.)	Wt. (Lbs.)	Length of Forearm (cm)
1	20	127	29.0
2	20	130	30.5
3	19	142	31.0
4	18	127	30.5
5	21	113	27.5
6	18	123	29.0
7	19	135	29.0
8	19	136	30.0
9	19	136	30.0
10	22	138	27.5
11	19	135	30.5
12	21	120	31.0
13	25	134	31.0
14	20	155	31.0
15	20	122	32.0
16	19	132	29.5
17	25	123	31.0
18	23	128	30.5
19	27	135	31.0
20	19	126	31.0
21	21	118	28.0

Subject	Age (Yrs.)	Wt. (Lbs.)	Length of Forearm (cm)
22	19	132	33.0
23	19	130	32.0
24	19	164	32.0
25	23	105	28.0
26	22	137	32.0
28	22	115	30.0
29	26	134	30.0
30	20	135	31.0
31	20	138	31.0
32	20	138	32.0
33	23	120	29.5
34	25	126	30.0
35	25	118	28.5
36	22	117	28.0
37	24	119	30.0
38	22	130	29.0
39	26	136	32.0
40	23	142	33.0
41	21	115	31.0
42	18	142	29.5

APPENDIX D

FORCE-VELOCITY-POWER CURVES - GROUPS I AND II

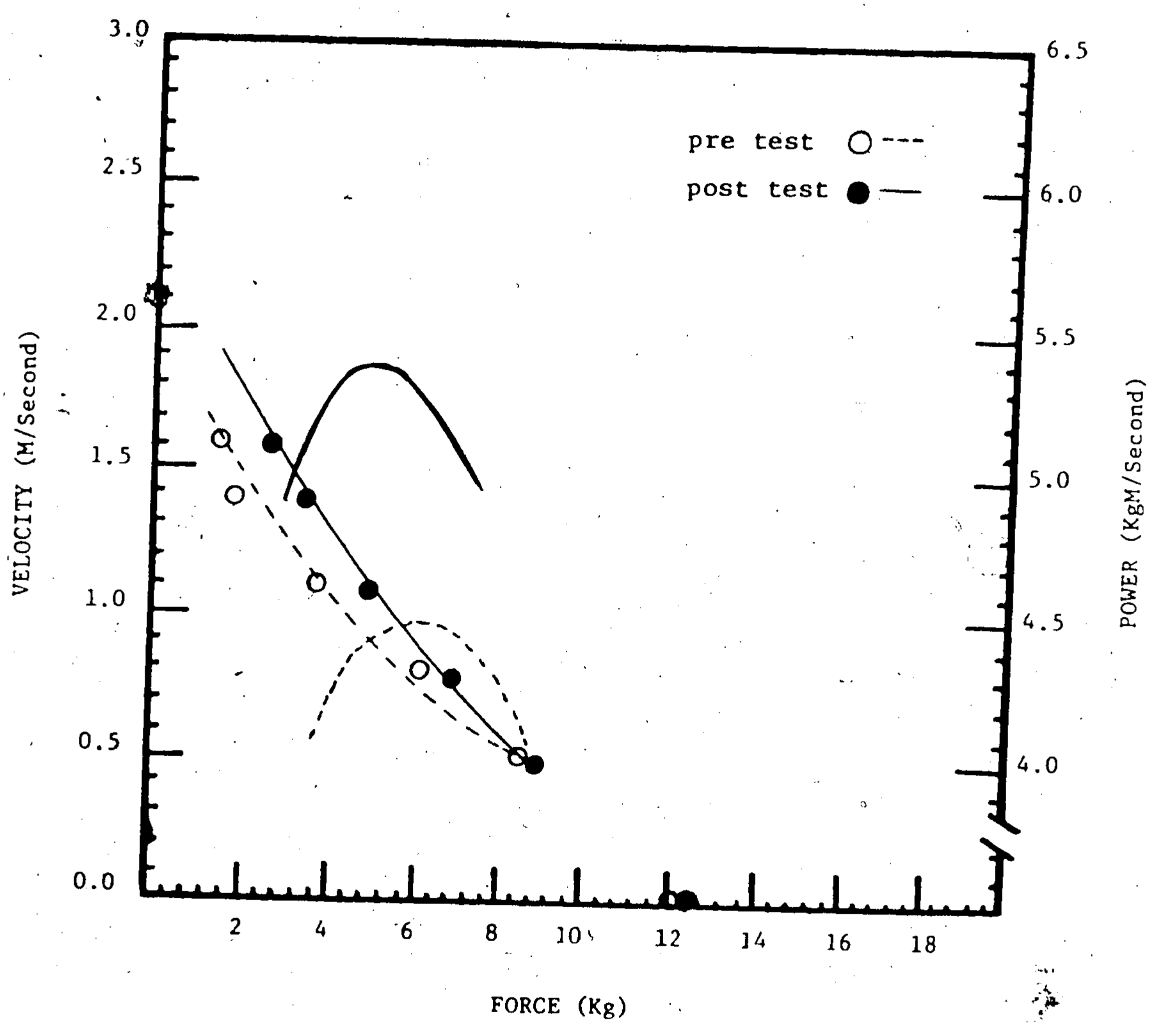

FIGURE 7

Group I 30% - Contralateral Force-Velocity-Power Curves

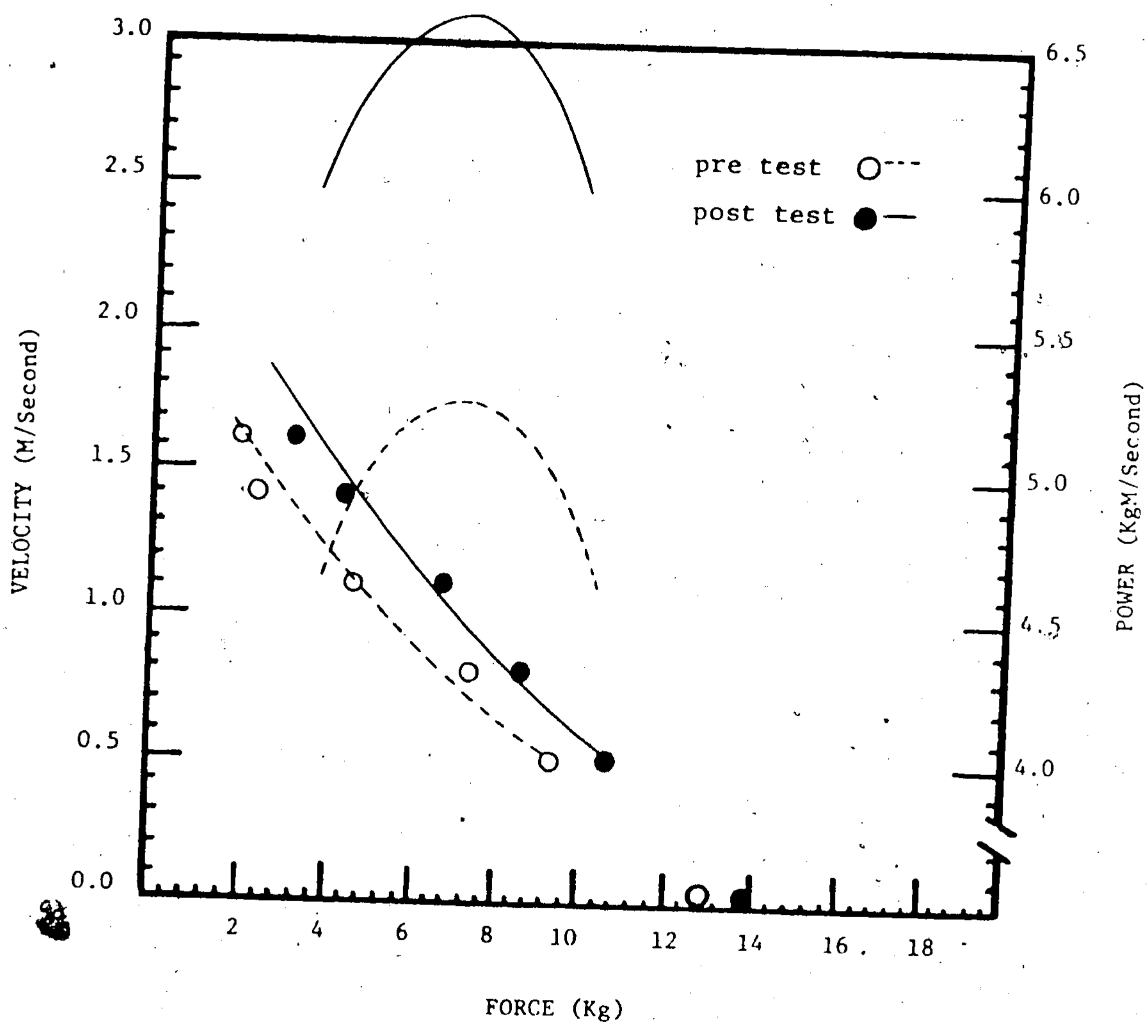

FIGURE 8

Group I 60% - Contralateral Force-Velocity-Power Curves

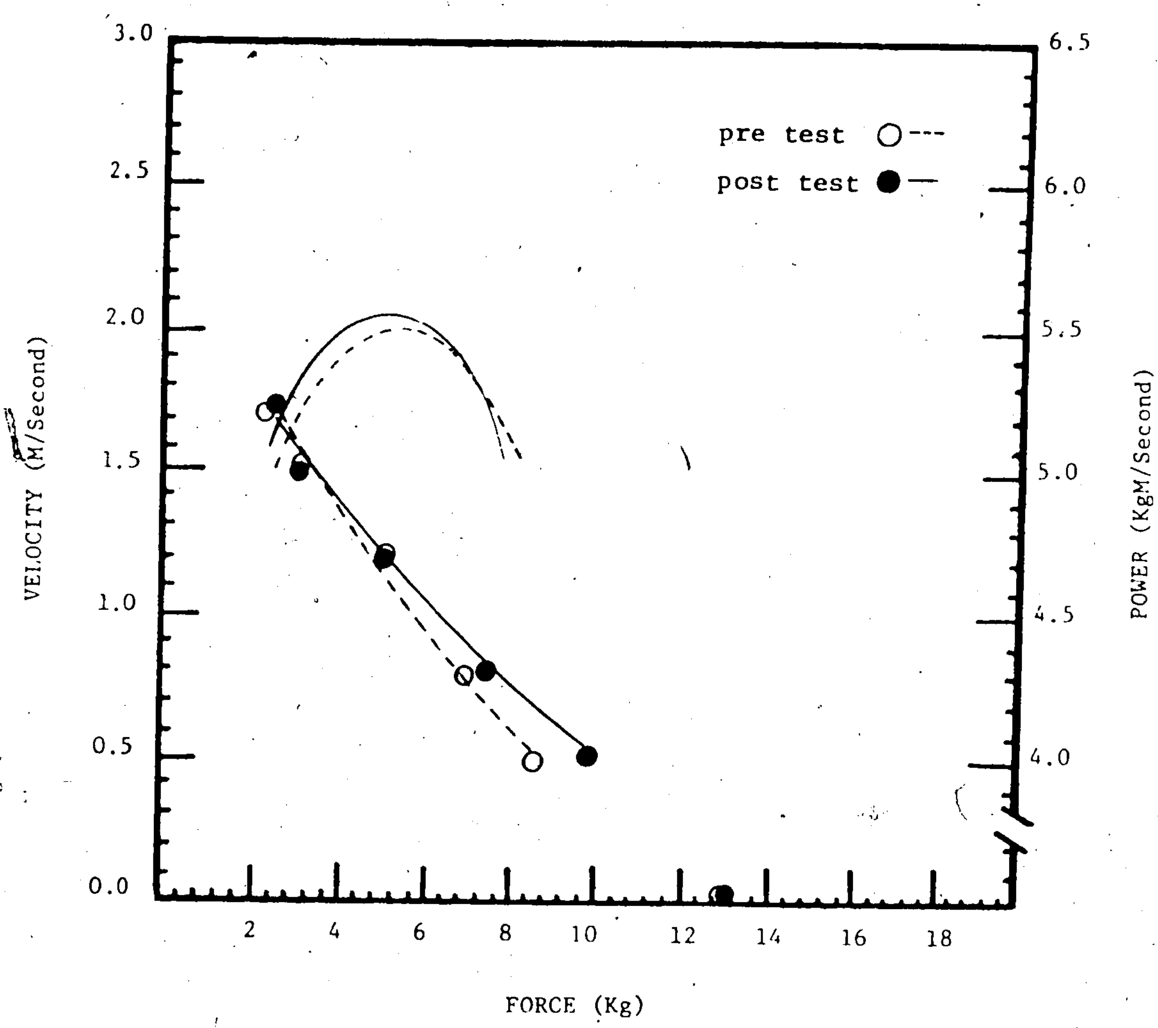

FIGURE 9

Group I Control - :ralateral
Force-Velocity-Pow Curves

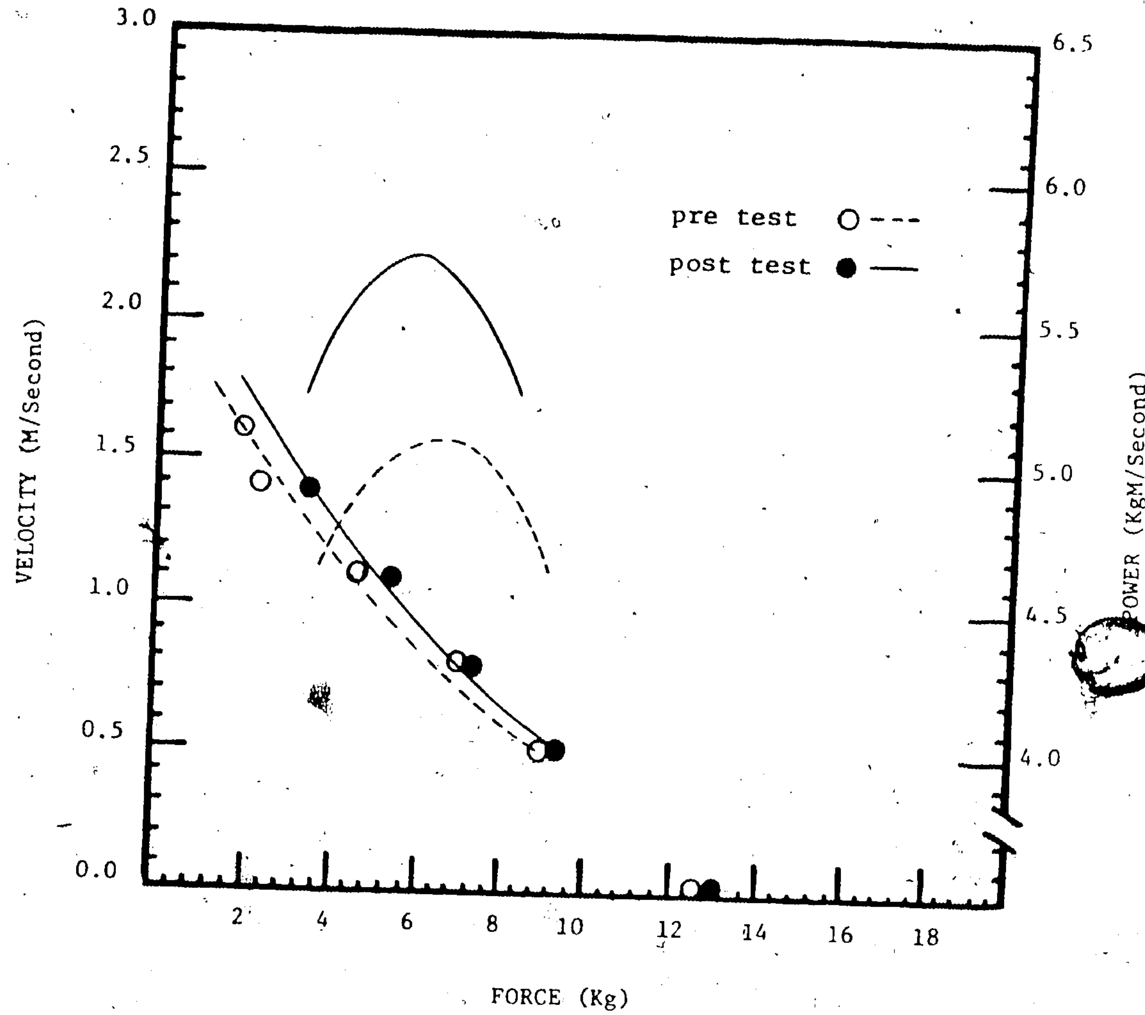

FIGURE 10

Group I: Contralateral Composite Force-Velocity-Power Curve

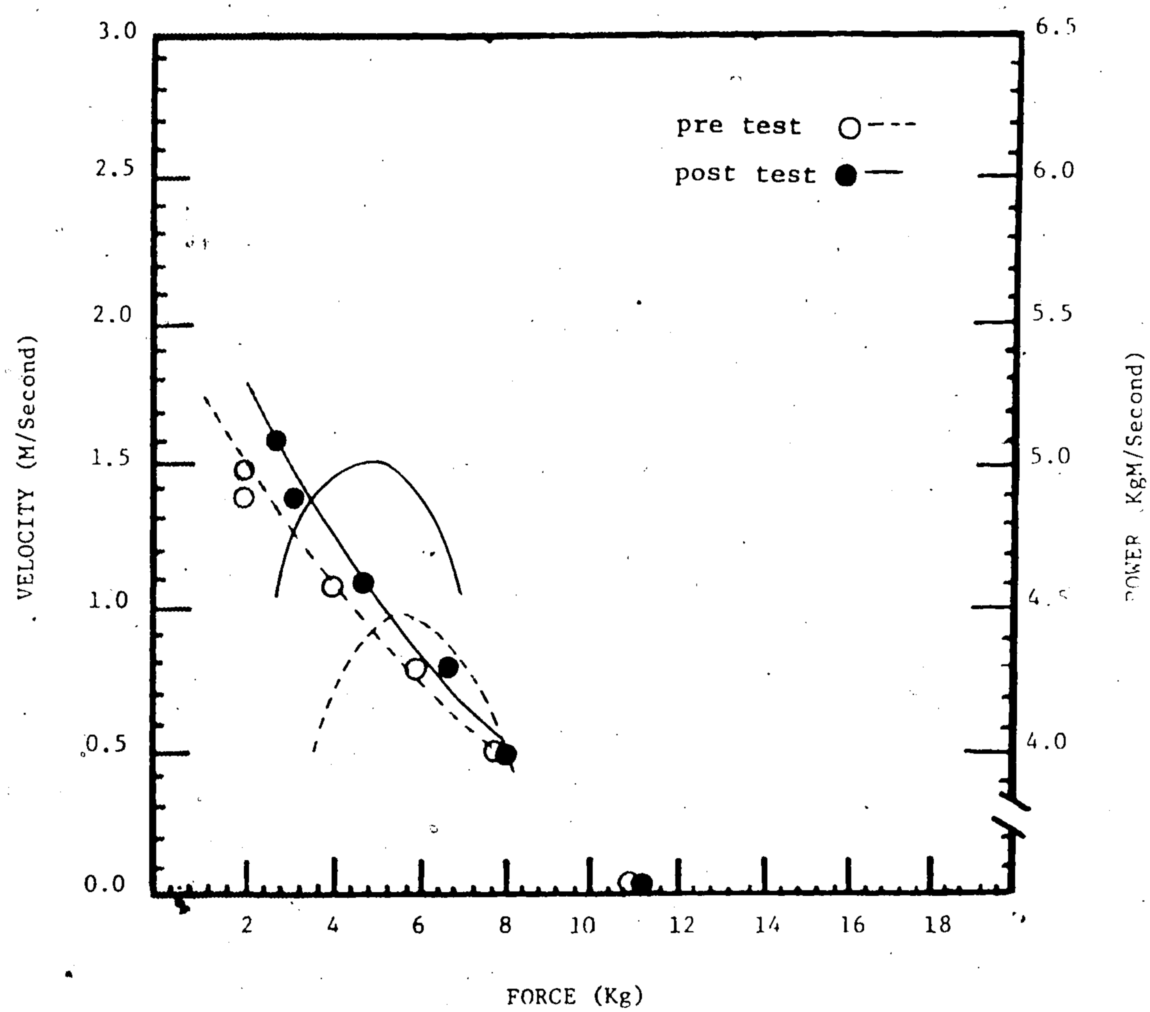

FIGURE 11

Group II 30% - Contralateral Force-Velocity-Power Curves

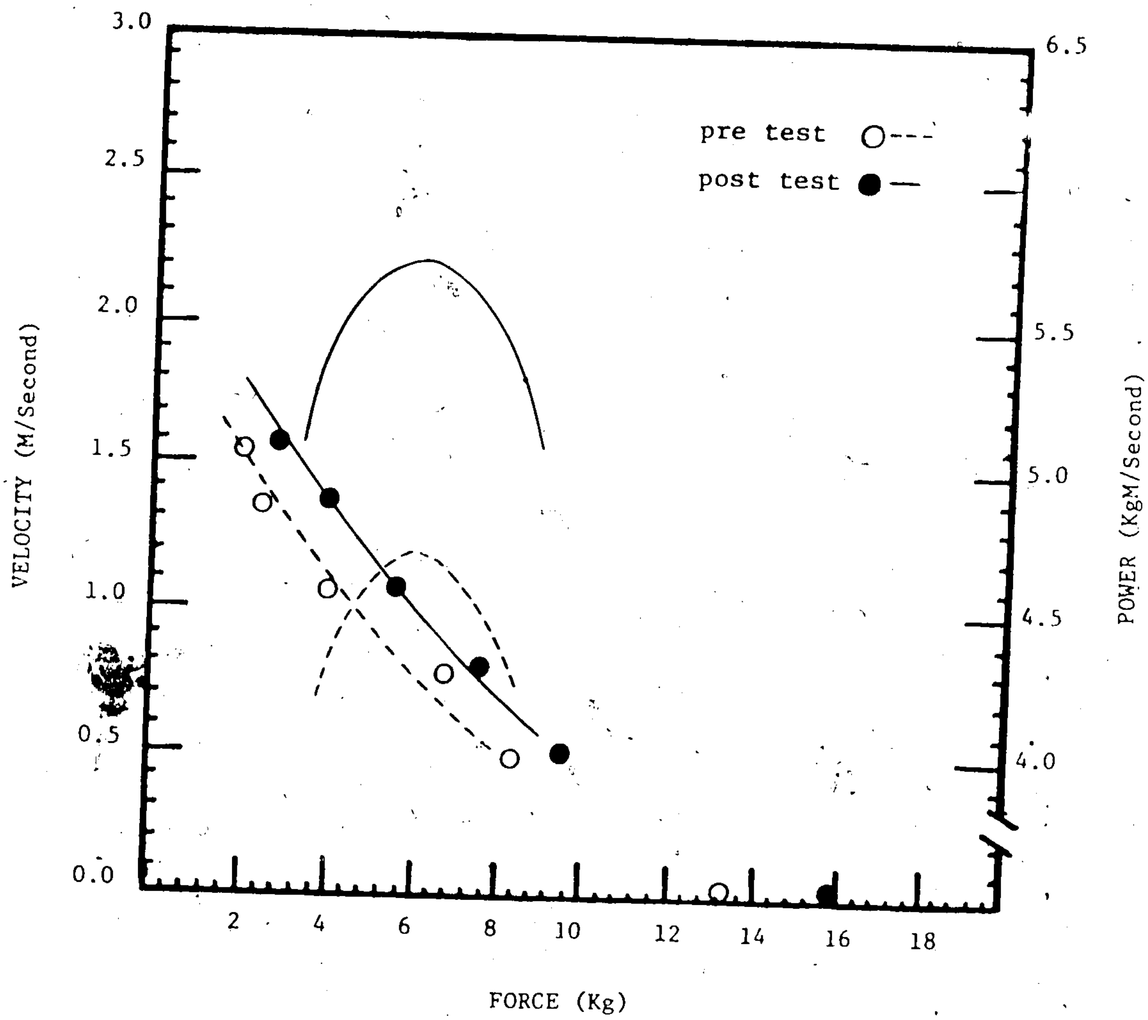

FIGURE 12

Group II 60% - Contralateral Force-Velocity-Power Curves

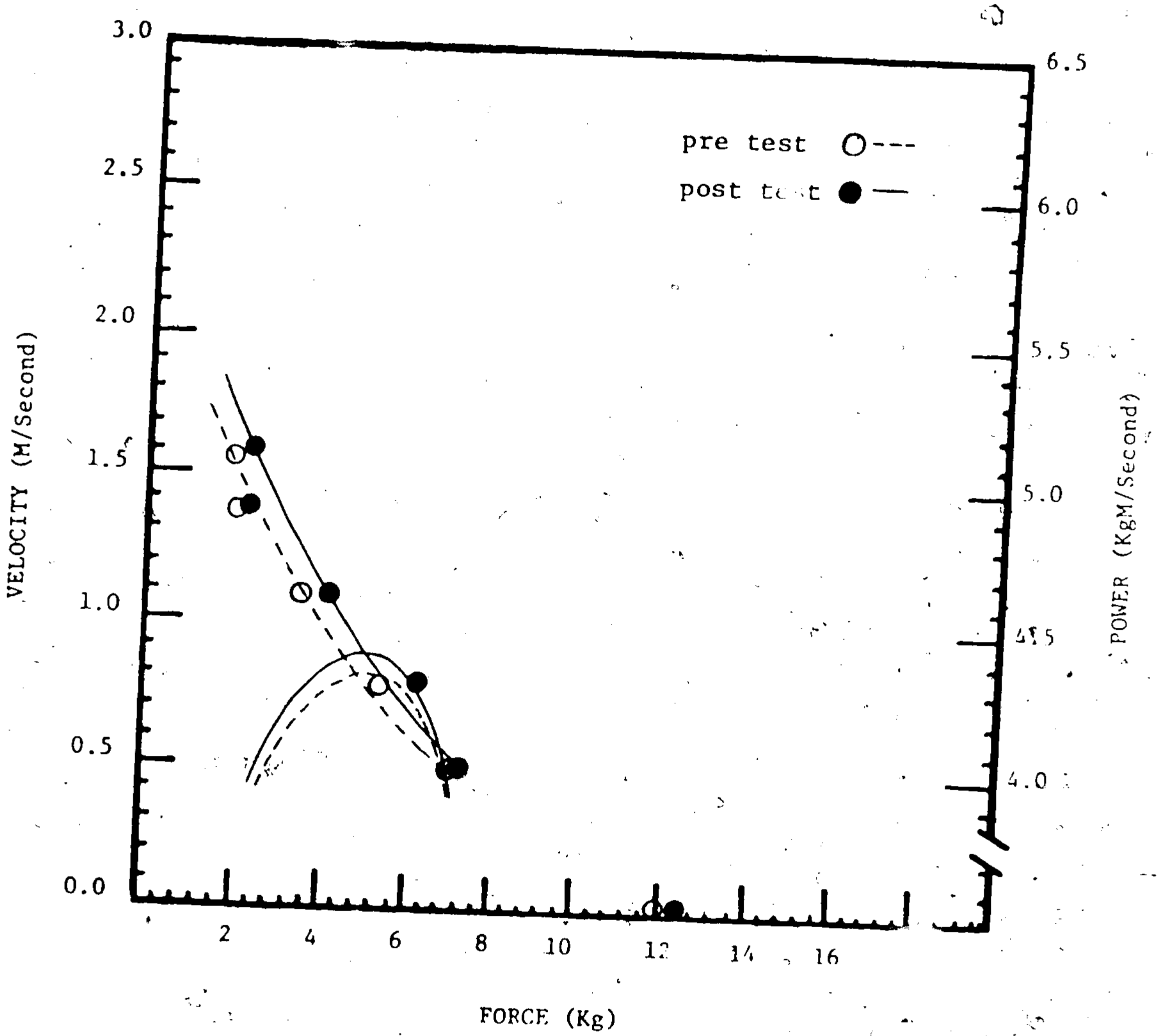

FIGURE 13

Group II Control - Contralateral Force-Velocity-Power Curves

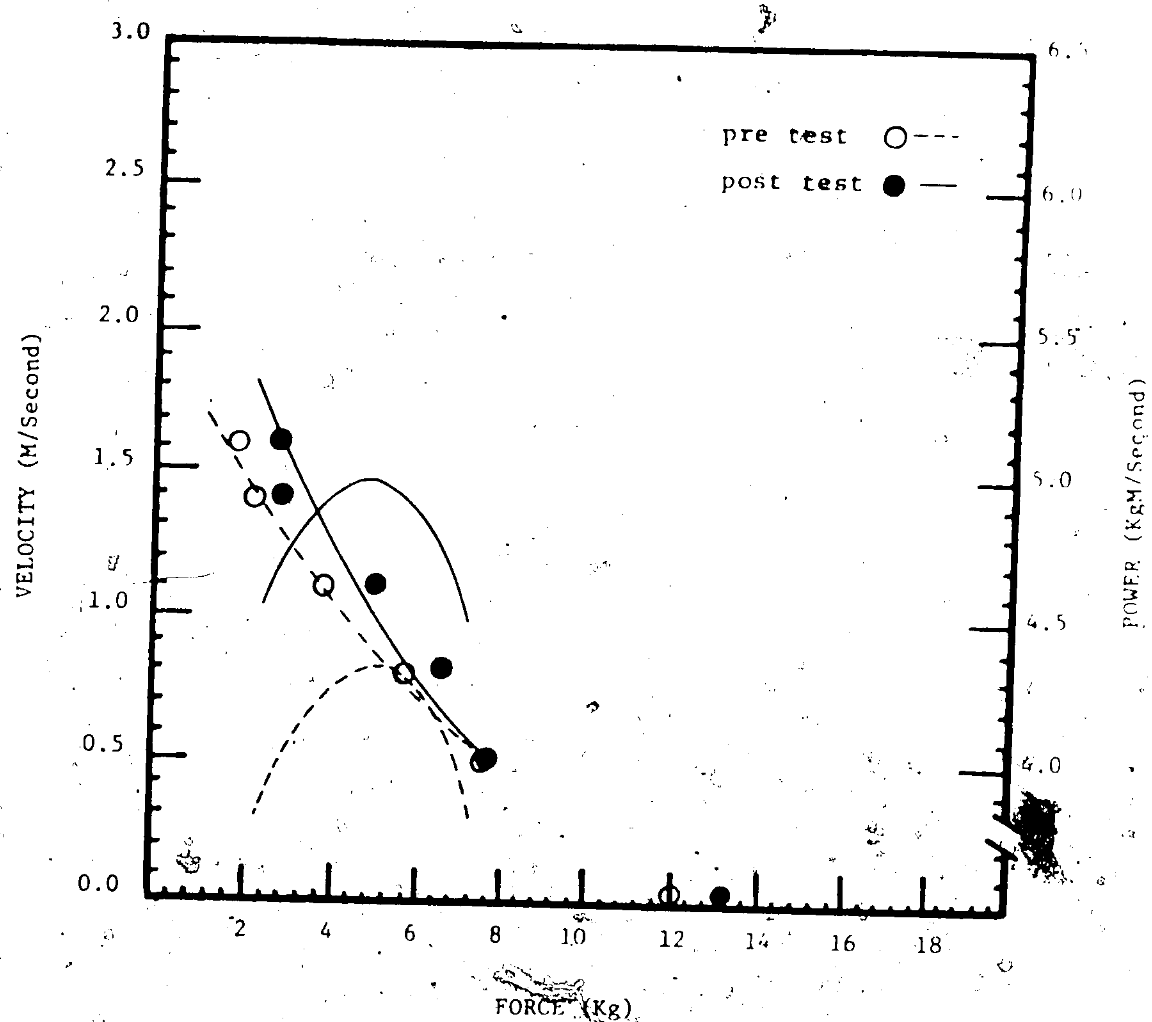

FIGURE 14

Group II: Contralateral Force-Velocity-Power Curves

APPENDIX E

Statistical Design

COMMENTS AND DIAGRAMMATICAL DESCRIPTION OF SUBJECTS TO BLOCKS AND TREATMENTS AND THE OVERALL EXPERIMENTAL DESIGN

1. Subjects were ranked in order of their maximal exerted force at peak MMPO. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, , 32, 33, 34, 35, 36, 37, 38, 39, 40, 4 , 42.

2. Subjects were then blocked according to their rank.

Block 1	Block 2
S1.....................S21	S22.....................S42

3. Subjects from each block were then randomly assigned to one of three treatments.

(a)	(30 P_o)	Block 1	Block 2
(b)	(60 P_o)	Block 1	Block 2
(c)	(C)	Block 1	Block 2

4. Subjects were tested twice, once prior to training and once following the training program.

5. Thus the design utilized was a 2 (blocks) x 3 (treatments) x 2 (time) factorial design (fixed model) with repeated measures on factor C.