

**THE EFFECTS OF VELOCITY SPECIFIC ISOKINETIC  
TRAINING ON STRENGTH, HYPERTROPHY, AND CROSS EDUCATION**

**by**

**Rodney P. Gaines**


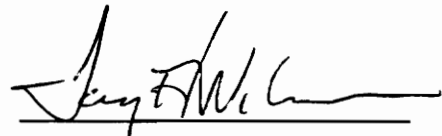
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**APPROVED:**

  
**Don Sebolt, Chairman**  
**Ronald Bos, Co-Chairman**  
**Jay Williams**

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## THE EFFECTS OF VELOCITY SPECIFIC ISOKINETIC TRAINING ON STRENGTH, HYPERTROPHY, AND CROSS EDUCATION

Rodney Gaines

This study examined the effects of six weeks of velocity specific isokinetic training on peak torque (PT), and the estimated cross-sectional area of the upper arm (AG) in the trained. Thirty volunteers (M=15, F=15) were randomly assigned to an experimental, slow velocity group (S), 60 degrees-per-second ( $n=9$ ;  $25.4 \pm 6.5$ yr), a fast velocity group (F), 450 degrees-per-second ( $n=11$ ,  $23.7 \pm 5.4$ yr), or control group (C) ( $n=10$ ,  $26 \pm 3.2$ yr). One limb was randomly selected for isokinetic training (3 d/wk-elbow flexion) using a Biodex System 2 isokinetic dynamometer. The contralateral limb served as a control and as the basis for measurements measure of cross education (CE). Both experimental conditions (S) and (F) were assigned equal training workloads, calculated from an isokinetic pre-test. Pre- and post-tests (PT) were recorded for both limbs at the training velocities of 60 and 450 degrees-per-second, as well as the velocity of 210 degrees-per-second. Pre and post-test (AG's) were measured on the training limb. The (S) condition was significantly different in strength gains from the control at 60 degrees-per-second, but not different from the fast velocity group in the trained limb. The (F) condition was significantly different in strength gains from the control at 450 degrees-per-second, but not different from the slow velocity group in the the trained limb. The conditions were not significantly different from each other in the trained limb at the test velocity of 210 degrees-per-second. The three conditions significantly different from each at the test velocity of 60 degrees-per-second in the trained limb. The conditions did not differ in strength at velocities of 210 and 450 degrees-per-second in the trained limb. The conditions did not differ in the cross-sectional area of the upper arm in the trained limb. The (S) and (F) training conditions improved (PT) by 12.36% and 18.84% at their

respective training velocities of 60 and 450 degrees-per-second. These improvements were significantly ( $p < .05$ ) larger than (C). The (S) and (F) training conditions also increased (PT) by 11.56% and 11.24% at the non-training velocity of 210 degrees-per-second ( $p < .05$ ). Significant 10.77% ( $p < .05$ ) improvement in (AG) was recorded in the (S) condition. No changes in (PT) were recorded in the contralateral limb within the three conditions. These data support the concept of limited (S) and (F) bi-directional (PT) overflow and (S) velocity hypertrophy enhancement. The presence of cross education (CE) was not supported by this investigation.

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## CHAPTER I

### INTRODUCTION

#### Historical Perspective

Historically, strength has been defined in many ways. An early definition of strength was "the maximal display of contractile power" (Steindler, 1935). This definition is somewhat vague, since power was not defined by Steindler. Clarke (1973) defined strength as the maximal tension muscles can apply in a single contraction. More recently, Costill and Wilmore (1994) defined strength as the maximum force a muscle or muscle group can generate. There is no single definition of strength; there are as many definitions of strength as there are ways to measure it (Caldwell, 1964); however, the definitions of Clarke, and Wilmore and Costill convey the most prevalent understanding of the term strength.

Strength has been further defined or classified as: static, dynamic, or explosive strength. Static strength is measured isometrically as force or torque against an immovable resistance. Dynamic strength is measured isotonicly as force or torque applied to a movable resistance. Explosive strength is usually expressed as power, implying fast, maximally forceful efforts. When any one of these definitions of strength manifests itself in a training regimen, it is known as strength training.

Strength training by humans extends well beyond the published record. In primitive time, humans relied on physical strength to fulfill personal needs and provide protection (Clarke, 1973). There have been reports of strength training in India some 5,000 years ago (Stutley and Stutley, 1977). Strength training has also been a way of giving a sacrificial offering to the gods. Instead of sacrificing blood, the Greeks performed strength training as a sacrifice to their gods. The Romans were the first to practice

progressive resistance exercise (Atha, 1981). This type of training has stayed with us for the last 2,000 years (Vegetius, cited by Zeigler, 1973).

Before World War II strength training was not widely practiced. During and after World War II due to the need to condition and, especially, to rehabilitate soldiers, strength training received much attention. Presently, strength training is extensively utilized in physical and occupational therapy, in the training of athletes, and in fitness programs.

### Types of Muscle Contraction

In strength training muscles exhibit one of three types of contraction: concentric, eccentric, or isometric. Concentric muscle contractions involve shortening of the muscle as tension develops. These contractions are often referred to as dynamic contractions. With concentric contractions the tension developed by the muscle varies somewhat over the range of joint motion. Eccentric muscle contractions are similar to concentric contractions, in that, they are dynamic, but opposite from concentric contractions, in that the muscles lengthen as tension develops. For example, during the extension segment of the biceps curl, with a moderate to heavy load, the elbow flexors contract eccentrically to control the descent of the weight. With isometric contractions the muscles remain at the same overall length as tension develops. An example of an isometric contraction is pushing against an immovable resistance. Isometric contractions are also referred to as static contractions, since no movement takes place. These three types of muscle contractions are the ingredients for various types of strength training: isotonic, isometric, plyometric, and isokinetic.

### Types of Strength Training

Isotonic strength training is often referred to as progressive resistance exercise or weight training. Isotonic training consists of repeated, concentric and/or eccentric contractions with a constant, movable load. Some of the modalities used for isotonic training include free weights (barbells, dumbbells, cuff weights), machine weights (Eagle, Nautilus, and Universal), and hydraulic systems.

A number of different training variables may be utilized in isotonic training. The load may be varied, often as a percentage of an individual's one-repetition-maximum. The load for isotonic training is typically 70-80% of the one-repetition-maximum. The number of repetitions may be varied. Typically, the recommendation for isotonic training ranges from six to ten repetitions, with the number of sets of repetitions ranging from three to six. The number of training sessions per week is between three and five.

The advantages of isotonic strength training consist of the following: the training takes place through the entire range of motion at a joint, consists of both concentric and eccentric contractions, utilizes progressive resistance, and effectively increases strength with relatively few repetitions. The disadvantages of isotonic training are: the maximal resistance is applied only at the weakest point in the range of motion, training takes place at a relatively slow velocity, pain or fatigue at a point in the range of motion is not accommodated, and it is impossible to vary the load as leverage changes occur throughout the range of motion.

Isometric training consists of repeated muscular contractions performed against a fixed or immovable resistance. This type of training was brought to our attention by two German scientists, Hettinger and Muller (1953). They demonstrated that isometric training increased strength an average of five percent per-week as the result of holding isometric

tension for six seconds at two-thirds maximum, once-a-day, five days-a-week. These findings revolutionized the use of isometric strength training.

Most types of strength training involve muscle contractions with changes in the length of the muscle. Isometric training generates tension in the muscle; however, there is no overall shortening or lengthening of the muscle during this type of contraction. The modalities used for isometric training invariably utilize an immovable resistance. For example, a wall against which one pushes is an immovable resistance. Tensiometers and dynamometers have often been utilized for isometric training, as well as for isometric testing. Electronic load cells are replacing these devices, since load cells are more accurate as testing equipment.

The variables for isometric training are similar to those utilized in isotonic training. The load in isometric training is usually from two-thirds maximum to maximum. These loads are usually applied for five seconds during five to ten repetitions, three to five times-a-week. One set of repetitions is usually as effective as more than one set.

The advantages of isometric strength training include the following: it can be performed anywhere in a very short period of time, and it is effective at increasing muscular strength at a specific joint angle or limb position. A disadvantage of isometric training is that muscle strength gains are somewhat specific to the training joint angle or limb position. Also, it is difficult to receive feedback during isometric training, thus lack of motivation due to lack of feedback is a disadvantage of this type of training.

Plyometric training consists of explosive movements against resistance. Plyometric training usually consists of jumping, running downhill, or throwing and catching. Plyometrics utilize an external force to stretch muscles and thus store energy in these muscles to be used in a subsequent contraction. An example of plyometric training is box jumps. An individual steps off of a box, upon hitting the ground the lower extremity

extensors are stretched due to the force of gravity, and subsequently shorten as the individual jumps as high as possible.

The basis of plyometric training is an eccentric muscle contraction followed by a concentric contraction. These contractions take place during the so-called stretch-shortening cycle. During the stretch portion of the cycle, potential energy is stored in the elastic elements of the muscle and the stretch reflex is activated. The stored energy and reflex facilitate strong eccentric and concentric contractions.

Plyometric training, like isotonic training, can be performed as progressive resistance exercise. The load may be varied by making changes to equipment. For example, more load can be produced on the muscles by increasing the height of the boxes in the box jumps. Repetitions may also be varied; a beginner in a plyometric training program performs 20 to 50 foot contacts or repetitions per set. Advanced plyometric training consists of 50 to 100 repetitions per set. The foot contacts or repetitions are usually divided into two to three sets. Plyometric training is usually practiced two times-a-week.

The advantages of plyometric training include the following: it can be very sports or activity specific, and it is somewhat velocity specific in that training takes place at high velocities. The disadvantages of plyometric training include the prevalence of injuries, and the lack of feedback to the individual during training.

Isokinetic training is a relatively new type of strength training. Isokinetic training consists of repeated muscular contractions at a constant velocity throughout the full range of motion at a joint. Isokinetic training may include both concentric and eccentric muscle contractions. Isokinetic equipment has a velocity controlling device that keeps the velocity constant no matter how much force is applied by the contracting muscles. Of equal or greater importance is the ability of isokinetic equipment to provide varying, maximally

resistive loads at all positions throughout the range of motion. The resistance always matches the effort of the individual. Examples of brand name isokinetic equipment are Cybex, Biodex, and Kin-Com.

Since isokinetic equipment controls the velocity of movement, isokinetic training may be performed at specific slow, moderate, or fast velocities. The capability of training at specific velocities has led to research comparing strength gains at relatively slow, moderate, and fast velocities (Moffroid and Whipple, 1970; Pipes and Wilmore, 1975; Coyle et al., 1981).

When considering the load in isokinetic strength training, one must consider the force-velocity relationship of contracting muscle. Higher velocities of training will result in less applied force or torque; slower velocities of training will result in greater applied force or torque, thus greater resistance. Negative training velocities, that is, eccentric training result in still greater loads. The number of repetitions utilized in isokinetic training usually ranges between 8 and 15, and the number of sets is usually limited to three. Training frequency is usually three days-per-week. Significant strength training effects are typically seen after six weeks of training.

Some of the advantages of isokinetic strength training include the following: it provides optimal loading of a muscle throughout the range of motion, provides minimal post-exercise soreness since the contractions are usually concentric, and it accommodates pain or weakness at specific points in the range of motion. A major disadvantage is the cost of the equipment. Another disadvantage is the difficulty of manipulating the equipment to include both concentric and eccentric contractions in the training regimen.

## **Training Effects**

The aforementioned types of strength training typically bring about significant strength gains. Caiozzo (1981) reported strength gains as high as 14 % with only four weeks of isokinetic strength training. Gains in strength have ranged from 8% to 44% with ten to twelve weeks of training (Allen et al., 1976; Wilmore et al., 1978). Strength gains are primarily due to muscle hypertrophy and adaptations in the neuromuscular system. The latter may bring about cross education, that is, strength gains in the contralateral limb.

Muscle hypertrophy is the enlargement of the muscles due to an increase in the cross sectional area of the individual muscle fibers. Hypertrophy is a normal response to strength training (Enoka, 1994). Bodybuilders train with moderate to heavy loads to increase hypertrophy. Muscle hypertrophy is the result of an alteration in the balance of protein synthesis and degradation at the cellular level. When protein synthesis is greater than protein degradation, muscle hypertrophy takes place. Strength training promotes accelerated protein synthesis (Behm, 1995).

Muscle hypertrophy is measured by determining the cross sectional area of individual muscle fibers. This determination requires a needle biopsy and a sample of muscle tissue. Muscle hypertrophy can also be assessed indirectly by anthropometric techniques which measure changes in limb girth, with adjustments for subcutaneous fat.

Most of the strength gains that occur early in a training program are not accompanied by hypertrophy (Moritani and deVries, 1979). These authors feel that these early strength gains are due to neuromuscular adaptations. Adaptations to the neuromuscular system may include the following: increased neural drive to the muscle, increased synchronization of the motor unit contractions, increased activation of the contractile apparatus, and inhibition of the protective mechanisms of the muscle, such as Golgi tendon reflex (Fleck and Kraemer, 1987).



Cross education is also a neural response to strength training. Cross education is an increase in the strength of an untrained limb resulting from the training of the opposing limb. These strength gains in the untrained limb are due to neural adaptations (Moritani & deVries, 1979). These researchers observed a significant increase in strength in the untrained limb in the absence of muscle hypertrophy. Moritani and deVries (1979) also noticed an increase in the Integrated Electromyogram in the absence of muscle hypertrophy in the untrained limb. Their conclusion was that the increase in strength was a result of neural factors acting at various levels of the nervous system.

#### Statement of the Problem

There have been several investigations of velocity specific training and its affect on strength in the trained limb. However, the reports of velocity specific training have been contradictory. Early investigations of velocity specificity report that strength increases only occurred at the training velocity and lower velocities, regardless of the training velocity (Moffroid And Whipple, 1970; Lesmes et al, 1978). Moffroid and Whipple (1970) reported that slow velocity training resulted in significant strength gains at and below the training velocity, but not above the training velocity. Their fast training group recorded, similarly, strength gains at the training velocity and slower velocities; however, they did not test at velocities higher than the training velocity of the fast training group. Lesmes et al. (1978) reported results similar to Moffroid and Whipple.

Coyle et al. (1981) reported that strength gains occurred above the training velocity. He found that at a slow training velocity ( 60 degrees-per-second) strength gains occurred at and above this training velocity. At a fast training velocity Coyle et al. (1981) observed that strength gains occurred at the training velocity and all velocities below. However, they did not test faster than the training velocity of the fast training group.

Caiozzo et al. (1981), similar to Coyle et al., reported that strength gains occurred above the training velocity. For a slow training group (1.68 radians-per-second) strength gains were reported at and above the training velocity. Caiozzo found that fast velocity training (4.19 radian per second) increased strength at that velocity and a few slower velocities, but not at all velocities below the training velocity. The slow training velocity (1.68 radian per second) increased strength at that training velocity at a faster velocity (4.19 radians-per-second).

A study conducted by Jenkins (1984) reported results which agreed, somewhat, with Caiozzo et al. Jenkins reported that training at slow training velocities failed to show strength gains below the training velocity, but did show strength gains at faster velocities. Jenkins also reported that the fast training group had strength gains at the training velocity, and at faster and slower velocities. Similar to Jenkins, Petersen (1989) showed that fast velocity training (3.14 radians per second) generated strength gains at and above the training velocities, and at some velocities below the training velocity. Slow velocity training (1.05 radian per second) similarly increased strength at and above the training velocity (4.19 radian per second). The researchers did not test below the training velocity of the slow group.

It is apparent from these studies that we do not have a clear picture of the effects of velocity specific, isokinetic training. It is apparent that velocity specific training increases strength at the training velocity. Whether velocity specific training increases strength above and below the training velocity is much less apparent.

There has also been research indicating that strength gains in a trained limb result in increases in strength in the contralateral limb (Hellebrandt et al., 1947; Coleman, 1969; Houston et al., 1983; Moritani and deVries, 1979). However, only a few studies (Housh and Housh, 1993; Stevens et al., 1980; Krotkiewski et al., 1979) have examined at the

effects of velocity specific training on strength gains in the contralateral limb. Narici et al. (1989) failed to report any strength gains in the contralateral limb from training at 120 degrees-per-second. Stevens et al. (1980) reported significant strength gains in the contralateral limb from velocity specific training at velocities of 0, 60, 120, 180, 240 and 300 degrees-per-second following training at a velocity of 180 degrees-per-second. Krotkiewski et al. (1979) trained subjects at a velocity of 60 degrees-per-second, and reported strength gains in the contralateral limb at test velocities of 0 and 120 degrees-per-second. They failed to report strength gains at 30, 60, and 180 degrees-per-second in the contralateral limb. Housh and Housh (1993) did not show any significant gains in strength in the contralateral elbow flexors following elbow flexion/extension and knee flexion/extension training, but strength gains in the elbow extensors and knee flexors and extensors in the contralateral limb were observed. Although strength gains in the contralateral limb have been demonstrated following velocity specific training, it is unclear whether velocity specific training has any effect in the strength gains in the elbow flexors or other upper extremity muscle groups.

Another area that has been the subject of only a few investigations is the relationship of velocity specific training to muscle hypertrophy. Katch (1975), utilizing isokinetic training, showed that slow velocity training is more advantageous for promoting muscle hypertrophy. Later, research done by Coyle et al. (1981) showed that fast velocity training caused a greater increase in the size of the type II fibers in the muscle as compared to the type I fibers.

In view of the aforementioned research and in some areas lack of research, the purpose of this study was to determine the relationship among velocity specific isokinetic training and strength gains in the trained limb and the contralateral limb. In addition, it was

the purpose of this study to determine the effect of velocity specific isokinetic training and muscle hypertrophy in the trained limb as measured by arm girth.

### Research Hypotheses

Ho: There were no differences in the changes of absolute peak torque in the trained limb, among the slow, fast, and control groups following six weeks of isokinetic elbow flexor training.

Ho: There were no differences in the changes of absolute peak torque, in the contralateral limb, in the isokinetic peak torque among the slow, fast, and control groups following six weeks of isokinetic elbow flexor training.

Ho: There were no differences in the estimated cross-sectional area of the upper arm, in the trained limb among the slow, fast, and control groups following six weeks of isokinetic elbow flexor training.

Ho: There were no differences in the changes of absolute peak torque, in the trained limb, within the slow, fast, and control groups when tested at elbow flexion velocities of 60, 210, and 450 degrees-per-second.

### Significance of the Study

The findings of this study have shed light on the question, is it more effective to train at slow or fast velocities? This question has been answered, in part, by determining peak torques at various test velocities, following slow or fast isokinetic training. In addition, to further elucidate training effects, muscle hypertrophy was measured through anthropometric techniques following slow and fast training. Strength gains were also

measured in the contralateral limb. The latter has considerable significance for rehabilitation of injured or diseased limbs.

### **Delimitations**

The following delimitations were present in this study:

1. The subjects were untrained males and females between the ages 18-40.
2. Isokinetic training took place over six weeks. The training consisted of elbow flexion at a velocities of 60 or 450 degrees-per-second. Following training, strength was measured at velocities of 60, 210, and 450 degrees-per-second. The subjects trained at 70% of their maximum work capacity during weeks 1 and 2, 80% during 3 and 4, and 90% of their work capacity for weeks 5 and 6. Maximum work capacity was based on the maximum work output of a single repetition in a five repetition set.
3. The independent variables were the training velocities of 60 and 450 degrees per second, and the training interval of six weeks.
4. The dependent variables were absolute peak torque in the trained and contralateral limb, and the estimated cross-sectional area of the trained arm.

### **Limitations**

The following limitations of the study were:

1. The training period was only six weeks.
2. Although subjects were asked to refrain from any other resistance training activities, they were not monitored to determine the efficacy of this request.
3. Since there was only one isokinetic machine, no more than 30 subjects could be accommodated in this study.

4. Volunteers who were not available for entire six weeks were assigned to the control group.
5. Selection of the fast training velocity of 450 degrees-per second precluded testing at faster velocities for the fast training group.

### **Definitions and Symbols**

The following definitions and symbols are utilized herein:

1. Absolute peak torque (PT): the highest torque generated about a joint's axis of rotation, that is, the single highest point on the recorded torque curve.
2. Concentric contraction: a muscular contraction in which the muscle shortens.
3. Eccentric contraction: muscular contraction in which the muscle lengthens.
4. Isotonic contraction: concentric or eccentric contractions with a constant load.
5. Isokinetic contraction: a contraction at a constant velocity with an accommodating variable resistance.
6. Isometric contraction: a static contraction against an immovable resistance.
7. Slow group (SG): subjects that trained at a velocity of 60 degrees per second.
8. Fast group (FG): subjects that trained at a velocity of 450 degrees per second.
9. Control group (CG): subjects that did not train during the six weeks of the study.
10. Muscle hypertrophy: increase in the cross-sectional area of individual muscle fibers.
11. Arm girth: the circumference of the arm at the midpoint between the elbow and shoulder joints.
12. Cross education: strength gain in an untrained limb.
13. Velocity specificity: strength training at a specific velocity.
14. Strength. referred to as absolute peak torque

### **Basic Assumptions**

The following basic assumptions were made:

1. All subjects performed no other strength training during the study.
2. It was assumed that all subjects gave a maximal effort during the testing and training.
3. It was assumed that all of the subjects were untrained or had been off any training program for at least one year.
4. It was assumed that all subjects abstained from the use of ergogenic aids.

### Summary

Strength is presently known as the maximum force or torque a muscle or a muscle group can generate. Strength training became widespread during and after World War II to better condition and rehab the soldiers. During strength training, muscles exhibit three types of contractions: concentric, eccentric, or isometric. These contractions are included in one or more various types of strength training: isotonic, isometric, plyometric, and isokinetic.

Of these training types, isokinetic training is unique in that training takes place at specific velocities. The effects of velocity specific training, although not completely clear, include strength gains, muscle hypertrophy, and neuromuscular adaptations including cross education.

The effects of velocity specific training on strength gains at the training velocity and faster and slower velocities have been varied and inconclusive. It is evident that velocity specific training generates strength gains at the training velocity. Whether velocity specific training causes strength gains below the training velocity, above the training velocity, or both is not clear.

The influence of velocity specific training on muscle hypertrophy has received some, but not a great deal of attention. Whether slow or fast velocity training is more

advantageous for bringing about muscle hypertrophy is not clear. Most of the strength gains occurring early in a training program are due to neuromuscular adaptations rather than muscle hypertrophy (Moritani and deVries, 1979).

Velocity specific training and its affect on cross education has also received little attention. There have been reports of strength gains in the untrained limb from velocity specific training. There have also been reports failing to show strength gains in the untrained limb from velocity specific training. The question still remains, is velocity specific isokinetic training effective for increasing strength in the untrained limb?

In view of the unresolved questions relative to velocity specific training, the purpose of this study was to determine the effects of velocity specific isokinetic training on strength gains in the trained limb, contralateral limb, and the effect of this training on muscle girths in the trained limb.



**Chapter II**  
**REVIEW OF LITERATURE**

The purpose of this review is to provide an overview of the effects of velocity specific, isokinetic training on strength in the trained limb and contralateral limb. In addition, it is the purpose of this review to summarize the effects of velocity specific, isokinetic training on muscle hypertrophy. To these ends, this review will be divided into three broad categories: studies of velocity specific strength gains in the trained limb, studies of velocity specific strength gains in the untrained limb, and studies of muscle hypertrophy following isokinetic training.

### Velocity Specific Strength Gains - Trained Limb

One of the early studies to focus on velocity specific, isokinetic training was reported by Moffroid and Whipple (1970). Thirty subjects were assigned to a slow velocity training group (36 degrees-per-second), a fast velocity training group (108 degrees-per-second), or a control group. The subjects trained the knee flexors and extensors on Cybex isokinetic equipment. The training of the slow velocity group consisted of two minutes of knee extensions and flexions, involving, on average, 20 repetitions. The fast group also trained with two minutes of knee extensions and flexions, involving, on average, 60 repetitions. The training took place every other day for six weeks. All subjects were tested before and after the training at velocities of 18, 36, 54, 72, 90, and 108 degrees-per-second.

The results of the Moffroid and Whipple study indicated that strength gains in each group were evident at its training velocity and at test velocities slower than the training velocity. To be more specific, the slow velocity group had significant strength gains at its training velocity (36 degrees-per-second) and the slower test velocity, 18 degrees-per-second, but a lack of significant strength gains at the four faster velocities. The fast

velocity group had significant strength gains at its training velocity (108 degrees-per-second) and at each of the five slower test velocities.

Moffroid and Whipple concluded that training effects were somewhat velocity specific, in that strength gains took place at the training velocity but not at all other velocities. The investigators also noted that fast velocity training may be more effective in producing strength gains at many velocities, simply because there are many more velocities slower than a fast training velocity. It should also be noted that the design of the study precluded the possibility of strength gains for the fast group at velocities faster than its training velocity.

Pipes and Wilmore (1975), in a study, investigated the differences between isokinetic and isotonic training in their ability to affect muscular strength, body composition, anthropometric measures, and motor ability tasks. In this study low and high velocity training velocities were investigated in the isokinetic training. Thirty-six men were randomly assigned to one of four groups: isokinetic slow velocity (24 degrees-per-second), isokinetic fast velocity (136 degrees-per-second), isotonic group, or a control group. The training groups completed workouts on the bench press, bicep curl, leg press, and bent rowing three days per week for eight weeks. Subjects in the isotonic group trained initially at 75% of their 1 repetition-maximum for three sets of eight repetitions. Resistance was increased when individuals were able to complete more than 10 reps on their last set. The training in the isokinetic groups was carried out on special isokinetic equipment designed by Lumex, Incorporated. The slow velocity group (24 degrees-per-second) trained with three sets of eight repetitions, and the fast velocity group (136 degrees-per-second) trained with three sets of fifteen repetitions.

The investigators were concerned with the specificity effect of strength training; thus, four different methods were used to assess muscular strength. There were tested

isometrically using a cable tensiometer at angles of 90 and 135 degrees on the involved limb of the elbow flexion, leg extension, triceps extension, and the bench press. A one-repetition maximum was determined for the leg press, bench press, elbow flexion, and bent rowing for the isotonic testing. Isokinetic testing was completed at velocities of 24 and 136 degrees-per-second on Cybex isokinetic equipment. The isokinetic included the elbow flexion, tricep extension, shoulder extension, and a simulated bench press. Testing was also done on the isokinetic training equipment, which was somewhat hydraulic in nature. Body density, lean weight and relative fat were assessed at the beginning and end of the training period by hydrostatic weighing. Anthropometric measurements were taken at the beginning and end of the training period at seven skinfold sites. Five motor ability tests were completed before and after training: the standing long jump, the 40-yard dash, the softball throw for distance, the vertical jump, and two handed sitting shotput.

The results indicted that control group had no significant changes in any of the test after training. The Slow velocity group (36 degrees-per-second) and the fast velocity group (136 degrees-per-second) increase significantly at 90 and 135 degree joint angles for all exercise movements (elbow flexion, leg extension, triceps extension, and the bench press) in the isometric testing. The isotonic group significantly increased strength only in bicep flexion and leg extension for the isometric testing. All training groups exhibited significant strength gains in all exercise movements when tested isotonicly. The isokinetic fast velocity group had significantly greater strength increases in leg press, bicep curls, and bent rowing when compared to the isokinetic group.

When assessing strength gains with the isokinetic training device (Lumex), the isotonic group failed to increase strength in any of the exercise movements. Both the slow and fast velocity training group increased strength significantly in all of the tested exercise movements. The fast velocity group increased strength significantly greater than the slow

velocity group in the biceps curl, bench press, and bent rowing when compared to the slow velocity group.

When testing with the isokinetic testing device (Cybex), the isotonic group significantly increased strength only in the bench press at the velocity of 24 degrees-per-second. Both the isokinetic slow and fast velocity groups significantly increased strength on all measures at the velocity of 24 degrees-per-second; however, the fast velocity group increased significantly more than the slow velocity group. At the fast velocity (136 degrees-per-second) the isotonic only increased strength significantly in the bench press. The slow velocity group significantly increased strength in the bench press, triceps extension, and shoulder flexion at the velocity of 136 degrees-per-second. The fast velocity group significantly increased strength in all of the exercise movements ( elbow flexion, leg extension, triceps extension, and the bench press).

All training groups had changes in the body composition. Total body weight increased for all groups, while lean body weight was significantly increased in only the isotonic group and fast velocity group. All training groups significantly decreased bodyfat, with the fast velocity group decreasing fat significantly more than the slow velocity group and isotonic group. When assessing subcutaneous fat stores, the high velocity group significantly reduced fat at all seven skinfold sites. The slow velocity group had significant losses in six of the seven sites, while the isotonic group had significant losses only two of the seven skinfold sites.

When measuring limb circumferences, the isotonic group significantly increased gains in the shoulder, chest, deltoid, and extended biceps and a significant decrease at the hips. Both the slow velocity group and fast velocity group had significant increases at the shoulder, chest, calf, deltoid, extended biceps and forearm sites, with significant decreases

at the hips. The slow velocity group also had significant improvements at the flexed biceps, and the fast velocity group had a significant decrease in the abdomen.

The isotonic group failed to have significant changes in any of the motor ability tests. The slow velocity group had significant improvements in the 40 yard dash, softball throw, and vertical jump. The fast velocity group had significant improvement in the 40 yard dash, softball throw, vertical jump, and the two-handed shotput.

From this study it can be concluded that isokinetic training is significantly better than isotonic training in affecting changes in muscular strength, body composition, and motor ability tasks. It was also observed in this study that a fast velocity of training affects muscular strength and motor ability more than the slow velocity training and isotonic training. Pipes and Wilmore concluded that fast velocity training affected strength more at the velocities typical to athletic and sports activities, as noted by greater significant improvements in the motor ability tasks.

Another early investigation (Lesmes et al., 1978) of velocity specific, isokinetic training reported results similar to those reported by Moffroid and Whipple. Five male volunteers trained the knee extensors and flexors four times-a-week over a seven week training period. All subjects trained at a velocity of 180 degrees-per-second on Cybex equipment. One limb was trained with six-second exercise bouts, repeated 10 times, with 114 seconds rest between each bout. The other limb was trained with thirty-second bouts, with 20 minutes of rest between each bout. The thirty-second bouts continued until the total work output equalled the total work completed during the six-second bouts. Both limbs were trained through a 90-degree range of motion. The isokinetic strength of both limbs was subsequently tested at 0, 60, 120, 180, 240, and 300 degrees-per-second.

This study found that the trained limbs gained isokinetic strength at velocities of 0, 60, 120, and 180 degrees-per-second. Neither limb gained strength at test velocities of 240

and 300 degrees-per-second. The investigators concluded that velocity specific training increased strength at and below the training velocity. An inherent limitation of this study was that it was not possible to consider the effects of cross education, since both lower limbs were trained. Another limitation of this study was that only five subjects were trained and tested.

Somewhat in contrast to Moffroid and Whipple, and Lesmes et al., Katch et al. (1975) reported that strength gains occurred at the training velocity, and at slower and faster velocities. Twenty-six college women trained on an isokinetic bench press for eight weeks. The subjects were either assigned to a slow velocity group (1 repetition/10 seconds), fast velocity group (1 repetition/2 seconds), or a control group. The training protocol consisted of two sets-a-day, three times-a-week. All training and testing was done on Cybex equipment. The slow training group executed 10 repetitions per set and the fast velocity group did 15 repetitions per set. The total work for the two groups was equal. Testing involved pre-, mid-, and post-tests at both of the training velocities. Arm and forearm circumferences were also measured. This study found that the slow and fast velocity groups increased strength at both of the test velocities, that is, there were no velocity specific training effects. Arm girths also significantly increased in both groups.

Smith and Melton (1981), similar to Katch et al., reported strength gains at the training velocity and at faster velocities. Twelve adolescent males volunteered for the study; they were divided into four groups: control, variable resistance (Nautilus), isokinetic slow velocity, and isokinetic fast velocity. Each group trained the knee flexors and extensors three times-a-week for six weeks. The variable resistance group trained with three sets of ten repetitions at 80% of its one-repetition maximum the first week, and followed a progressive Nautilus protocol thereafter. The isokinetic slow velocity group trained at 30, 60, and 90 degrees-per-second continuing the repetitions in each of three

sets until fatigue depressed the peak torque by 50 percent. The isokinetic fast velocity group trained at velocities of 180, 240, and 300 degrees-per-second. This group also sustained repetitions until fatigue depressed the peak torque by 50 percent. All subjects were tested isometrically at knee joint angles of 45 degrees (flexors) and 65 degrees (extensors), isokinetically at velocities of 30, 60, 90, 120, 180, 240, and 300 degrees-per-second, and isotonicly on a Universal leg press machines. The authors, however, reported only the results of the isokinetic tests at 60 and 240 degrees-per-second. The subjects were also given the following motor ability tests: 40-yard dash, standing broad jump, and standing vertical jump.

Smith and Melton, reporting the results of this study, stated that the control group had no significant strength gains on any of the tests. The variable resistance group, the slow velocity group, and the fast velocity group achieved disparate strength gains of 14.64 %, .51 %, and 6.6 % respectively in the isometric, knee extension testing. At an isokinetic test velocity of 60 degrees-per-second the variable resistance group, slow velocity group, and the fast velocity group, again, had variable strength gains of 3.14 %, 21.32 %, and 3.38 %, respectively, for knee extension. At the test velocity of 240 degrees-per-second the variable resistance group, slow velocity group, and the fast velocity group varied widely in strength gains of 2.25 %, 24.73 %, and 60.92 %, respectively, for knee extension.

Similarly, variable results were reported for knee flexion. The variable resistance group, slow velocity group, and fast velocity group had strength gains of 10.91 %, 15.53 %, and 9.05%, respectively, for isometric knee flexors. At the velocity of 60 degrees-per-second, the variable resistance group, slow velocity group, and the fast velocity group had strength gains of 14.51 %, 17.36 %, and 8.64 %. At the velocity of 240 degrees-per-second, the variable resistance group, slow velocity group, and the fast velocity group had strength gains of 13.60 %, 10.26 %, and 51.33 %. The variable resistance group, slow



velocity group, and fast velocity group had strength gains of 10.54 %, 9.83%, and 6.74% when retesting on the Universal leg press.

In the motor ability tests, which emphasize rapid movement, the variable resistance group, slow velocity group, and fast velocity group had improvements of 1.57 %, 3.87 %, and 5.38 %, respectively, in the standing vertical jump. The variable resistance group, slow velocity group, and fast velocity group had improvements of .28 %, .42 %, and 9.14 % in the standing broad jump. When testing the 40 yard dash the variable resistance group, slow velocity group, and fast velocity group had increments and decrements of 1.35 %, -1.12 %, and 10.11 %, respectively.

Smith and Melton concluded , in their discussion, that training effects are velocity specific, that is, training at a fast velocity is advantageous for the performance of rapid motion.

A study by Coyle et al. (1981) also reported strength gains at velocities faster than the training velocity. The purpose of this study was to compare the effects of slow and fast isokinetic knee extension training on peak torque. Twenty-two college age males volunteered for the study and were assigned either to a slow training group (60 degrees-per-second), fast training group (300 degrees-per-second), a mixed group training at both the slow and fast velocities, a placebo group, or a control group. The subjects in the slow, fast, and mixed groups trained isokinetically three times-a-week for six weeks. These groups trained with two-leg knee extension on Cybex equipment. The slow velocity group (60 degrees-per-second) completed five sets of six repetitions each. The fast velocity group (300 degrees-per-second) completed five sets of twelve repetitions. The mixed group did half of its work at 60 degrees-per-second (2 or 3 sets, 6 repetitions/set) and half at 300 degrees-per-second (2 or 3 sets, 12 repetitions/set). There was 8 minutes of rest between each set for all training groups. Testing of both legs together and each leg

individually took place at velocities of 0, 60, 180, and 300 degrees-per-second. Muscle biopsies were obtained from all subjects before and after training to assess muscle hypertrophy.

Results of the Coyle et al. study indicated that the control group did not have any significant changes in strength. The placebo group had a significant improvement in isometric strength (0 degrees-per-second), but no gains in isokinetic strength at the three isokinetic test velocities, 60, 180, and 300 degrees-per-second. The slow velocity group (60 degrees-per-second) had significant improvements at test velocities of 0, 60, and 180 degrees-per-second. The fast velocity group (300 degrees-per-second) had significant improvements at all test velocities (0, 60, 180, and 300 degrees-per-second). The mixed velocity group also improved significantly at all training velocities. Morphological adaptations included a significant increase in the mean cross sectional area of the type II fibers in the fast velocity group. There was no fiber hypertrophy in the other groups. From this study, Coyle et al. concluded that strength gains can occur at the training velocity, and at velocities faster than and slower than the training velocity. As with Katch et al. (1995) the effects of training did not appear to be velocity specific. However, it should be noted that the investigators did not test faster than the fast training velocity.

A study done by Caiozzo et al. (1981) also reported strength gains at and faster than the isokinetic training velocity. Seventeen sedentary subjects participated in the four week study. They trained the right knee extensors on Cybex isokinetic equipment. The subjects were assigned to one of three experimental groups: a slow velocity group (96.4 degrees-per-second), a fast velocity group (240 degrees-per-second), and a control group. The training protocol consisted of two sets of ten maximal contractions three times-a-week for four weeks.

The subjects in this study, were tested isokinetically at velocities of 0, 48, 96, 144, 192, 240, and 288 degrees-per-second. The slow velocity group (96 degrees-per-second) had significant strength gains at test velocities of 0, 48, 96, 144, 192, and 240 degrees-per-second, but not at a velocity of 288 degrees-per-second. The fast velocity group (240 degrees-per-second) showed strength gains at the training velocity of 240 degrees-per-second and at 144 and 192 degrees-per-second. The fast velocity had non-significant strength gains at velocities of 0, 48, 96, and 288 degrees-per-second. There were no significant changes for the control group. Caiozzo et al. concluded that strength gains can occur at the training velocity, and at slower and faster velocities.

Instead of using peak torques as the criterion to determine the effects of velocity specific training, Kanehisa and Miyashita (1983) investigated power changes. Twenty-one healthy male subjects participated in the experiment. They trained the knee extensors on Cybex isokinetic equipment. The subjects were assigned to one of three groups: a slow velocity group (60 degrees-per-second), an intermediate velocity group (180 degrees-per-second), or a fast velocity group (300 degrees-per-second). All subjects trained the knee extensors six days-per-week for eight weeks. The slow velocity group trained with three sets of 10 repetitions with two minutes rest between each set. The intermediate velocity group performed three sets of 30 repetitions, and the fast velocity group trained with three sets of 50 repetitions. All subjects were tested before and after the training program at velocities of 60, 120, 180, 240, and 300 degrees-per-second.

The results of this study indicated that the slow velocity group (60 degrees-per-second) significantly improved average power at the training velocity and at all other velocities, with greater increases occurring near the training velocity. The intermediate velocity group (180 degrees-per-second) also significantly improved average power at its training velocity and all other test velocities. The fast velocity group (300 degrees-per-

second) increased average power at its training velocity and at a velocity of 240 degrees-per-second. The fast group had non-significant gains in power at velocities of 60, 120, and 180 degrees-per-second. Kanehisa and Miyashita concluded that the intermediate velocity may be the best training velocity to elicit power gains over a wide range of velocities.

Jenkins et al. (1984) reported results following velocity specific training. Twenty-four subjects participated in the study. They were assigned to a slow or a fast velocity group. A control group was not used in this study. All subjects were trained and tested on Cybex isokinetic equipment. Both groups trained three times-a-week for six weeks. Both the slow velocity group (60 degrees-per-second) and the fast velocity group (240 degrees-per-second) trained with one set of fifteen repetitions. Training with one set of repetitions is minimal and may be a significant limitation of this study. All subjects were tested before and after training at velocities of 30, 60, 180, 240, and 300 degrees-per-second. The slow velocity group (60 degrees-per-second) increased strength at its training velocity and at a velocity of 180 degrees-per-second. The fast velocity group (240 degrees-per-second) increased strength at its training velocity and at all test velocities (30, 60, 180, and 300 degrees-per-second).

Rutala et al. (1984) investigated the effects of velocity specific training on peak torque. Twenty-five women were assigned to either a slow velocity group (60 degrees-per-second) or a fast velocity group (180 degrees-per-second). Both groups were tested before and after training at velocities of 30, 60, 90, 120, 180, and 240 degrees-per-second. The investigators did not report what muscle groups were tested and trained in the abstract. Both groups trained with three sets of ten repetitions for ten days, five days a week.

The slow velocity group significantly increased strength at its training velocity and at all test velocities. The fast velocity group failed to increase strength at any of the

velocities. It should be noted that the training only lasted 10 days, and the investigators did not report whether work was equated among the training groups.

Garnica (1987), similar to Kanehisa and Miyashita, looked at the effects of velocity specific training on average power as well as peak torque. Twenty untrained women were selected to participate in the study. They were assigned either to a slow velocity training group (60 degrees-per-second) or a fast velocity group (180 degrees-per-second). The subjects trained and tested the shoulder extensors and flexors through a 180 degree range of motion on Cybex isokinetic equipment. The training protocol for both groups consisted of four sets of five maximal repetitions, three times-a-week for four weeks. The shoulder extensors, only, were tested in this study before and after the training period at velocities of 60 and 180 degrees-per-second through 90 and 180 degree ranges of motion.

The results of this study indicated that neither the slow velocity group (60 degrees-per-second) nor the fast velocity group (180 degrees-per-second) improved peak torque or average power through the 90 degree range of motion. The slow velocity group (60 degrees-per-second) increased peak torque and average power over 180 degrees of motion at its training velocity and a velocity of 180 degrees-per-second over 180 degrees of motion. The fast velocity group showed significant gains in peak torque over 180 degrees of motion at its training velocity (180 degrees-per-second), but not at 60 degrees-per-second through the 180 degree range of motion. The fast velocity group (180 degrees-per-second) had significant improvements in average power at its training velocity and at 60 degrees-per-second.

Another investigation of velocity specific training was conducted by Timm (1987). Thirty volunteers participated in the study. All subjects trained the knee extensors and flexors at a single velocity of 180 degrees-per-second. The subjects trained with three sets

of repetitions, continuing until fatigue decreased the peak torque by 50 percent. Training took place three times-a-week for eight weeks. The left knee extensors of all subjects were tested at velocities of 60, 120, 180, 240, and 300 degrees-per-second.

Test results from the Timm study indicated that the training (180 degrees-per-second) increased strength at the training velocity and at velocities of 60, 120, 240, and 300 degrees-per-second. Since the investigator only used one training velocity in this study, it is not possible to make a comparison of slow and fast velocity training.

Perrin et al. (1989) also investigated velocity specific training at a single training velocity. Seventeen intercollegiate lacrosse players participated in the study. They were assigned to a control group or a training group. All training was done on Cybex isokinetic equipment. The subjects trained the knee extensors and flexors at a velocity of 270 degrees-per-second. The training protocol consisted of three sets of twenty-five repetitions, three times-a-week for seven weeks. The testing consisted of four maximal extensions and flexions at velocities of 60, 180, and 270 degrees-per-second. The peak extensor and flexor torques were recorded for each velocity.

The results of this study indicated that the training group (270 degrees-per-second) had significant strength gains at the training velocity (270 degrees-per-second), but failed to have significant strength gains at velocities of 60 and 180 degrees-per-second for knee extension. There were no significant strength gains for knee flexion at any of the test velocities. The control group had no significant strength gains on any test. Perrin et al. concluded that training at 270 degrees-per-second produced a velocity specific training effect for knee extension only. It should be noted that the investigators used only one training group and that the training protocol was somewhat different from previous investigations in that only one, relatively fast training velocity was used with a high number of repetitions (twenty-five).

A study by Petersen et al. (1989) supports earlier investigations of velocity specific training, finding strength gains at the training velocity, and faster than the training velocity. In this study 30 healthy, male varsity athletes were placed in either a slow velocity training group (60 degrees-per-second), a fast velocity training group (180 degrees-per-second) , or a control group. The training protocol consisted of two 20-second sets of maximal repetitions at each of six hydraulic resistance stations. The exercises included unilateral seated knee extension and flexion, bilateral seated leg press, a unilateral seated hip extension and flexion, a unilateral supine hip abduction and adduction, and a bilateral inclined leg drive. The resistance or load was adjusted to maintain the necessary velocity of each training group. The hydraulic systems utilized allowed for fast or slow motion, but did not maintain a constant velocity of movement. All knee extension testing was done on Cybex isokinetic equipment at velocities of (60, 90, 120, 150, 180, 210, and 240 degrees-per-second).

Petersen reported results which indicated that the fast velocity training group (180 degrees-per-second) significantly increased strength at 150, 180, 210, and 240 degrees-per-second. The slow velocity group (60 degrees-per-second) increased strength at all seven velocities. Petersen et al. concluded that both the slow and fast velocity groups had significant strength gains at the training velocity and faster than the training velocity, and that the fast velocity group also had strength gains at a velocity slower than the training velocity. The investigators also concluded that high velocity training is no more effective in increasing peak torque than slow velocity training. A limitation of this study was that the subjects did not train with isokinetic equipment; therefore, they were not tested in the manner that they trained. There is also some question whether the training groups were training at the selected velocity.

Ewing et al. (1990) investigated the effects of velocity specific training on strength, power, and quadriceps muscle fiber characteristics. Twenty untrained, adult men participated in the study. They were trained and tested with Orthotron isokinetic equipment. The subjects were either assigned to a slow velocity group (60 degrees-per-second) or a fast velocity group (240 degrees-per-second). The training protocol consisted of, for the slow velocity group, three sets of eight maximal repetitions, and for the fast velocity group, three sets of twenty maximal repetitions. Subjects rested one minute between each set of repetitions. The subjects trained the knee extensors three times-a-week for ten weeks. All subjects were tested before and after training at velocities of 60, 180, and 240 degrees-per-second.

The slow velocity groups (60 degrees-per-second) in this study had significant strength gains at its training velocity and at 180 degrees-per-second, but it did not improve significantly at 240 degrees-per-second. The fast velocity group (240 degrees-per-second) had significant strength gains at its training velocity and at a velocity of 180 degrees-per-second, but it failed to have significant strength gains at the slower velocity of 60 degrees-per-second. When considering power, the slow group had significant gains in power at the training velocity of 60 degrees-per-second. Both the slow and the fast velocity groups had a significant increase in power at the test velocity of 180 degrees-per-second. Neither the slow nor the fast velocity group significantly improved power at the test velocity of 240 degrees-per-second. In this study, the slow velocity group (60 degrees-per-second) increased strength at its training velocity and one faster velocity, and the fast velocity group (240 degrees-per-second) increased strength at its training velocity and one velocity below the training velocity; however, testing was not conducted faster than the training velocity of the fast velocity group.



Behm (1991) investigated velocity specific training using a variety of training equipment, such as surgical tubing, Hydragym, and Universal equipment. Thirty-one healthy male subjects participated in the ten-week study. Subjects were randomly assigned to one of three training groups: Hydragym (H-group), surgical tubing (S-group), or Universal (U-group). All groups trained using a shoulder press, moving the resistance from behind the head and neck. Group H trained on a Hydragym multi-purpose hydraulic resistance device. The S group trained with a straight back chair to which loops of surgical tubing were attached, and the U group trained on a Universal multi-purpose weight machine. The subjects trained with three sets of ten repetitions at a rate of one repetition per second (180 degrees-per-second). The correct timing was achieved by way of a metronome. All subjects were tested with shoulder abduction on Cybex isokinetic equipment before and after the training. Testing was conducted at velocities of 60, 120, 180, 240, and 300 degrees-per-second. Subjects were also tested for their one-repetition maximum on the shoulder press station of the Universal multi-purpose machine.

The results of this study indicated that isokinetic torque in shoulder abduction increased significantly (13.2%) when pooling all groups and all training velocities. There were no significant differences among the training groups. The Universal shoulder press increased significantly 14.8% overall when pooling all groups. On this test, The U-group increased 17.5%, 14% for the H group, and 13.8% for the S group. Behm concluded that there was no velocity specific response to training, since the training groups increased strength at all isokinetic velocities. He also concluded that all three training methods are equally effective in promoting strength gains.

Doherty et al., (1993) investigated the effects of periodized velocity specific training. Thirty-four females volunteered for the eight-week training study. The equipment used for training and testing was not isokinetic. The subjects trained and were

tested on a hydraulic, semi-accommodating seated chest-press machine, which was designed by the investigators. The subjects were randomly assigned to one of four groups: a slow velocity group (60 degrees-per-second), a fast velocity group (180 degrees-per-second), or a periodized group (5 weeks at 60 degrees-per-second and 3 weeks at degrees-per-second), or a control group. The groups trained three times-a-week for eight weeks. Each training session consisted of three sets of repetitions, each set 20-seconds in duration. Since the hydraulic cylinder on the chest-press machine could not control velocity, average angular velocity was determined from the range of motion, the number of repetitions and the duration of each exercise set.

Doherty et al. found that, after training, there was no significant difference among the groups. The results of the study also indicated that peak force was significantly increased in all groups at the two training velocities of 60 and 180 degrees-per-second. The investigators concluded that similar strength gains occurred at slow (60 degrees-per-second) and fast (180 degrees-per-second) velocities, regardless of the training program.

Behm and Sale (1993) took a different approach to velocity specific training. They believed that it was the intention to make a fast velocity movement rather than the actual movement, that was the stimulus to strength gains. These investigators based this belief on the findings of Desmedt and Godaux (1979), who showed that it was the intent to make a rapid movement, rather than the actual movement that was important, because the motor unit discharge was the same whether the limb is freely moving or restricted in its motions. Therefore, Behm and Sale examined whether or not rapid and extensive muscle shortening was a necessary stimulus to produce strength gains at high velocities. Sixteen subjects participated in the sixteen week training study. The subjects trained and tested the ankle flexors on Cybex isokinetic equipment. They trained both limbs, following an instructions to attempt to execute maximal ballistic dorsiflexion; that is, they were directed

to move as fast as possible regardless of the imposed resistance. In one limb the imposed resistance was designed to be immovable. In the other leg the imposed resistance allowed the foot to move at a relatively high velocity (300 degrees-per-second). The subjects trained for a period of sixteen weeks, but there was a three week interruption due to a holiday season after eight weeks of training. All subjects trained three times-a-week. The subjects did three sets of repetitions the first week, four sets during the second week, and five sets for the following six weeks. Ten maximal contractions were performed during each set. Subjects were tested before training, after eight weeks of training, and after sixteen weeks of training. Subjects were tested at movement velocities of 0, 14, 29.8, 60, 88, 173, 240, and 300 degrees-per-second.

The results of this study indicated that two training protocols produced similar training effects; thus, Behm and Sale pooled the test results of the "immovable" limb and the "movable" limb. After sixteen weeks of training, the strength increases were 12.7%, 11%, 16.3%, 23.9%, and 37.7%, respectively, at the velocities of 60, 88, 173, 240, and 300 degrees-per-second. At the four slower test velocities there were no significant increases in strength. Behm and Sale concluded that it is the intention to perform a ballistic movement which is important in bringing about strength gains. They further concluded that the type of muscle action (isometric or concentric) is not as important as attempting a ballistic movement.

Housh and Housh (1993) investigated velocity specific training of the extensors and flexors of the elbow and knee. Twelve adult men volunteered for the eight week study. All subjects trained at 120 degrees-per-second on Cybex isokinetic equipment. The training protocol consisted of the subjects performing six sets of ten maximal repetitions over the eight week period. All subjects were tested at velocities of 60, 120, 180, 240, and 300 degrees-per-second. The results after training demonstrated that significant increases

in peak torque occurred in elbow extension and flexion, and knee flexion and extension at all test velocities. Housh and Housh (1993) concluded that strength gains from velocity specific training take place at the training velocity, and at faster and slower velocities.

#### Cross Education- Early Studies

There have been numerous investigations which have demonstrated that exercise on one side of the body can cause strength changes in the other side of the body. This "adaptation in motor capabilities that occurs in one limb as a consequence of training the contralateral limb is referred to as cross education" (Enoka, 1994).

There were reports of cross education before the turn of the century. Scripture et al. (1894) pioneered the research of cross education. These investigators observed that after a of training muscles in the subject's right hand, the subjects improved the strength of their left hand. Davis (1898) followed up the work of Scripture et al., observing similar results, in that, systematic exercise with dumbbells in one part of the body produced strength gains in other symmetrical and related parts of the body. Davis (1898), as reported by Clarke (1973), attributed these findings and similar findings to "a central mechanism operating in addition to those peripheral factors associated with muscular nutrition." Wisler and Richardson (1900) observed cross education when training two subjects. The subjects exercised with a dynamometer, pulling with one arm. The investigators observed that this training of one arm increased muscular performance of the unexercised arm.

Walsh (1923) studied the movements in spastic hemiplegic patients, observing that these movements are evoked by forceful voluntary contractions on the contralateral side. Walsh attributed the movements in the patients to tonic postural reflexes in and acting on the limb. Walsh further observed that the associated movements only occurred, " If the voluntary contractions are forceful and of a kind demanding widespread synergic fixation

of the musculature. These findings gave further support to cross education; that is, dependence upon reflex mechanisms situated in the brain stem which unite the musculature of the extremities into a adaptive postural substrate upon which cortically controlled movements may be superimposed" (Walsh, 1923).

Hellebrant et al. (1947) renewed the interest in cross education. Subjects in this study exercised the knee extensors and flexors and the elbow flexors. The investigators subsequently observed cross education in the unexercised, contralateral musculature. From these findings they concluded that the cross education may be related to isometric cocontractions of the contralateral muscles. Later, Hellebrandt and Houtz (1950) concluded "that cross education was demonstrable only when the subject was cooperative and trained to put forth an all out effort which approximated in its severity the maximal physiological work attainable under the condition imposed" (Hellebrant and Houtz (1950), cited by Clarke 1973).

Slater-Hammel (1950) had subjects train the right elbow flexors for three weeks, then compared these subjects with a control group. The subjects increased strength significantly in the contralateral limb as compared to the control group. He concluded that the training the elbow flexors and extensors of one arm resulted in a significant increase in strength in the contralateral arm.

Gardener (1963) followed the isometric prescriptions of Hettinger and Muller in training subjects with two-thirds maximal isometric contractions held for a contraction for six seconds. Four different groups participated in the study: The groups consisted of a control group, a group that trained at an isometrically angle of 115 degrees, a similar group that trained at an isometric angle of 135 degrees, and a group that trained at an isometric angle of 155 degrees. Gardner trained the knee extensors of the preferred limb, three times-a-week for six weeks. The training groups improved significantly at the training

angle, but not at other angles. There were no significant improvements in strength in the untrained limb when compared to the control group.

Meyers (1967) continued the investigations of the effects of isometric training on cross education. In this study, one group of subjects trained the elbow flexors with three sets of 6-second maximal isometric contractions three times-a-week for six weeks. A second group trained the elbow flexors with 20 second maximal contractions three times-a-week for six weeks. The group that trained with 6-second maximal isometric contractions improved significantly in its contralateral limb, and the other group failed to exhibit cross education.

Coleman (1969) studied the effects of isotonic and isometric contractions of equal load and duration on cross education. After 12 weeks of training two groups of subjects significantly improved strength in the elbow flexors of the untrained limb. Similarly, Moritani and deVries (1979) trained the elbow flexors of 15 subjects with isometric exercise at an intensity of 67 percent of their maximum. The exercise was executed 10 times, twice daily, three days-per-week for eight weeks. The investigators observed an increase of 36.4 percent in the trained limb and 24.7 percent in the untrained limb.

Not all studies, however, have reported cross education. Young et al. (1983) had subjects isometrically train the knee extensors by holding 60-second contractions at 30 percent of the maximum. The subjects performed seven repetitions of the 60-second curl each day. After three weeks there was no change in the strength of the untrained limb. However, the investigators only used 30 percent maximal contractions; this may not have been sufficient to evoke a cross education effect.

Parker (1985) trained the quadriceps femoris muscles isometrically. Subjects trained three times-a-week for four months, completing 10 repetitions at 50 percent of maximum. Parker observed a 15% increase in contralateral strength of the subjects.

### Cross Education- Isokinetic Studies

With the availability of isokinetic equipment, it was natural that investigators turned their attention to velocity specific training and cross education.

Krotkiewski et al. (1979) were the first of these investigators to study the effects of velocity specificity training on cross education. Ten women participated in the five-week study. They trained the knee extensors on Cybex isokinetic equipment. The subjects trained at a velocity of 60 degrees-per-second, completing three sets of 10 maximal repetitions three times-a-week for five weeks. The trained and untrained limbs were tested before and after training at velocities of 0, 30, 60, 120, and 180 degrees-per-second. The results indicated that the subjects significantly increased strength in the trained limb at the training velocity and at all other test velocities. The subjects also significantly increased strength in this limb at 0 and 120 degrees-per-second in the contralateral, untrained limb, but failed to increase strength at 30, 60, and 180 degrees-per-second

Stevens et al. (1980) also assessed the effects of velocity specific training on cross education. Nine subjects participated in seven weeks of maximal isokinetic, unilateral training. The subjects trained the knee extensors and flexors four times-a-week, completing four sets of maximal repetitions at 180 degrees-per-second for each of the muscle groups. Measurements of peak torque were obtained before and after training at velocities of 0, 60, 120, 180, 240, and 300 degrees-per-second in both the trained and untrained limbs. Subjects also completed a muscular fatigue test for each limb, during which one minute of maximal knee extensions and flexions were evaluated.

In this study, the trained limb subjects significantly increased strength at the training velocity (180 degrees-per-second) and at all slower test velocities. In the untrained limb

subjects significantly increased strength at all test velocities. Also, both the trained and untrained limbs significantly improved in the muscular fatigue test.

Narici et al. (1989) continued the study of velocity specific training and cross education. Four male subjects participated in this sixty-day study. The subjects trained the knee extensors of one limb four times-a-week, at a velocity of 120 degrees-per-second. Training consisted of six sets of ten maximal contractions on Cybex isokinetic equipment. Each limb was subsequently tested, every twenty days, at velocities of 0, 60, 120, 180, 240, and 300 degrees-per-second. Also, every twenty days integrated electromyograms were recorded, and the quadriceps cross-sectional area was determined. After sixty days the trained limb significantly increased peak torque at 0, 60, and 120 degrees-per-second, but failed to increase peak torque at velocities of 180, 240, and 300 degrees-per-second. The untrained limb failed to increase strength significantly at any of the test velocities. In the trained limb there were also significant increases in the integrated electromyogram and the cross-sectional area of the quadriceps. These latter changes were not observed in the untrained limb, thus cross education was not apparent in this study.

Kannus et al. (1992) assessed the effects of unilateral exercise on the strength, power, and endurance of the trained and contralateral limbs. Twenty young adults (10 men and 10 women) participated in this eight-week study. The subjects were separated into a training group and a control group. Training consisted of the following velocity spectrum: five sets of ten maximal repetitions of knee extension and flexion at a velocity of 240 degrees-per-second with 50-second rest intervals, five sets of five maximal repetitions at a velocity of 60 degrees-per-second with 45 second rest intervals, five sets of ten-second maximal isometric contractions of the knee extensors with 50 second rest intervals, five sets of ten second maximal isometric contractions of the knee flexors with 50 second rest intervals, and five sets of twenty-five maximal knee extensions and flexions at a



velocity of 240 degrees-per-second. The untrained limb was kept completely immobile and relaxed during the training. All subjects were tested before and after training on Cybex isokinetic equipment. Both limbs were tested at velocities of 0, 60, and 240 degrees-per-second. The investigators also tested muscle endurance before and after the training period by administering a 25-repetition-maximum set at a velocity of 240 degrees-per-second.

The results of this study indicated that the control group had no significant changes in strength. The trained limb and the contralateral limb of the training group improved significantly at 0, 60, and 240 degrees-per-second. Also, both the trained limb and untrained limb had significant increases during the muscle endurance test. The investigators concluded that cross education effect was evident from the results.

Housh and Housh (1993) evaluated the effects of velocity specific, unilateral training on cross education. Twelve adult men volunteered for the eight-week study. They trained the non-dominant upper and lower extremities (extensor and flexor muscles of the elbow and knee) three times-per-week with six sets of 10 maximal repetitions. The subjects trained at a velocity of 120 degrees-per-second. All subjects were tested at velocities of 60, 120, 180, 240, and 300 degrees-per-second in both limbs. The results indicated that subjects significantly increased strength at all test velocities.. In the contralateral lower extremity subjects increased significantly at all test velocities. In the contralateral upper extremity strength increases were observed in the elbow extensors at all test velocities except 300 degrees-per-second, but were not observed in the elbow flexors at any velocity. The investigators concluded that training at more than one velocity is not required for strength increases at a variety of velocities and that velocity specific training of a non-injured limb may be useful in the rehabilitation of an injured contralateral limb.

## Muscle Hypertrophy

Two mechanisms may bring about skeletal muscle enlargement with training. The first of these is muscle hypertrophy. Muscle hypertrophy is an increase in the size of the existing muscle fibers, leading to an increase in the size of the muscle. The second mechanism is hyperplasia. Hyperplasia is the process by which muscle fibers split, causing an increase in the total number of fibers, thus an increase in the size of the muscle. Hyperplasia may also occur as a result of additional muscle fibers developing from satellite cells (Gonyea et al., 1986). Many of the studies reporting hyperplasia have been characterized by methodological problems; thus, hypertrophy, not hyperplasia, is considered the major mechanism causing muscle enlargement in response to resistance training. This review will focus on hypertrophy related studies.

### Isotonic and Isometric Studies

The initial investigations of muscle hypertrophy extend back as early as 1897. Morpurgo et al. (1897) removed the left sartorius muscle of two dogs and then trained them with eight weeks of treadmill running. Before and after training fiber sizes in the right sartorius were measured. Because of the removal of the left sartorius, the right sartorius compensated. This compensation resulted in a 53 % increase in the cross-sectional area of the right sartorius, without any increase in the number of muscle fibers.

Most of the early research reporting human muscle hypertrophy was based on limb circumference measurements. Delorme (1945, 1952) observed that muscles responded to progressive resistance exercise by increasing in size. McMorris and Elkins (1945) reported an increase in upper arm circumference when progressive resistance exercise was employed during training. Rasch and Morehouse (1957) reported significant increases in upper arm girth following both isometric and isotonic training. Barney and Bangerter (1961) observed a significant increase in thigh circumference when subjects trained with

ten-repetition maximums. Meyers (1967) found that subjects training isometrically significantly increased their relaxed arm girth.

In contrast to the early human studies, which focused on the overall size of skeletal muscles, animal research in the sixties focused on the size and composition of individual muscle fibers. Goldspink (1964) trained mice to pull on a weight to retrieve food, and, subsequently, reported a 30% increase in the cross-sectional area of the fibers. He also observed a three to fourfold increase in the number of myofibrils per fiber. Rowe et al. (1969) reported significantly higher weight and cross-sectional area of the soleus muscle in mice, accompanied by a 140% increase in total myofibril cross-sectional area. Goldberg (1967) also observed histological evidence that the weight increase of muscle following training was correlated with the increased diameter of the muscle fibers. Both Harnish et al. (1967) and Gordon et al. (1967) trained rats with resistive exercise and reported an increase in the myofibrillar protein concentration, but no overall muscle weight gain. Walker (1966, 1968) trained rats extensively and reported a significant increase in the mean fiber diameter. Carrow et al. (1967) trained male and female rats with resistance exercise and reported a greater increase in the cross-sectional area of the red gastrocnemius fibers as compared to the white fibers, but a greater number of capillaries per white fiber than per red fiber.

Following the aforementioned animal studies, Penman (1969, 1970) reported a significant increase in myosin filament diameters and concentrations in human skeletal muscle. He also observed a smaller distance between myosin filaments, signifying an increase in the density of these filaments "within a cell", as well as a change in the ratio of actin to myosin filaments. Schreiber et al. (1970) reported that one of the early responses to overload was an increase in the synthesis of myosin.

More recently, MacDougall et al. (1980a) trained the elbow flexors and extensors of subjects for six months. The subjects completed 3 to 4 sets for 6 to 8 maximal repetitions three times-a-week. Before and after training needle biopsies were taken from either the triceps or biceps brachii. MacDougall et al. reported significant hypertrophy in the muscle fibers, and also concluded that heavy resistance training results in a significant increase in the cross-sectional area of the type I and type II fibers. There was, however, a greater degree of hypertrophy in the type II fibers. The greater hypertrophy that occurred in the type II fibers may indicate a greater relative involvement of these fibers in the adaptive response to training. Davies et al. (1988) had novice subjects train the elbow flexor muscles for six weeks and reported a 5% increase in the cross-sectional area of these muscles. Garfinkel and Cafarelli (1992) reported a 15% increase in the quadriceps femoris of subjects following eight weeks of isometric training.

### Isokinetic Studies

Katch et al. (1975) trained subjects at a slow velocity (1 repetition/10 seconds) or a fast velocity (1 repetition/ second) for eight weeks. Upper arm circumferences were measured in both groups before and after training. The results indicated that upper arm girths increased significantly in both groups, with the slow velocity group having a two-fold greater increase than the fast velocity group.

Pipes and Wilmore (1975) also investigated the effects velocity specific training on muscle hypertrophy. A slow velocity group and a fast velocity group trained the elbow flexors and extensors, and leg extensors isokinetically. An isotonic bench press was also included in the training. Circumference measures were taken around the shoulders, chest, and each upper arm before and after the training period. The results demonstrated that

both the slow and fast velocity groups significantly increased girth measures of the shoulders, chest, and upper arms.

Krotkiewski et al. (1979) studied the effects of isokinetic training at 60 degrees-per-second on muscle hypertrophy. Ten healthy women trained the knee extensors for five weeks. Muscle hypertrophy was measured with ultrasonic equipment. The results confirmed that type I fibers decreased in size, and type IIa fibers increase significantly in size. There was a non-significant change in the number of fibers and the ratio of type I to type IIa fibers.

Costill et al. (1978) investigated the effects of velocity specific training on muscle hypertrophy in five healthy males, who trained the knee extensors at a velocity of 180 degrees-per-second over seven weeks. The subjects trained one limb with six-second sets of maximal repetitions and the other limb with twenty-second sets of maximal repetitions. Muscle biopsies were taken before and after training from the vastus lateralis to determine fiber size and number. The results indicated that the proportion of type I, IIa, and IIb fibers did not change with either form of training. The type I fibers, however, showed a decrease in size in both limbs. The type IIa fibers, in contrast, significantly increased in cross-sectional area. The size of the type IIb fibers remained unchanged with training.

Coyle et al. (1981) assessed the effects of velocity specific training on muscle hypertrophy in twenty-two males assigned to a control group, a mixed group, a slow velocity group, a fast velocity group, or a placebo group. Muscle biopsies were obtained from the vastus lateralis muscle. Results indicated that there were no significant changes in the mid-thigh circumference of any of the training groups. Furthermore, the mean area of type I muscle fibers was not significantly altered in any of the groups. Type II fibers, however, increased in size in the fast velocity group, but did not change significantly in any other group.

Petersen et al. (1989) trained the knee extensors of thirty subjects for six weeks. Subjects were assigned either to a slow velocity group (60 degrees-per-second), a fast velocity group (180 degrees-per-second), or a control group. The cross-sectional area of the quadriceps femoris was obtained from serial computer tomography. The data demonstrated that the control group had no significant changes in cross-sectional area. However, both the slow and fast velocity groups had significant increases in the cross-sectional area of the quadriceps femoris muscles.

Narici et al. (1989) trained the knee extensors of four subjects for sixty days. The training protocol consisted of six sets of ten maximal contractions at 120 degrees-per-second. All subjects trained four times-a-week. The cross-sectional area of the quadriceps femoris was measured through nuclear magnetic resonance imaging. After sixty days of training, the results indicated an 8.5% increase in the cross-sectional area of the quadriceps.

Ewing (1990) trained groups at velocities of 60 and 240 degrees-per-second over a 10-week period. Muscle fiber types and fiber cross-sectional areas were determined through muscle biopsy. The findings demonstrated no significant change in the percentages of type I, type IIa, and type IIb fibers. However, both the slow and fast velocity groups demonstrated significant increases in type I and type IIa fiber areas, but no increase in the area of type IIb fibers. There were no differences among the training groups with regards to hypertrophy.

Young and Bilby (1993) investigated the effects of velocity specific training, using free weights. Eighteen subjects trained with the half-squat. The training program consisted of four sets of an 8-12 repetition-maximum. The subjects were assigned either to a slow training group or a fast training group. The slow group subjects were instructed to lower the bar in a controlled manner; the fast velocity subjects were instructed to move the bar

rapidly. All subjects were tested before and after training for muscle hypertrophy.

Hypertrophy was measured through ultrasound. Measurements were taken of the vastus intermedius and rectus femoris. Also, thigh circumferences were taken before and after the training period. The results indicated that hypertrophy occurred in both training groups, based on measures of quadriceps thickness and thigh circumference. The increase in the vastus intermedius thickness was greater than 20% for all subjects, however, the rectus femoris had a very modest increase of 2%. Young and Bilby hypothesized that "since hypertrophy development was similar for both slow and fast groups, speed of contraction may not be a factor."

Counsilman et al. (1976) reported that slow velocity training only increased the size of the slow twitch fibers (Type I), but MacDougall et al. (1980a) reported that slow velocity training increased the size of Type I and Type II fibers.

### Summary

There have been numerous investigations of velocity specific strength training. It is evident from these velocity specific training studies that the greatest strength gains usually occur at or near the training velocity, but these findings are not conclusive. There have been studies in which fast velocity training increased strength at all test velocities, slower and faster than the training velocity (Moffroid and Whipple, 1970; Coyle et al. 1981; Doherty et al. 1991). There also have been studies in which a slow training velocity increased strength at all test velocities slower and faster than the training velocity (Katch et al. 1975; Karnehisa and Miyoshita, 1983; Rutala et al. 1984, Petersen et al. 1989). Even though there are reports of velocity specific strength gains, there is still some question whether slow or fast velocity training is more effective in increasing strength over the velocity spectrum.

Cross education has been demonstrated in several isometric and isotonic studies (Coleman, 1969; Moritani and deVries, 1979; Parker, 1985). Hellebrandt et al. (1947) explained cross education as a "diffusion of motor impulses to the contralateral side of the body and tonic postural reflexes that result in cocontractions of the musculature of the contralateral side of the body." With the widespread use of isokinetics in clinical settings, it was only natural for investigators to study the effects of isokinetic training on cross education (Stevens et al. 1980; Narici et al. 1989; Housh and Housh, 1993). There have been studies reporting cross education following isokinetic training. There is, however, limited research reporting whether slow or fast velocity isokinetic training is more advantageous in producing cross education.

One of the adaptive responses to strength training is the enlargement of the trained muscles. There have been two proposed mechanisms to explain this enlargement, muscle hypertrophy and muscle hyperplasia. Muscle hypertrophy is the enlargement of the size of the individual muscle fibers; muscle hyperplasia is an increase in the number of muscle fibers. Muscle hypertrophy is generally accepted as the cause of muscle enlargement. Hypertrophy takes place in both slow and fast twitch fibers with resistance training, with larger increases in the fast twitch fibers. There have been several isokinetic studies reporting muscle hypertrophy following velocity specific training (Krotkiewski et al. 1979; Coyle et al. 1981; Narici et al. 1989; Ewing et al. 1990). However, there is some question whether slow or fast velocity training is more effective in producing muscle hypertrophy. MacDougall (1986) reported that the magnitude of the hypertrophy is not only related to the intensity and length of the training period, but the length of time the muscle is under tension. With slow velocity training, the muscle is under tension longer than during fast velocity training, thus more hypertrophy would be expected in slow velocity training.



However, Young and Bilby (1993) reported no differences in muscle hypertrophy between slow and fast velocity training.

**Chapter III**  
**JOURNAL MANUSCRIPT**

**The Effects of Velocity Specific Isokinetic Training on Strength Gains in the  
Trained Limb, Untrained limb, and on Muscle Hypertrophy**

**Rodney Gaines, Don Sebolt, Ronald Bos, and Jay Williams**

**Human Nutrition and Foods, Virginia Polytechnic Institute and State University**

## Introduction

Strength is presently understood to be the maximum force or torque a muscle can generate (Costill and Wilmore, 1994). During strength training three types of muscle contractions may be exhibited during strength training: concentric, eccentric, and isometric. Concentric contractions involve shortening of the muscles as tension develops. Eccentric contractions involve lengthening of the muscle as tension develops. Isometric contractions are characterized by no change in the length of the muscle. These contractions are executed in various types of strength training: isotonic, isometric, plyometric, and isokinetic. Isotonic training consists of repeated concentric and/or eccentric contractions with a constant, movable load. Isometric training consists of repeated muscular contractions performed against a fixed or immovable resistance. Plyometric training consists of explosive movements, such as jumping, running, and skipping with an emphasis on an eccentric followed by a concentric contraction. Isokinetic training takes place with specialized equipment, that controls the velocity of movement during concentric and/or eccentric contractions.

Isokinetic training is unique in that training takes place at specific velocities. The effects of velocity specific training, although not completely clear, include strength gains, muscle hypertrophy, and neuromuscular adaptations including cross education. The effects of velocity specific training on strength gains at the training velocity and faster and slower velocities have been varied. It is evident that velocity specific training generates strength gains at the training velocity. Velocity specific training also has demonstrated that the greatest strength gains occur at or near the training velocity (Behm and Sale, 1993). Even though research has shown strength gains at and near the training velocity, there are reports of velocity specific strength gains, there is still some question whether slow or fast velocity training is more effective at increasing strength over the velocity spectrum.

There have been several investigations of velocity specific training and its affect on strength in the trained limb. However, these reports have been somewhat contradictory. Early investigations of velocity specific training report that strength increases occurred only at the training velocity and slower velocities, regardless of the training velocity (Moffroid and Whipple, 1970; Lesmes et al, 1978). Moffroid and Whipple (1970) reported that slow velocity training resulted in significant strength gains at and slower than the training velocity, but not faster than the training velocity. Their fast training group recorded strength gains at the training velocity and slower velocities; however, they did not test at velocities faster than the training velocity of the fast training group. Lesmes et al. (1978) reported results similar to Moffroid and Whipple.

Coyle et al. (1981) reported that strength gains occurred at velocities faster than the training velocity. At a fast training velocity (300 degrees-per-second) Coyle et al. observed that strength gains occurred at the training velocity and all velocities slower than the training velocity. However, they did not test faster than the training velocity of the fast training group. Caiozzo et al. (1981), similar to Coyle et al., reported that strength gains occurred at velocity faster than the training velocity. For a slow training group (96.4 degrees-per-second) strength gains were reported at and faster than the training velocity. Caiozzo found that fast velocity training (240 degrees-per-second) increased strength at that velocity and a few slower velocities, but not at all velocities slower than the training velocity. The slow training velocity (96.4 degrees-per-second) increased strength at that training velocity and at a faster velocity (240 degrees-per-second).

A study conducted by Jenkins (1984) reported results which agreed, somewhat, with Caiozzo et al. Jenkins reported that training at slow training velocities failed to show strength gains at slower velocities, but did show strength gains at faster velocities. Jenkins also reported that the fast training group (240 degrees-per-second) had strength gains at the

training velocity, and at faster and slower velocities. Similar to Jenkins, Petersen (1989) showed that fast velocity training (180 degrees-per-second) generated strength gains at the training velocity, at faster velocities, and at slower velocities. Slow velocity training (60 degrees- per-second) similarly increased strength at the training velocity and a faster velocity (280 degrees-per-second). The researchers did not test slower than the training velocity of the slow group.

It is apparent from these studies that we do not have a clear picture of the effects of velocity specific, isokinetic training on strength. It is apparent that velocity specific training increases strength at the training velocity. Whether slow or fast velocity specific training increases strength at velocity faster than a slower than the training velocity is much less apparent.

There has also been research indicating that strength gains in a trained limb result in increases in strength in the contralateral limb (Hellebrandt et al., 1947; Coleman, 1969; Houston et al., 1983; Moritani and deVries, 1979). However, only a few studies (Housh and Housh, 1993; Stevens et al., 1980; Krotkiewski et al., 1979) have looked at the effects of velocity specific training on strength gains in the contralateral limb. Narici et al. (1989) failed to report any strength gains in the contralateral limb from training at 120 degrees-per-second. Stevens et al. (1980) reported significant strength gains in the contralateral limb based on test velocities of 0, 60, 120, 180, 240 and 300 degrees-per-second following training at a velocity of 180 degrees-per-second. Krotkiewski et al. (1979) trained subjects at a velocity of 60 degrees-per-second and reported strength gains in the contralateral limb at test velocities of 0 and 120 degrees-per-second. They failed to report strength gains at 30, 60, and 180 degrees-per-second in the contralateral limb. Housh and Housh (1993) did not show any significant gains in strength in the contralateral elbow flexors following elbow flexion/extension and knee flexion/extension training, but strength

gains in the elbow extensors and knee flexors and extensors in the contralateral limb were observed. Although strength gains in the contralateral limb have been demonstrated following velocity specific training, it is unclear whether velocity specific training has any effect on the strength gains in the elbow flexors or other upper extremity muscle groups.

Another area that has been the subject of only a few investigations is the relationship of velocity specific training to muscle hypertrophy. Katch (1975), utilizing isokinetic training, showed that slow velocity training is more advantageous for promoting muscle hypertrophy. Later research done by Coyle et al. (1981) showed that fast velocity training caused a greater increase in the size of the type II fibers in the muscle as compared to the type I fibers.

In view of the aforementioned research and in some areas lack of research, the purpose of this study was to determine the relationship among velocity specific, isokinetic training and strength gains in the trained limb and the contralateral limb. In addition, it was the purpose of this study to determine the effect of velocity specific isokinetic training on muscle hypertrophy in the trained limb, measured by estimating the cross-sectional area of the muscle.

## Methods

### Subject Selection

Thirty untrained subjects (15 male and 15 female) between the ages of 18 and 38 volunteered to participate in the six-week training study. The mean age was 24.6 years, the mean height was 169.08 cm., and the mean bodyweight was 70.45 kg. Subjects were eligible to participate in the study upon meeting the following requirements: 1) subjects had not trained with weights in the last year, 2) subjects were free of orthopedic injuries and other medical complications, and 3) subjects were not presently taking ergogenic aids.

### Subject Orientation

Orientation began with a brief interview. Subjects then completed and signed a health questionnaire and signed an informed consent form. Prior to the subject orientation, the informed consent form and the experimental procedures had been approved by the Department of Human Nutrition and Foods at Virginia Tech and the Human Subjects Committee of the University. Following the signing of the informed consent form, a personal profile of the subject was entered into the Biodex software system. This profile included the subject's name, height, weight, birthdate, and address.

The subject orientation continued with steps to familiarize each subject with the Biodex equipment. Subjects were seated in the Biodex chair and secured across the shoulders to prevent any movement of the upper body. The upper arm was secured to an attachment on the chair to isolate the forearm during elbow flexion and extension. The seat height and forearm position were, at this time, added to the subject's personal profile. The contralateral limb of each subject remained relaxed.

After a brief warm-up of ten "easy" repetitions at 210 degrees-per-second, the familiarization continued as subjects were instructed to complete 5 to 8 submaximal, then 5 to 8 maximal repetitions at each of the three velocities of 60, 210, and 450 degrees-per-second. The subjects were tested and trained through an approximate 110 degrees range of motion. These procedures were carried out for each extremity. After this orientation session the subject was scheduled for his/her pre-test.

### Experimental Test Sessions

The experimental test sessions consisted of a two pre-tests and a post-test. The first pre-test was administered after all subjects had completed the orientation session. On the day of the first pre-test limb circumferences were taken before the testing started. The circumference of each upper arm was measured at the midline of the upper arm. Skinfolts



were also taken at four sites on the upper arm: medial, lateral, posterior, and anterior. The cross-sectional area of the muscle was determined by entering the circumference and skinfolds in a formula that would estimate the cross-sectional area of the muscle.

Following limb circumference and skinfold measurements, the subject was positioned in the equipment for the initial pre-test. Gravity correction procedures were employed to account for the weight of dynamometer's lever arm and the weight of the limb being tested. Since the acceleration of the limb and lever arm due to gravity reduces the applied torque, a gravity correction was required. All testing and training was completed through a 110 degrees range of motion.

Before data collection began, the subject warmed-up with one set of ten submaximal contractions at 210 degree-per-second. Pre-test data were then recorded for of five maximal contractions at 60 degrees-per-second, and eight maximal contractions at 210 and 450 degrees-per-second. The rest time between each set of contractions ranged from two to five minutes. The highest peak torque during each of the three sets of contractions for each limb was recorded. Both limbs were tested in the same manner.

A second pre-test, duplicating the initial pre-test, was repeated within 72 hours of the initial pre-test. The second pre-test provided additional data for test reliability calculations. The highest absolute peak torque of the two pre-test was used as the criterion score. Following the second pre-test, the subjects were assigned to one of three treatments: CG, SG, and FG. Within each of these treatments the limb to be trained was randomly selected.

### Training Protocol

Following the assignment of subjects to the treatment groups, the two training groups trained for six weeks. The control group did not train. All subjects in the control group were instructed to forego any weight training during the subsequent six weeks.

The training regimen for each of the two experimental groups was established on the basis of pre-test data. Since more torque, thus more work, is developed during each repetition at slower isokinetic velocities, and the work output for each training session was to be equated for the two training groups, the sets and repetitions had to be different for the two training velocities.

From the pre-test data it was determined that it takes approximately twice as many repetitions at 450 degrees-per-second for to equal the work output of a set of repetitions at 60 degrees-per-second. In addition, since the subjects had different initial strength levels, the training routine was subject specific, based on the maximum work output at 60 degrees-per-second in the pre-tests. Subjects with greater strength were required to produce more work in each training session.

To be more specific, based on the initial pre-test, the work output in a single, maximal repetition at 60 degrees-per-second was determined for the each subject. This work output was multiplied by 48 (representing six sets of eight repetitions) to determine the work output to be accomplished in each training session for subjects the slow group (60 degrees-per-second). These subjects subsequently completed 70 % of this total work output at each training session in the first two weeks, 80 % of the total work output at each session in the third and fourth weeks, 90 % in the fifth week, and 100 % of the total work output in the sixth week. At each training session, multiple sets of eight repetitions were completed until the total work output was achieved for that session.

Based on the work output in a single maximal repetition at 60 degrees-per-second during the initial pre-tests, the total work output for each training session was also

determined for subjects in the fast velocity group (450 degrees-per-second). The work output of the single repetition was multiplied by 100 repetitions (representing 10 sets of 10 repetitions) to determine the total work output for each training session for subjects in the fast velocity group. Subjects then completed 70 % of their maximum work output the first two weeks of training, 80 % of their maximum work output in the third and fourth weeks, 90 % in the fifth week, and 100 % in the sixth week. During each training session, sets of ten repetitions were completed until the total work output was achieved for that training session.

### Statistical Procedures

The Number Cruncher Statistical Analysis for Windows (NCS, 1995) and Minitab (Minitab, 1995) were used for all data analyses. The basic statistical routines utilized by the investigator were descriptive statistics, correlation and analysis of variance. Sigma Plot (Sigma Plot, 1993) was used to generate graphic representations of selected data analyses. A two-way analysis of variance (Group\*Speed) with repeated measures was used to determine the changes across the training velocities of 60, 210, and 450 degrees-per-second for both the training and untrained limbs. A one-way analysis of variance with repeated measures was used to detect the changes in the estimated cross sectional area of the upper arm in the training limb. When the analysis of variance showed significant main effects, a Tukey-Kramer multiple-comparison test was performed. A paired t-test was also used for selected within group comparisons. For all analyses, an alpha level of .05 was accepted as showing statistical significance.

### Results

#### Physical characteristics of subjects

A total of thirty subjects (15 male and 15 female) completed the two pre-tests, six-week training protocol, and post-test. Five subjects were dismissed from the study for

failing to comply with procedures. The physical characteristic of the subjects measured were: age, height, pre-training body weight and post-training body weight. These average values for each of these variables were consistent across each of the three experimental conditions. Table 1 provides the descriptive statistics for these variables.

#### Reliability estimates

Subjects were given two pre-tests, administered on separate days to establish stability reliability estimates of the absolute peak torque in the trained limb and untrained limb and upper arm girth measurements. Pearson product moment correlation (test-retest) was used to compute the stability reliability estimates. The reliability estimates for absolute peak torque of the trained limb range from  $r=.81$  to  $r=.93$ . The reliability estimates for absolute for absolute torque of the un-trained limb range from  $r=.81$  to  $r=.91$ . The reliability estimates for arm girths ranged from  $r=.87$  to  $r=.96$ . Reliability results are displayed in Table 2.

#### Training limb

A two-way analysis of variance (group\*Speed) with repeated measures was used to test for changes in absolute peak torque. The ANOVA source table indicated no significant difference ( $P>.05$ ) in Group, a significant difference ( $P<.05$ ) in the main effect of speed, and a significant difference ( $P<.05$ ) in the Group\*Speed interaction.

The Tukey-Kramer multiple-comparison test indicated that the slow condition's mean change score of 3.43 significantly differed from the control group's mean change score of -2.24. Figure 1 contrasts the changes in absolute peak torque among the three experimental conditions at 60 degrees-per-second. The slow and fast training conditions were not significantly different from each other at 60 degrees-per-second. The fast training condition was not significantly different from the control at the test velocity of 60 degrees-per-second. The slow, fast, and control conditions were not significantly different from

each other at the test velocity of 210 degrees-per-second. The fast training condition mean change score of 4.66 significantly differed from the control's group's mean change score of .59. Figure 2 contrasts the changes in absolute peak torque among the three experimental conditions at 450 degrees-per-second. The slow and fast training conditions were not significantly different from each other at 450 degrees-per-second.

Paired T-tests were used to test for changes in absolute peak torque within each of the two training conditions. The slow group improved significantly ( $P < 0.05$ ) at velocities of 60 degrees-per-second and 210 degrees-per-second; but failed to indicate significant gains at 450 degrees-per-second.

The fast velocity group improved significantly ( $P < 0.05$ ) at velocities of 450 degrees-per-second and 210 degrees-per-second; but failed to produce significant gains at 60 degrees-per-second.

#### Untrained limb

A two-way analysis of variance (Group\*Speed) with repeated measures was used to test for changes in absolute peak torque. The ANOVA indicated no significant difference ( $P > .05$ ) in Group, a significant difference ( $P < .05$ ) in the main effect of speed, and a significant difference ( $P < .05$ ) in the Group\*Speed interaction.

A Tukey-Kramer multiple-comparison test showed that the slow condition's mean change score of -.28 to be significantly different from the mean change scores of the fast condition (-.44) and the control group (-4.02) at the test velocity of 60 degrees-per-second. Figure 3 contrast the differences in strength gains among the slow, fast, and control groups at the test velocity of 60 degrees-per-second. The slow, fast, and control conditions were not significant different from each other at test velocities of 210 and 450 degrees-per-second in the untrained limb. Paired T-tests were used to test for changes in absolute peak torque within each of the training conditions. The slow velocity group failed

to improve significantly ( $P>0.05$ ) at velocities of 60 degrees-per-second, 210 degrees-per-second, or at the velocity of 450 degrees-per-second. The fast velocity group also failed to improve significantly ( $P>0.05$ ) at any of the test velocities.

#### Estimated Cross-Sectional Area of the Upper Arm in the Trained Limb

A one-way analysis of variance (ANOVA) with repeated measures was used to test for changes in the estimated cross-sectional area of the upper arm measured at the exercise test velocity of 60 degrees-per-second among the exercise training conditions (slow training and fast training) and a control group. There were no significant differences ( $P>0.05$ ) in girth measures among the slow, fast, and control groups.

Paired T-test were used to determine if significant changes occurred within each of the two experimental conditions. The slow training group produced significant ( $T=2.38$ ,  $P<0.05$ ) changes in arm girth from pre-test to post-test arm girths in the Fast training condition. Figure 4 illustrates the changes estimated cross-sectional area among the slow, fast, and control groups.

### Discussion

#### Strength Gains in the Trained Limb

The aforementioned results indicate that the strength gain of the slow velocity group significantly differed from that of the control group at the test velocity of 60 degrees-per-second, but did not significantly differ from the strength gain of the fast velocity group. However, the strength gains of the three experimental groups were not significantly different from each other at the test velocity of 210 degrees-per-second. The fast velocity group significantly differed from the control group at the velocity of 450 degrees-per-second, but did not significantly differ from the slow velocity group at 450

degrees-per-second. Both the slow and fast velocity groups did increase strength significantly at their training velocity (60 and 450 degrees-per-second respectively) and 210 degrees-per-second, but failed to increase strength significantly at the third, more distant velocity.

Overall, the following results of this study show strength gains at the training velocity and at a velocity close to the training velocity, but no significant gains at velocities more distant from the training velocity. These results demonstrate velocity specificity, as described by Behm and Sale (1993). "Velocity specificity has demonstrated that the greatest strength gains occur at or near the training velocity".

The underlying mechanisms which account for velocity specificity are still not clear, may be due to both neural and muscular adaptations. One reason for velocity specific adaptations may be that as isokinetic test velocities move further apart, the motor tasks become more dissimilar, requiring different recruitment patterns and patterns of coordination (Knapik and Ramos, 1980). There appears to be a neural limiting mechanism that inhibit slow velocity training groups from generating a significantly greater force increase at considerably faster velocities, and that inhibits a fast velocity training group from generating a significant increase in force at distant slower velocities (Perrine and Edgerton, 1979; Behm and Sale, 1991). Caiozzo et al. (1981) reported that training at a slow velocity elicits a greater neural limiting mechanism. There may need to be longer training periods to observe differences among slow velocity and fast velocity groups at distant velocities. There have been reports similar to the present findings that show that strength gains are often limited to the training velocity and velocities near to the training velocity (Smith and Melton, 1981; Ewing et al., 1990).

It has been found that maximum strength gains are developed with loads of 90% or more of maximum strength, executed at a slow velocity (Bompa, 1983). Relatively

slow training (0 and 120 degrees-per-second) of movement are similar to velocities used in dynamic resistance training with free weights, during which the muscles maintain contractile tension for a longer duration than fast velocities. The slow velocity group in the present study significantly differed from the control, and the greater strength gains in the slow velocity group may be due to the fact that the muscle is under tension longer. In order for hypertrophy of muscles to occur, the muscles need to be overloaded and under tension (MacDougall, 1986). Hypertrophy in the slow group may also explain why the slow velocity group had greater strength gains than the control group. The slow velocity group had a 10.77% increase in the estimated cross-sectional area of the upper arm along with a 12.39% increase in strength gains. Most of the strength gains in the slow velocity group at 60 degrees-per-second were related to muscle hypertrophy.

The fast velocity group (450 degrees-per-second) was significantly different from the control group at its test velocity of 450 degrees-per-second, but the fast velocity group was not significantly different from the slow velocity group (60 degrees-per-second) at the test velocity of 450 degrees-per-second. The fast velocity training group significantly increased strength from pre-tests to post-tests at its training velocity of 450 degrees-per-second and at 210 degrees-per-second, but failed to significantly increase strength at a distant velocity of 60 degrees-per-second. Similar to the findings with the slow velocity training group, the strength gains in the fast velocity group may be attributed to velocity specificity. The fast velocity group had strength gains of 11.24% and 18.84% from pre-test to post-test at test velocities of 210 and 450 degrees-per-second. The fast velocity group had a 3.05% increase in the estimated cross-sectional area of the muscle. The findings in this study may indicate that most of the strength gains from slow velocity training may be due to muscular adaptations, while the strength gains from fast velocity training may be related to neural adaptations. Some of the neural adaptations that may



have taken place in the present findings are increase in motor unit activation. It is believed with training that a subject is able to recruit more motor units before training. Training velocity may have an effect on the magnitude of the increase in motor unit activation. Selective activation of motor units and/or muscles may also be a neural adaptation with training, and training velocity may alter the selective activation of motor units. Another neural adaptation from velocity specific training is an increased synchronization of the motor units, and synchronization is defined as the coincident timing of impulses from two or more e motor units. Synchronizations of the muscle units may be attributed to the strength gains in this study. A change in the motor unit firing frequency is another neural adaptation that may have occurred in the present study. This may have an improvement on the rate of force output. The neural adaptations may vary depending on the training velocity. From these findings it may be concluded that there were more neural adaptations in the fast velocity group than the slow velocity group, since there were smaller changes in hypertrophy in the fast velocity group.

Changes in the muscle properties also take place with velocity specific training. It is apparent that slow velocity training is more suited for stimulating muscle hypertrophy due to the higher amounts of tension (Goldberg et al., 1975). Hypertrophy may have an effect on velocity specificity. There is a strong relationship between the cross-sectional area of the muscle and the amount of strength generated (Rodahl, K. and Horvath, S.M., 1962). Another velocity specific training adaptation may be fibre type transformation. Jansson et al. (1990) reported a 9% decrease in the proportion of type I fibres with a concomitant 6% decrease increase in type IIa fibres following 4 to 6 weeks of Wingate cycle sprint training. This may explain the velocity specific adaptations in the fast velocity group. In the past muscle hypertrophy or muscle-boundness was thought to decrease flexibility and velocity of limb movements. It was felt that slow velocity training, which produced hypertrophy,

may interfere with high velocity movement. Tesch and Larson (1982) reported impaired ability of a hypertrophied muscle to develop torque at high velocities, such as sport-specific movements. The slow velocity group had significant strength gains at its training velocity and at the intermediate test velocity, but failed to have strength gains at the distant velocity. Bell and Jacobs (1992) also reported that bodybuilders, who train at slow velocities, perform better at the slow velocities. This may explain why the slow velocity group (60 degrees-per-second) did not significantly increase strength at the distant velocity of 450 degrees-per-second in this study.

The present study differ from some of the other velocity specific studies which report that fast velocities increase strength at all test velocities, and that slow velocity training only increased strength at the training velocity and slower velocities (Moffroid and Whipple, 1970; Coyle et al, 1981; Jenkins et al., 1984; Timm et al., 1987; Housh and Housh, 1993). It has been also stated in a review that slow velocity training only increase strength at slow velocities, while fast velocity training increases strength at all velocities (Sale and MacDougall, 1981). One explanation for the present study findings is the different interpretations of slow and fast velocities. Back in the early 1970's Moffroid and Whipple referred to 36 degrees-per second as a slow velocity and 108 degrees-per-second as a fast velocity. Today, isokinetic dynamometers can test and subjects can train at velocities as high as 450 degrees-per-second. The limitation in testing velocities in the early 1970's may explain why Moffroid and Whipple reported strength gains at all test velocities, because the 108 degrees was very close to the slow test velocities of 18, 36, 54, , 72, and 92 degrees-per-second. The investigators did not test faster than 108 degrees-per-second. Other investigators report that intermediate velocities (120-240 degrees-per-second) may increase strength over a wider range of slower and faster velocities (Karnehisa and Miyoshita, 1983; Doherty et al. 1993) and the aforementioned studies may also explain

why investigators report that fast velocities increase strength at all velocities. Jenkins reported that training at 240 degrees-per-second increased strength at all test velocities. When comparing a fast velocity of 240 degrees-per-second used in Jenkins study to 450 degrees-per-second in the present study, the 240 degrees-per-second is considered an intermediate velocity. Training at a velocity of 180 degrees-per-second has increased strength at test velocities ranging from 0-300 degrees-per-second (Lesmes et al., 1978, Kaneshisa and Miyoshita, 1983; Timm, 1987; Behm, 1991). The earlier mixed interpretations may explain why some studies report that fast velocities report strength gains at all velocities; however, there needs to be more consistency in what is a fast velocity and a slow velocity.

The slow velocity group (60 degrees-per-second) in this study increased strength above its training velocity. This is consistent with other velocity specific studies (Caiozzo et al., 1981; Kanehisa and Miyoshita, 1983; Petersen et al., 1989; Ewing et al., 1991). Investigators have referred to slow velocities in velocity specific studies as velocities ranging between 0 and 96 degrees-per-second. Housh and Housh (1993) reported that subjects training at 120 degrees-per-second increased strength at test velocities of 60, 120, 180, 240, and 300 degrees-per-second; however, there is some question whether 120 degrees-per-second is a slow or intermediate velocity. Some velocity specific studies have reported that slow velocity training increasing strength at all test velocities (Katch, 1975; Kanehisa and Miyoshita, 1983; Petersen et. al, 1989; Behm and Sale, 1991). It is unclear why these findings have occurred. Since the slow velocities generate a greater tension in the muscle, hypertrophy factors may increase strength at all test velocities.

#### Velocity Specificity in the Untrained Limb

The slow, fast, and control groups significantly differed from each other in strength gains in the untrained limb at a test velocity of 60 degrees-per-second. The groups failed

to significantly differ in strength gains at velocities of 210 and 450 degrees-per-second. The slow velocity group, fast velocity group, and control group failed to increase strength significantly from pre-test to post-test in the untrained limb at test velocities of 60, 210, and 450 degrees-per-second. Even though there has been training studies failing to show cross education (Rutherford and Jones, 1986; Young et al. 1983), there has been enough studies showing cross education to give support to the phenomenon (Coleman, 1969; Komi et al. 1978; Moritani and deVries, 1979). Hellebrandt et al. (1947) explained cross education as a result of "diffusion of motor impulses to the contralateral side of the body and tonic postural reflexes that result in cocontractions of the musculature of the contralateral side of the body."

It is unclear why cross education from velocity specific training did not occur in this study. There has been other reports of velocity specific training failing to find cross education (Coyle et al., 1981; Narici et al., 1989; Housh and Housh, 1993). Narici et al, 1989 had only four subjects. With so few subjects, significant changes would be difficult to ascertain. Housh and Housh (1993) demonstrated strength in the untrained limb with knee flexion and extension and elbow extension, but failed to show significant strength gains in elbow flexion of the untrained limb. Housh and Housh believed that the non-significant strength increases in elbow flexion may reflect a response that is specific to this muscle group. Since the elbow flexors were the muscle group trained in this study. There have been investigations of velocity specific training demonstrating significant increases in the untrained limb (Krotkiewski et al. 1979; Stevens et al., 1980; Kannus et al., 1992). All of these studies involved knee extension and flexion.

Another issue in cross education is the cooperation and motivation of the subjects. All subjects were trained to give a maximum effort in this investigation. Hellebrandt and Houtz (1947), cited by Clarke 1973) concluded "that cross education was demonstrable

only when the subject was cooperative and trained to put forth an all out effort which approximated in its severity the maximal physiological work attainable under the condition imposed" . Hellebrandt also stated that it is the magnitude of the cross education effect was related to the severity of the effort evoking the response rather than the duration of the exercise. The intensity of exercise may have an effect on the magnitude of cross education takes place after training. Intensity is often referred to as the percentage of maximal effort. With velocity specific training there is some question whether the intensity is high enough for cross education to occur. The force-velocity relationship of muscle shows that the greatest amount of contractile force occurs at and near isometric contractions and eccentric contractions. This relationship may explain why there has been mixed results with velocity specific training and cross education. With velocity specific training there is a longer acceleration period before peak torque takes place, and much of the muscle force is lost in generating limb velocity and is not recorded in external force production (Barnes, 1981). However, there has been strength gains in the untrained limb following isokinetic studies with training velocities ranging from 60 to 240 degrees-per-second (Krotkiewski et al., 1979; Steven et al., 1980; Kannus et al., 1992). Kannus et al. did have a more intense training protocol than that used in the present study. From the present study it can be concluded that cross education may not occur in certain limbs, and the training protocol, even though specific to each individuals strength may have not been intense enough to cause cross education. More research with velocity specific training needs to be done in order to confirm its effects on cross education. Along with Housh and Housh, elbow flexion in this study failed to produce significant strength gains in the untrained limb. Cross education may be limited in certain musculature, such as the upper extremity.

### Estimated Cross-sectional Area of the Upper Arm

Muscle hypertrophy is the enlargement of the size of the individual muscle fibers; muscle hyperplasia is an increase in the number of muscle fibers. Muscle hypertrophy is generally accepted as the cause of muscle enlargement. Hypertrophy takes place in both slow and fast twitch fibers with resistance training, with larger increases in the fast twitch fibers. There have been several isokinetic studies reporting muscle hypertrophy following velocity specific training (Krotkiewski et al. 1979; Coyle et al. 1981; Narici et al. 1989; Ewing et al. 1990). However, there is some question whether slow or fast velocity training is more effective in producing muscle hypertrophy. MacDougall (1986) reported that the magnitude of the hypertrophy is not only related to the intensity and length of the training period, but the length of time the muscle exerts tension. The slow, fast, and control groups were not significantly different from each other in muscle hypertrophy. The slow velocity group did have significant strength gains from pre-test to post-test in the estimated cross-sectional area of the muscle. With slow velocity training, the muscle exerts tension longer than during fast velocity training, thus more hypertrophy would be expected in slow velocity training. However, Young and Bilby (1993) reported no differences in muscle hypertrophy between slow and fast velocity training.

It has been well documented that early increases in strength are due to neural adaptations with hypertrophy being dominant after three to five weeks of training (Moritani and deVries, 1979). Even though no significant differences among groups were found in the estimated cross-sectional area of the muscle in the present study, there was a within group pre-test to post-test change in the estimated cross-sectional area of the upper arm of the slow velocity group. Goldberg et al. (1975) concluded that slow velocity training may be necessary to stimulate maximum adaptation within the muscle, and muscle growth is

related to the amount of tension developed within the muscle. Also, Sale and MacDougall (1981) indicate that low force or tension will not produce hypertrophy of the muscle, even if large amounts of work is done. Bodybuilders, who train purposely for hypertrophy, use slow velocities that keep the muscles under longer and greater tension (Bell and Jacobs, 1993; MacDougall et al. 1986). The aforementioned findings are related to the force-velocity relationship where as the velocity of contraction increases, the force that can be developed decreases, despite maximal effort. This may explain why the slow velocity group had a significant increase in the cross-sectional area of the muscle. Katch et al (1975) reported significant increases in upper arm girths with both slow and fast velocity training, with the slow group having a two-fold greater increase than the fast velocity group. Pipes and Wilmore (1975) reported that both slow and fast velocity groups increased significantly in chest, arm, and shoulder girths. Coyle et al. 1981, contrary to Katch and Pipes and Wilmore (1975), reported that fast velocity training resulted in significant increases in the type II fibers, which was not present at other velocities. Fwing et al. (1990) found significant increases in type I and type IIa fibers with no difference between the slow and fast velocity groups. Young and Bilby (1993) reported similar findings. Counsilman et al. (1976) reported that slow velocity training only increased the size of the slow twitch fibers (Type I), but MacDougall et al. (1980) reported that slow velocity training increased the size of Type I and Type II fibers. MacDougall et al. (1986) also reported that they hypertrophy not only depends on the intensity level, but on how long the muscle is under tension.

### Summary

It was the purpose of this study to examine the strength gains due to velocity specific training in the trained limb and its effects on the untrained limb, and to examine the change in the cross-sectional area of the upper arm in the trained limb. The results

indicated that the slow velocity group significantly differed from the control group at 60 degrees-per-second in the trained limb, but was not different from the fast group. The groups were not different from each other at velocities of 210 and 450 degrees-per-second, and there were no significant differences across velocities within each group. Within group changes indicated that the slow velocity group (60 degrees-per-second) significantly increased strength at its training velocity (60 degrees-per-second) and 210 degrees-per-second, but not at 450 degrees-per-second. The fast velocity group (450 degrees-per-second) had significant pre-test to post-test changes at its training velocity and 210 degrees-per-second, but failed to have significant changes at 60 degrees-per-second.

There were no significant gains among the experimental groups in the trained limb at velocities of 210 and 450 degrees-per-second, and no significant changes across velocities within each group. There were no significant differences within each group at the different velocities of 60, 210, and 450 degrees-per-second. Even though cross education has been reported in previous findings, it was not supported in this study. More research needs to be done in this area to clarify effects of velocity specific training on cross education, and also to find out if cross education is specific to upper extremities.

The groups were not significantly different from each other in the estimated cross-sectional area of the upper arm; however, the slow velocity group did have significant increases in the estimated cross-sectional area of the upper arm from pre-tests to post-test. This may indicate that slow velocity training is more advantageous for increasing hypertrophy of the muscle than fast velocity training.

Since the training groups were not significantly different from each other, slow and fast velocity training together should be used to produce strength gains and hypertrophy. It is felt from this investigation that training is velocity specific, and slow velocity training may be more effective for hypertrophy. Based on the findings in this study, most of the



strength gains that occurred in the slow velocity group may be attributed to muscular hypertrophy, while neural adaptations may explain the strength gains from fast velocity. Therefore, both slow and fast velocity training should be used to fully adapt the neuromuscular system.

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TABLE 1

Characteristics Of Slow Velocity, Fast Velocity, and Control Groups

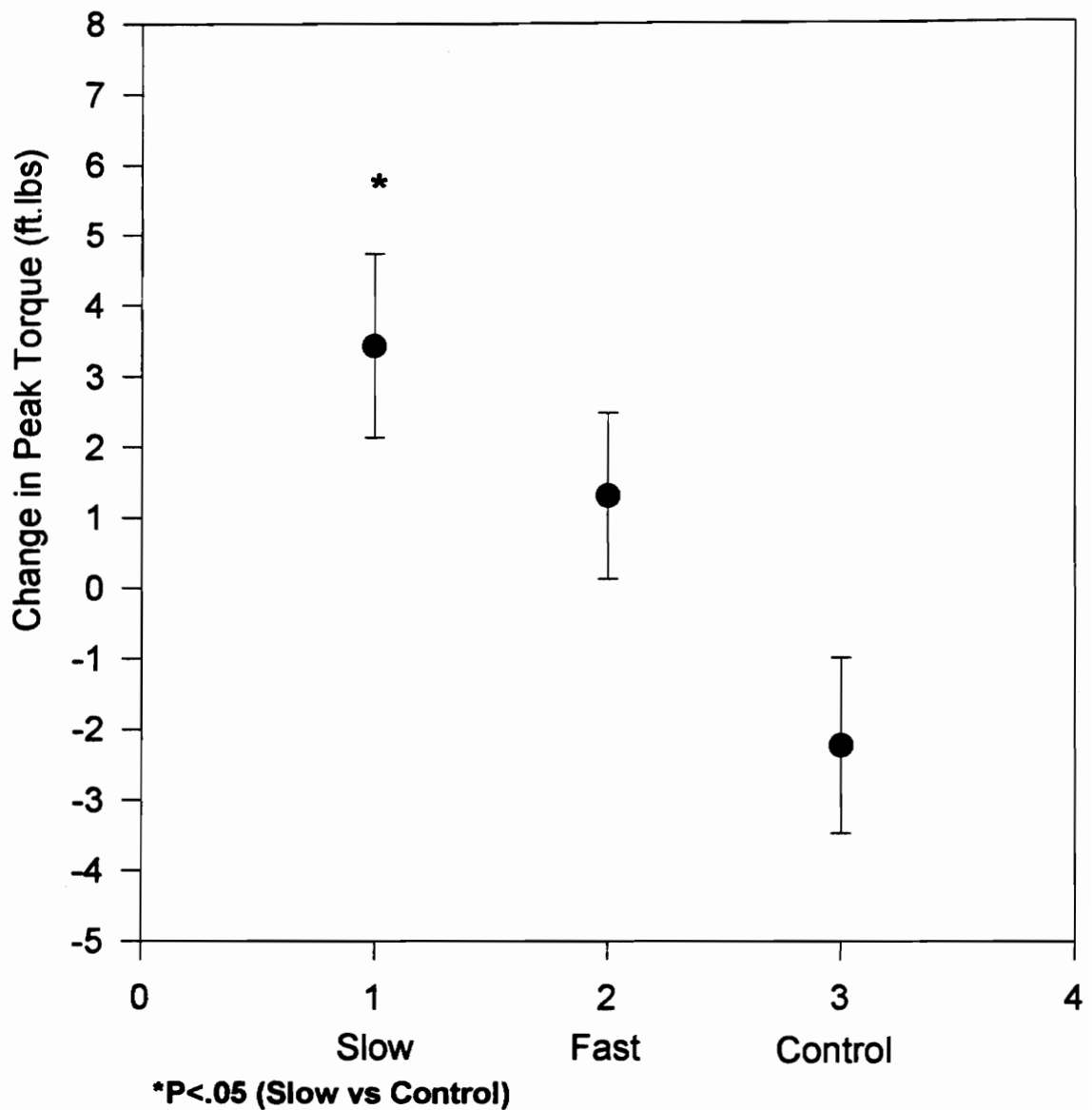
Variable	Slow (n=9)	Fast (n=11)	Control (n=10)
	Mean	Mean	Mean
Age (years)	21.0 (0.5)	23.1 (1.0)	23.5 (1.0)
Height(cm)	166.1 (8.43)	169.3 (8.55)	172.1 (6.82)
Weight pretraining (kg)	84.1 (3.6)	80.6 (2.8)	81.4 (2.6)
Weight post-training (kg)	83.8 (3.5)	81.2 (2.6)	81.8 (2.5)

( ) denote  $\pm$  Standard deviation

Table 2

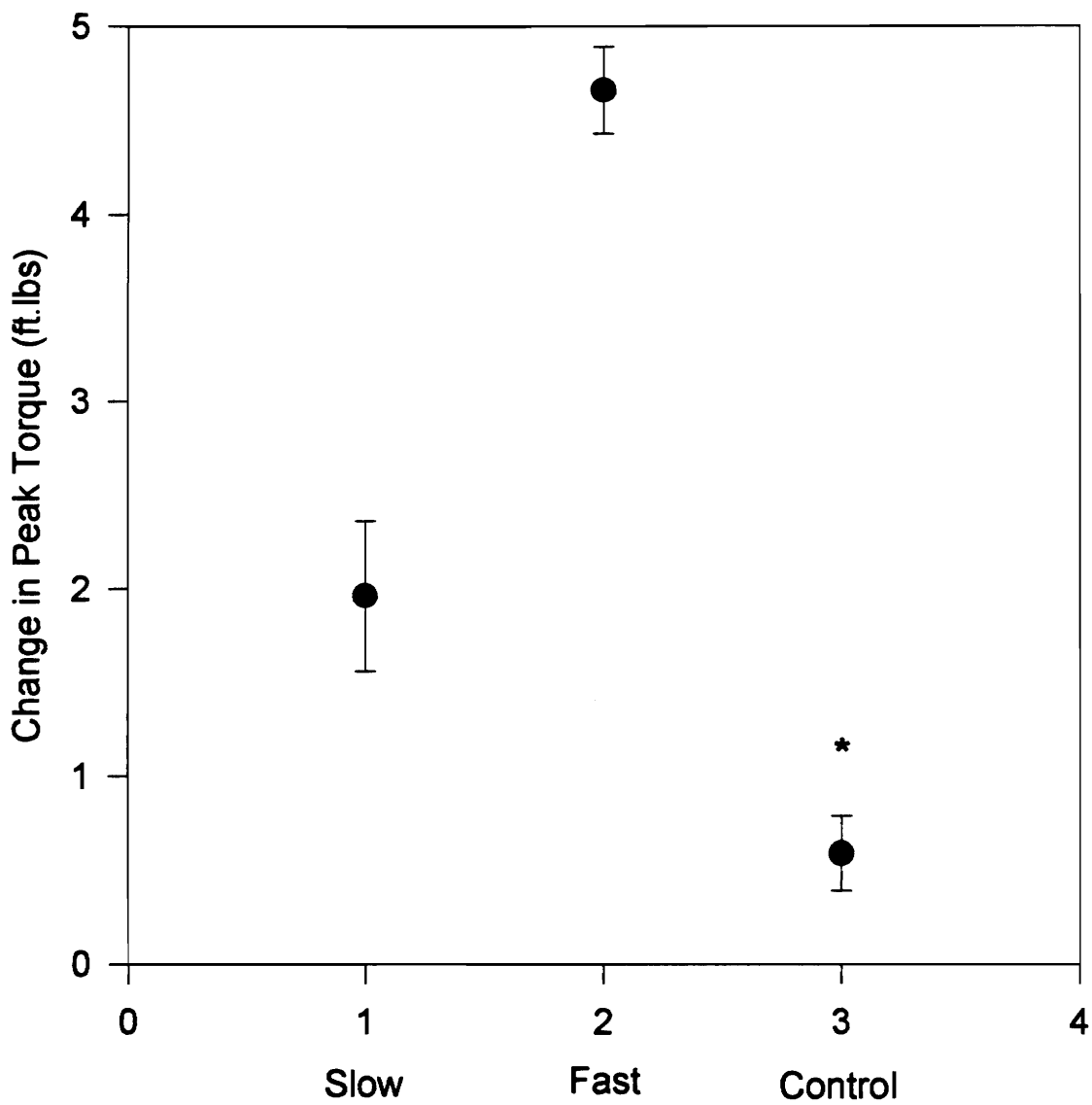
Reliability Estimates Of Trained Limb, Untrained Limb, And Cross-sectional Measures

Variables	Correlation Coefficients
Trained Limb at 60 degrees-per-second	$r=.93$
Trained Limb at 210 degrees-per-second	$r=.91$
Trained Limb at 450 degrees-per-second	$r=.81$
Untrained Limb at 60 degrees-per-second	$r=.91$
Untrained Limb at 210 degrees-per-second	$r=.87$
Untrained Limb at 450 degrees-per-second	$r=.81$
Control Estimated cross-sectional measures	$r=.96$
Slow Estimated cross-sectional measures	$r=.92$
Fast Estimated cross-sectional measures	$r=.87$



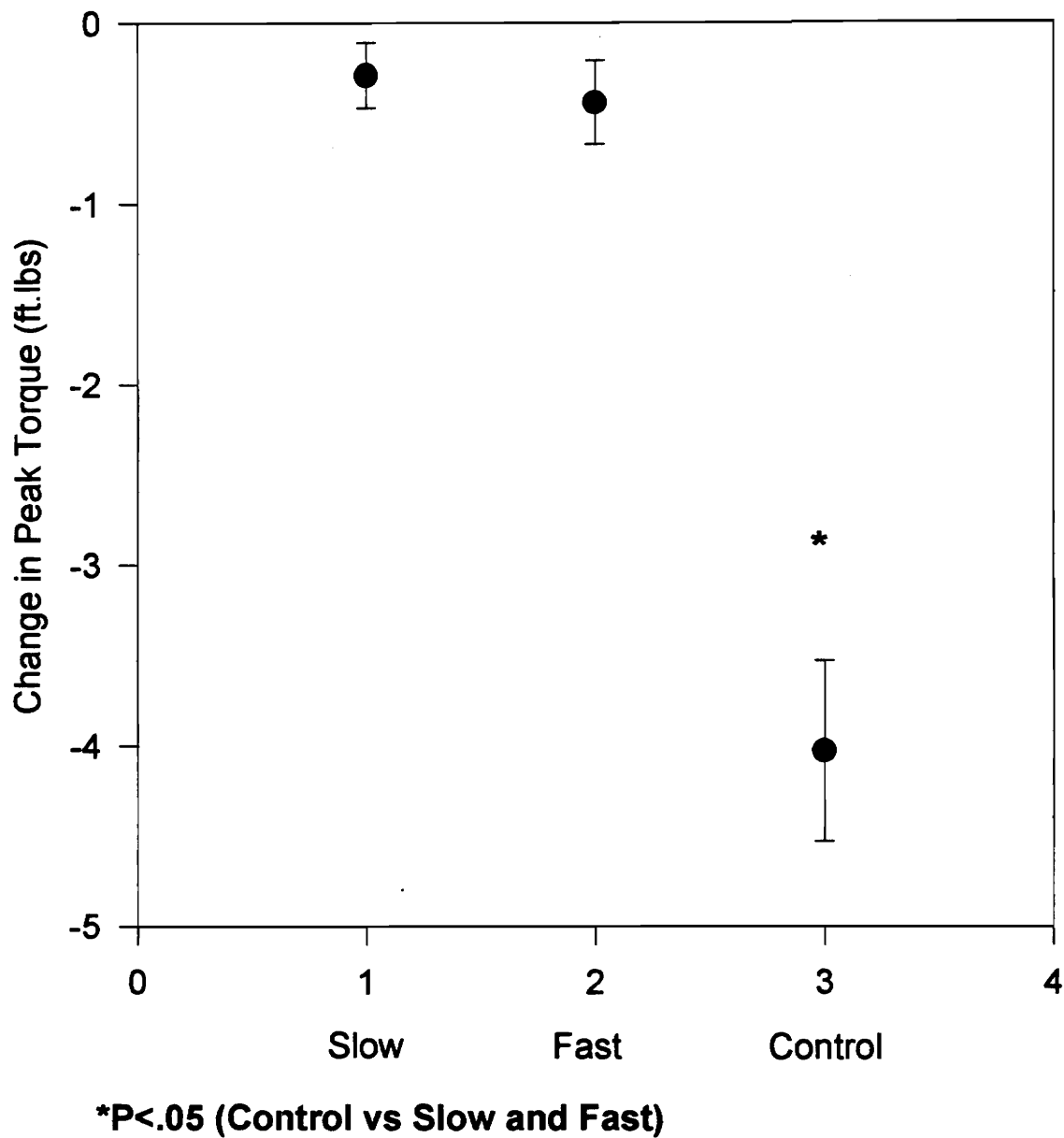
**Figure 1.** Pretest-Posttest changes in peak torque of the training limb at the exercise speed of 60 deg-sec.



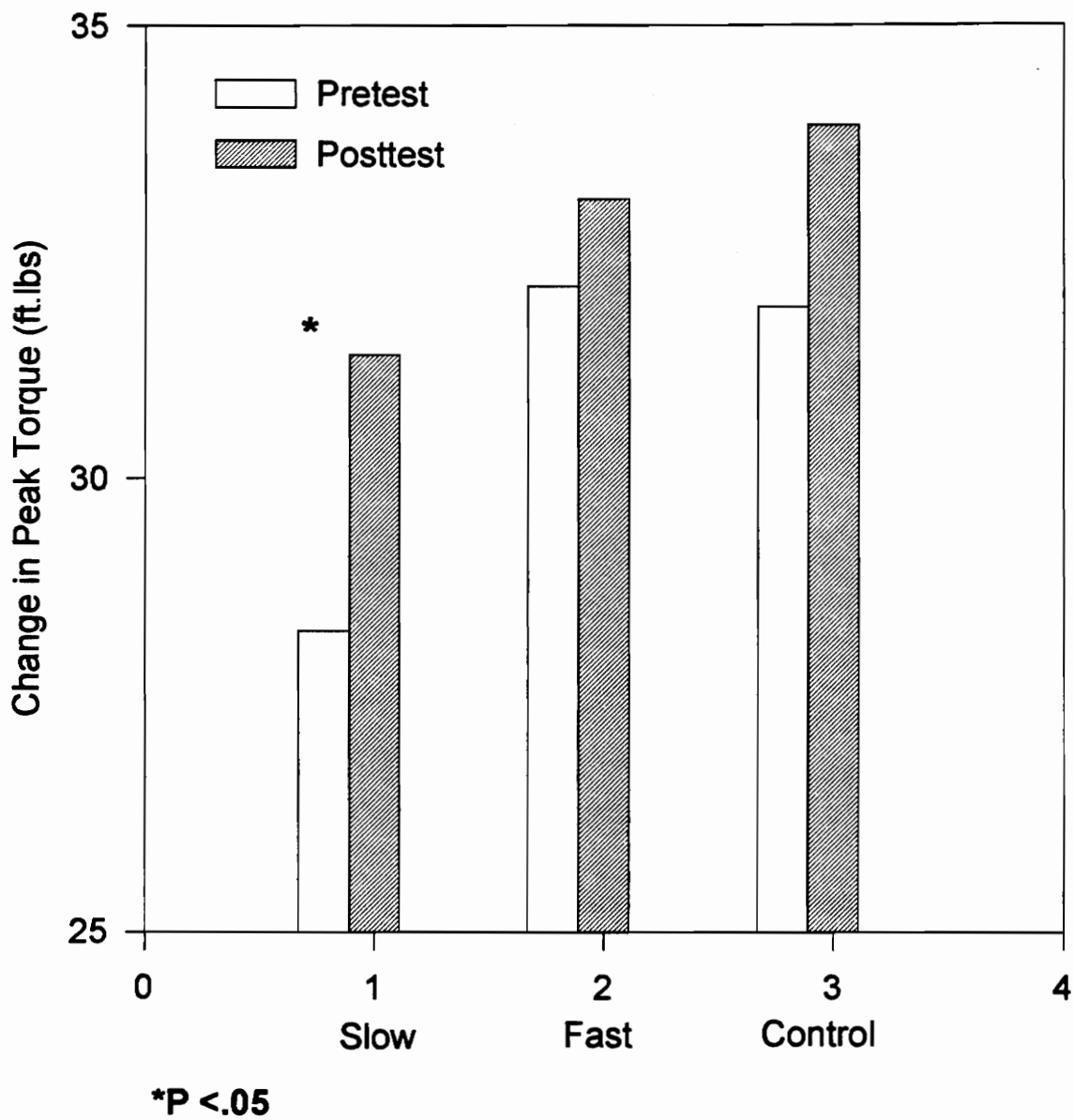


\*P<.05 (Control vs Fast)

**Figure 2. Pretest-Posttest changes in peak torque of the training limb at the exercise speed of 450 deg-sec**



**Figure 3.** Pretest-Posttest changes in peak torque of the untrained limb at the exercise speed of 60 deg-sec



**Figure 4.** Pretest-Posttest changes in estimated cross section area of the upper arm of the training limb

**Chapter IV**  
**SUMMARY**

This study was investigated the effects of velocity specific training on strength in the trained limb and the untrained limb, and estimated cross-sectional area of the upper arm in the trained limb. Thirty untrained subjects between the ages of 18 and 38 participated in the six-week training study. The study was approved by the Virginia Tech Human Subjects Committee; all subjects completed an informed consent form and health questionnaire. An orientation session was given to all subjects to familiarize them with the equipment and testing, and training procedures. After the familiarization sessions, all subjects completed two pre-tests on separate days.

The greatest absolute peak torque and the greatest cross-sectional area were used as criterion scores. During the pre-tests subjects were tested for peak torque at velocities of 60, 210, and 450 degrees-per-second in both limbs. Upper arm girths were also recorded in both limbs. Subjects were then randomly assigned to either a slow velocity training group (60 degrees-per-second), a fast velocity training group (450 degrees-per-second), and a control group. At this time one limb was randomly assigned as the trained limb and the other the untrained limb.

The subjects were assigned a specific training protocol based on performances during the pre-tests. Slow and fast velocity groups trained elbow flexors three times-a-week for six weeks. After six weeks of isokinetic training, a post-test was completed in the same manner as the pre-tests.

Two-way analyses of variance with repeated measures were used to measure the differences in strength gains among the experimental groups at velocities of 60, 210, and 450 degrees-per-second in the trained limb and untrained limb. A one-way analysis of variance with repeated measures was also used to measure the difference in estimated cross-sectional area of the upper arm among the slow velocity group, fast velocity group, and the control group. One-way analyses of variance with repeated measures were

performed across the velocities (60, 210, and 450 degrees-per-second) within the slow velocity, fast velocity, and control group in the trained limb and untrained limb. Individual paired T-tests were used to assess strength gains in the trained limb and untrained limb within each group at the test velocities of 60, 210, and 450 degrees-per-second. Individual paired T-tests were also used to assess changes in upper arm girth within the slow, fast, and control group. Pearson product-moment correlations were used to estimate the reliabilities of the two pre-tests for the trained limb, untrained limb, and estimated cross-sectional area of the upper arm. The reliability estimates for absolute peak torque of the trained limb ranged from  $r = .81$  to  $r = .93$ . The reliability estimates for the absolute peak torque of the untrained limb ranged from  $r = .81$  to  $r = .91$ . The reliability estimates for upper arm girths ranged from  $r = .87$  to  $r = .96$ .

The slow velocity group (60 degrees-per-second) was significantly different from the control group in strength gains at the test velocity of 60 degrees-per-second in the trained limb, but not significantly different from the control at 210 and 450 degrees-per-second. The slow velocity group was not significantly different in strength gains from the fast velocity group and control group at test velocities of 210 and 450 degrees-per-second. The fast velocity group significantly differed in strength gains from the control group at the test velocity of 450 degrees-per-second, but the fast velocity group was not significantly different from the slow velocity group at the test velocity of 450 degrees-per-second. With pre-test to post-test measures within the experimental conditions, the slow velocity group significantly increased strength at its training velocity of 60 degrees-per-second and 210 degrees-per-second. The fast velocity group significantly increased strength at its training velocity of 450 degrees-per-second and 210 degrees-per-second. Both the slow and fast velocity group failed to increase strength significantly at the more distant velocities. There were no significant differences in strength gains in the untrained limb among the

slow, fast, and control group. Pre-test to Post-test measures indicated that there were no significant differences within each group at the test velocities of 60, 210, and 450 degrees-per-second in the untrained limb. There were no significant differences in estimated cross-sectional area of the upper arm from pre-test to post-test among the slow, fast, and control groups. The slow velocity group did significantly increase the estimated cross-sectional area of the muscle from pre-test to post-test.

These findings are not consistent with early studies that reported that fast velocity training increased strength at all test velocities, and slow velocity training only increased strength at the training velocity and slower test velocities (Moffroid and Whipple, 1970; Lesmes et al. 1978). The findings in this study show strength gains above the training velocity, and the fast velocity group did not increase strength at all test velocities. Other studies are consistent with the present findings in that a velocity specific effect was observed (Garnica et al., 1987; Ewing et al., 1991). One reason for the velocity specific effect in this study may be related to force-velocity relationships. It is known that concentric isokinetic torque decreases as the speed of movement increases. More force is generated by the muscle at slower velocity and negative velocity. This may explain the why the slow velocity group and fast velocity group increased strength significantly at their training velocities when compared to the control group in the present study. There appears to be neural and muscular adaptations that occur with velocity specific training; they may be the mechanisms responsible for velocity specificity. Much of the strength gain in the slow velocity group may be attributed to muscle hypertrophy, while the strength gain in the fast velocity group may be due to muscular adaptations within the muscle. Some of the neural adaptations that may occur with velocity specific training are increases in motor unit activation, selective activation of motor units and/or muscles, increased synchronization of the motor units, and a change in the motor unit firing frequency (Behm and Sale, 1993).

Some of the neural adaptations that may have taken place in the present findings are increase in motor unit activation. It is believed with training that a subject is able to recruit more motor units before training. Training velocity may have an effect on the magnitude of the increase in motor unit activation. Selective activation of motor units and/or muscles may also be a neural adaptation with training, and training velocity may alter the selective activation of motor units. Another neural adaptation from velocity specific training is an increased synchronization of the motor units, and synchronization is defined as the coincident timing of impulses from two or more motor units. Synchronizations of the muscle units may be attributed to the strength gains in this study. A change in the motor unit firing frequency is another neural adaptation that may have occurred in the present study. This may have an improvement on the rate of force output. The neural adaptations may vary depending on the training velocity. From these findings it may be concluded that there were more neural adaptations in the fast velocity group than the slow velocity group, since there were smaller changes in hypertrophy in the fast velocity group.

Cross education did not occur in this study. Hellebrandt and Houtz concluded "that cross education was demonstrable only when the subject was cooperative and trained to put forth an all out effort which approximated in its severity the maximal physiological work attainable under the condition imposed" (Hellebrandt and Houtz (1947), cited by Clarke 1973). Hellebrandt also stated that the magnitude of cross education was related to the severity of the effort evoking the response rather than the duration of the exercise. Force-velocity relationships show that the greatest contractile force is generated at isometric to negative velocities, and that this force decreases with increases in the velocity of movement. Since the slow velocity training group and the fast velocity training group failed to significantly increase strength in the untrained limb, this may indicate that



isokinetic velocities may not elicit sufficient contractile force to increase strength in the untrained limb.

Other isokinetic studies have found cross education (Krotkiewski et al., 1979; Stevens et al., 1980; Kannus et al., 1992), but there have been studies failing to show cross education (Narici et al., 1989; Housh and Housh, 1993). Housh and Housh reported strength gains in the untrained limb with the knee extensors and flexors, and elbow extensors, but failed to show strength gains in the elbow flexors of the untrained limb. The elbow flexors of the slow and fast training group failed to show strength gains in the untrained limb in the present study. Further investigations of cross education in the elbow flexors are warranted.

Even though there were no significant difference in estimated cross-sectional area of the upper arm in the trained limb among the slow, fast, and control groups, the slow velocity group did have a significant increases in upper arm girth from pre-test to post-test. Goldberg et al. (1975) conclude that slow velocity training may be necessary to stimulate maximum adaptation within the muscle, and muscle growth is related to the amount of tension developed within the muscle. Also, Sale and MacDougall (1981) indicate that low force or tension will not produce hypertrophy of the muscle, even if large amounts of work is done. These findings are related to the force-velocity relationship where as the velocity of contraction increases, the force that can be developed decreases, despite maximal effort. Since the slow velocity group produce more torque than the fast velocity group explain the hypertrophy of the slow velocity group.

#### Research Implications

The findings in this study confirm the concept of velocity specificity. These findings may be of interest to coaches, athletes, and of exercise scientists. It is apparent from this study that the greater strength gains occur at and near the training velocity.

Athletic movements elicit high velocities; thus, may need to train with high velocity movement. The slow velocity group had greater strength gains at the slow velocity, and it had greater hypertrophy. The slow velocity group did increase strength at velocities of 210 degrees-per-second, so slow velocity may increase strength at higher velocities. Muscle hypertrophy is important in some sports, so athletes need a combination of slow and fast velocity training to fully adapt the musculature. It was unclear why cross education did not occur in this study. There have been previous investigations of velocity specific training supporting cross education. Cross education may be of use to physical therapists and other exercise physiologist, who train the uninjured limb of patients to increase strength in the injured limb. Cross education may be limited to certain muscles, and if cross education is to occur high intensities training protocols are accomplished in order to achieve cross education.

### Further Research

Since isokinetic dynamometers can now test and train at velocities as high as 450 degrees-per-second, more research needs to be done with these faster velocities. Most of the previous literature has referred to fast velocities as 240 to 300 degrees-per-second. There also needs to be longer training periods to observe the effects of slow and fast velocity training on strength in the trained limb and the untrained limb, and the effect on estimated cross-sectional area of the upper arm in the trained limb. More cross education research needs to be done on upper extremities with slow and fast velocity training. It is still unclear whether slow or fast velocities of training are more suited for cross education. There also needs to be further investigations of velocity specific training on muscle hypertrophy. Previous research has shown that early increases in strength are due to neural adaptations, and hypertrophy is observed after four to six weeks of training. Investigations

of velocity specific training on fiber types, contractile properties, and neural adaptations are still unclear and are warranted.

**APPENDIX A**  
**METHODOLOGY**

## METHODOLOGY

### Subject Selection

Thirty untrained subjects (15 male and 15 female) between the ages of 18 and 38 volunteered to participate in the six-week training study. Subjects were eligible to participate in the study upon meeting the following requirements: 1) subjects had not trained with weights in the last year, 2) subjects were free of orthopedic injuries and other medical complications, and 3) subjects were not presently taking ergogenic aids.

### Subject Orientation

Orientation began with a brief interview). Subjects then completed and signed a informed consent form (Appendix B) and signed a health questionnaire form (Appendix C). Prior to the subject orientation, the informed consent form and the experimental procedures had been approved by the Department of Human Nutrition and Foods at Virginia Tech and the Human Subjects Committee of the University. (Appendix E). Following the signing of the informed consent form, a personal profile of the subject was entered into the Biodex software system. This profile included the subject's name, height, weight, birthdate, and address. All data collection forms are located in Appendix I.

The subject orientation continued with steps to familiarize each subject with the Biodex equipment (Appendix G). Subjects were seated in the Biodex chair and secured across the shoulders to prevent any movement of the upper body. The upper arm was secured to an attachment on the chair to isolate the forearm during elbow flexion and extension. The seat height and forearm position were, at this time, added to the subject's personal profile. The contralateral limb of each subject remained relaxed.

After a brief warm-up of ten "easy" repetitions at 210 degrees-per-second, the familiarization continued as subjects were instructed to complete 5 to 8 submaximal, then 5 to 8 maximal repetitions at each of the three velocities of 60, 210, and 450 degrees-per-

second. These procedures were carried out for each extremity. After this orientation session the subject was scheduled for his/her pre-test.

### Experimental Test Sessions

The experimental test sessions consisted of a two pre-tests and a post-test. The first pre-test was administered after all subjects had completed the orientation session. On the day of the first pre-test limb circumferences were taken before the testing started. The circumference of each upper arm was measured at its largest dimension. Skinfolts were also taken at four sites on the upper arm: medial, lateral, posterior, and anterior. Lean muscle mass of the upper arm was determined from the circumference and skinfold measures (Appendix F).

Following limb circumference and skinfold measurements, the subject was positioned in the equipment for the initial pre-test. Gravity correction procedures were employed to account for the weight of dynamometer's lever arm and the weight of the limb being tested. Since the acceleration of the limb and lever arm due to gravity reduces the applied torque, a gravity correction was required. The range of motion for elbow flexion was set for a 110 degree range of motion for testing and training.

Before data collection began, the subject warmed-up with one set of ten submaximal contractions at 210 degree-per-second. Pre-test data were then recorded for of five maximal contractions at 60 degrees-per-second, and eight maximal contractions at 210 and 450 degrees-per-second. The rest time between each set of contractions ranged from two to five minutes. The highest peak torque during each of the three sets of contractions for each limb was recorded. Both limbs were tested in the same manner.

A second pre-test, duplicating the initial pre-test, was repeated within 72 hours of the initial pre-test. The second pre-test provided additional data for test reliability

calculations. The highest absolute peak torque and the highest estimated cross-sectional area of the upper arm was selected as the criterion score. Following the second pre-test, the subjects were assigned to one of three treatments: control group, slow velocity group (60 degrees-per-second), or fast velocity group (450 degrees-per-second). Within each of these treatments the limb to be trained was randomly selected.

### Training Protocol

Following the assignment of subjects to the treatment groups, the two training groups trained for six weeks. The control group did not train. All subjects in the control group were instructed to forego any weight training during the subsequent six weeks.

The training regimen for each of the two experimental groups was established on the basis of pre-test data. Since more torque, thus more work, is developed during each repetition at slower isokinetic velocities, and the work output for each training session was to be equated for the two training groups, the sets and repetitions had to be different for the two training velocities.

From the pre-test data it was determine that it takes approximately twice as many repetitions at 450 degrees-per-second for to equal the work output of a set of repetitions at 60 degrees-per-second. In addition, since the subjects had different initial strength levels, the training routine was subject specific, based on the maximum work output at 60 degrees-per-second in the pre-tests. Subjects with greater strength were required to produce more work in each training session.

To be more specific, based on the initial pre-test, the work output in a single, maximal repetition at 60 degrees-per-second was determined for the each subject. This work output was multiplied by 48 (representing six sets of eight repetitions) to determine the work output to be accomplished in each training session for subjects the slow group (60

degrees-per-second). These subjects subsequently completed 70 % of this total work output at each training session in the first two weeks, 80 % of the total work output at each session in the third and fourth weeks, 90 % in the fifth week, and 100 % of the total work output in the sixth week. At each training session, multiple sets of eight repetitions were completed until the total work output was achieved for that session.

Based on the work output in a single maximal repetition at 60 degrees-per-second during the initial pre-tests, the total work output for each training session was also determined for subjects in the fast velocity group (450 degrees-per-second). The work output of the single repetition was multiplied by 100 repetitions (representing 10 sets of 10 repetitions) to determine the total work output for each training session for subjects in the fast velocity group. Subjects then completed 70 % of their maximum work output the first two weeks of training, 80 % of their maximum work output in the third and fourth weeks, 90 % in the fifth week, and 100 % in the sixth week. During each training session, sets of ten repetitions were completed until the total work output was achieved for that training session (Appendix H).

#### Statistical Procedures

The Number Cruncher Statistical Analysis for Windows (NCSS, 1995) and Minitab (Minitab, 1995) were used for all data analyses. The basic statistical routines utilized by the investigator were descriptive statistics, correlation and analysis of variance. Sigma Plot (Sigma Plot, 1993) was used to generate graphic representations of selected data analyses. A two-way analysis of variance (Group\*Speed) with repeated measures was used to determine the changes across the training velocities of 60, 210, and 450 degrees-per-second for both the training and untrained limbs. A one-way analysis of variance with repeated measures was used to detect the changes in the estimated cross sectional area of the upper arm in the training limb. When the analysis of variance showed significant main



effects, a Tukey-Kramer multiple-comparison test was performed. A paired t-test was also used for selected within group comparisons. For all analyses, an alpha level of .05 was accepted as showing statistical significance.

## **Results**

### **Physical characteristics of subjects**

A total of thirty subjects (15 male and 15 female) completed the two pre-tests, six-week training protocol, and post-test. Five subjects were dismissed from the study for failing to comply with procedures. The physical characteristic of the subjects measured were: age, height, pre-training body weight and post-training body weight. These average values for each of these variables were consistent across each of the three experimental conditions. Table 1 (Appendix D) provides the raw data and descriptive statistics for the subjects.

### **Reliability estimates**

Subjects were given two pre-tests, administered on separate days to establish stability reliability estimates of the absolute peak torque in the trained limb and untrained limb and upper arm girth measurements. Pearson product moment correlation (test-retest) was used to compute the stability reliability estimates. The reliability estimates for absolute peak torque of the trained limb range from  $r=.81$  to  $r=.93$ . The reliability estimates for absolute for absolute torque of the un-trained limb range from  $r=.81$  to  $r=.91$ . The reliability estimates for arm girths ranged from  $r=.87$  to  $r=.96$ . Reliability results are displayed in Table 2 (Appendix D).

### **Training limb**

A two-way analysis of variance (group\*Speed) with repeated measures was used to test for changes in absolute peak torque. Table 3 (Appendix D) contains the ANOVA

source table which indicates no significant difference ( $P>.05$ ) in Group, a significant difference ( $P<.05$ ) in the main effect of speed, and a significant difference ( $P<.05$ ) in the Group\*Speed interaction.

The Tukey-Kramer multiple-comparison test indicated that the slow condition's mean change score of 3.43 significantly differed from the control group's mean change score of -2.24. The slow and fast training conditions were not significantly different from each other at 60 degrees-per-second. The fast training condition was not significantly different from the control. The slow, fast, and control conditions were not significantly different from each other at the test velocity of 210 degrees-per-second. The fast training condition mean change score of 4.66 significantly differed from the control's group's mean change score of .59. The slow and fast training conditions were not significantly different from each other at 450 degrees-per-second. Table 4 (Appendix D) contains the results of the Tukey-Kramer multiple-comparison test for the Group\*Speed interaction.

Paired T-tests were used to test for changes in absolute peak torque within each of the two training conditions. All paired T-test results for the training limb are located in Table 5 (Appendix D). The slow group improved significantly ( $P<0.05$ ) at velocities of 60 degrees-per-second and 210 degrees-per-second; but failed to indicate significant gains at 450 degrees-per-second.

The fast velocity group improved significantly ( $P<0.05$ ) at velocities of 450 degrees-per-second and 210 degrees-per-second; but failed to produce significant gains at 60 degrees-per-second

#### Untrained limb

A two-way analysis of variance (Group\*Speed) with repeated measures was used to test for changes in absolute peak torque. Table 6 (Appendix D) contains the

ANOVA source table which indicates no significant difference ( $P>.05$ ) in Group, a significant difference ( $P<.05$ ) in the main effect of speed, and a significant difference ( $P<.05$ ) in the Group\*Speed interaction.

A Tukey-Kramer multiple-comparison test showed that the slow condition's mean change score of  $-.28$  to be significantly different from the mean change scores of the fast condition ( $-.44$ ) and the control group ( $-4.02$ ) at the test velocity of 60 degrees-per-second. The slow, fast, and control conditions were not significant different from each other at test velocities of 210 and 450 degrees-per-second in the untrained limb. Table 7 (Appendix D) contains the results of the Tukey-Kramer multiple-comparison test for the Group\*Speed interaction.

Paired T-tests were used to test for changes in absolute peak torque within each of the training conditions. All paired T-test results for the training limb are located in Table 8 (Appendix D). The slow velocity group failed to improve significantly ( $P>0.05$ ) at velocities of 60 degrees-per-second, 210 degrees-per-second, or at the velocity of 450 degrees-per-second. The fast velocity group also failed to improve significantly ( $P>0.05$ ) at any of the test velocities.

#### Estimated Cross-Sectional Area of the Upper Arm in the Trained Limb

A one-way analysis of variance (ANOVA) with repeated measures was used to test for changes in the estimated cross-sectional area of the upper arm measured at the exercise test velocity of 60 degrees-per-second among the exercise training conditions (slow training and fast training) and a control group. There were no significant differences ( $P>0.05$ ) in girth measures among the slow, fast, and control groups. Table 9 (Appendix D) contains these statistical computations.

Paired T-test were used to determine if significant changes occurred within each of the two experimental conditions. The slow training group produced significant ( $T=2.38$ ,  $P<0.05$ ) changes in arm girth from pre-test to post-test arm girths in the Fast training condition. Table 10 (Appendix D) displays the computations for the paired T-tests. Tables 11, 12, and 13 illustrate the pre-test to post-test percent changes in the trained limb absolute peak torque, the untrained limb absolute peak torque, and the estimated cross-sectional area of the muscle in the trained limb.

**APPENDIX B**  
**INFORMED CONSENT FORM**

## **VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY**

### **Informed Consent for Participants of Investigative Projects**

#### **TITLE**

**Effects of slow and fast isokinetic training on peak torque and average power over six weeks training in physically, active college students.**

#### **PURPOSE**

To compare the effects of slow and fast isokinetic training in physically, active college students. The two training speeds are 60 degrees per second and 450 degrees per second. The main purpose of the study is to see whether training at either the slow or fast speed over six weeks will cause increases in peak torques at that speed and other variable speeds. Many speed-specific, isokinetic studies have been done on the knee joint, but few to none exist using the upper extremity, such as the elbow joint. There has been an isotonic study done on the elbow joint. Most of the literature indicates that peak output(torque) and power training at slow speeds only cause increases at that speed, but it does not induce changes at faster speeds; fast speed training tends to cause increases in peak torque at slow and fast speeds. Cross education will also be examined, since the subjects will have one limb as a control. The idea behind cross education is that if you train one limb the other limb will adapt with strength gains. The study will last for six weeks, and by taking measurements of the arm any changes in hypertrophy will also be measured. Most research demonstrates that initial gains in strength result from neural adaptations, not hypertrophy. This is important for rehabilitation protocols and athletic strength training for specificity of sport.

#### **PROCEDURES**

The length of the study will last a total of nine weeks, which includes a week of learning and practicing on the equipment. All testing and training will be supervised by the experimenter and/or other trained staff on the equipment. Only the flexion measurements will be used for the study. During this period, informed consent and morphological measurements(height, weight, and bicep skinfold ) will be taken. The second week will consist of the pretesting at the various speeds, such as 60/sec, 250/sec, and 450/sec. During the next six weeks after the pretesting, participants will train at a workload of 2000 ft-lbs per session with an increase of 200 ft-lbs each week. This increase in workload is necessary for muscle hypertrophy, and to continue the level of stress to prevent adaptations of just 2000 ft-lbs. The sets or number of exercise bouts will consist of 3-6 sets with five minutes rests between each set. The number of repetitions or curls during a set will range between 4 and 30 repetitions, but the amount of work will be the same for everyone. We

encourage you to maintain a similar weight throughout the study, and refrain from other similar upperbody exercises during the training period. At the end of the six weeks, post testing will be done to look at changes of peak torque and average power across various speeds over the six week period.

There will be three total groups in the study: a control group who will only do pre and post testing, a group training at 60 degree per second on the elbow flexion/extension for the nine weeks, and a group training at 450 degrees per second for the nine weeks. Each training session in the Human Performance Laboratory will begin with a warm-up period of 1 to 2 sets at the training speed. During pre and post testing there will be a warm up at all speeds before the test will proceed. A five minute rest period will be allotted between each exercise bout. The training session should last between 20-30 minutes. During the sets you will be asked to curl the bar as hard and fast as you can until the investigator says stop. This pattern will be repeated until the necessary work is completed for the training speed.

The initial week in the Human Performance Lab will be "treatment" and "placebo" tests, and will consist of three mock training sessions either on Monday, Wednesday, and Friday or Tuesday, Thursday, and Saturday. During this time you will become familiar with the laboratory(bathrooms, equipment, phone, etc.). The main purpose of this time is to familiarize you with the use and setup of the isokinetic equipment. You will be trained at the various speeds to get a feel for the different resistance levels. The equipment has an emergency stop button, which will stop all motion during anytime of the test. The range of motion of the curl lever arm will be the same for everyone, and you will be exercising in a safe and applicable range. After initial testing the next six weeks training will be as followed for slow or fast training:

Amount of Work	sets	reps	rest time	work
1. 60/sec group	3-6	3-15	5 minutes	2000 ft-lbs
2. 450/sec group	3-6	4-30	5minutes	2000 ft-lbs

Each week of the training period will consist of a 200 ft-lb increase to provoke hypertrophy and stress level.

We will ask you to refrain from a few things during the study, and they are as follows: alcohol consumption, tobacco or caffeine use, making any dietary changes, performance of other upperbody exercises and workouts, no supplementation during this period, eating immediately before the test, and other resistance exercise. Please feel free to ask questions about the test and training procedures. A final outline for test procedures is listed below:

Week 1:	Orientation, Informed consent, habituation and learning, 3 workouts
Week 2:	Pretesting at the various speeds
Week 3-8	Training at either 60/sec. or 450/sec.
Week 9:	Posttesting at the various speeds, end of study

## **POSSIBLE RISKS OF PARTICIPATION**

Your safety is our main concern in this experiment. However, there are some slight risks involved, such as, but not limited to: fatigue, muscle soreness, strains, sprains, and bursitis. You have been selected on the basis of your level of physical activity, and we feel that the risks associated with this performance test should be minimized.

Proper warm-up and stretching prepare the muscle for exercise, and you will be instructed to do so before the test. After warming up with stretches, you will be given some light resistance to perform arm curls on the isokinetic equipment. The machine will be calibrated weekly to assure proper ranges of motion and to prevent injury.

## **BENEFITS OF PARTICIPATION**

You have been prescreened through interviews and selected to participate in this study on the basis of your activity level. You will receive the results of your tests, as well as the conclusions of the experiment in general. This will better educate you on your strength levels, body composition, exercise tolerance, and help you with future training. A major asset is free use of isokinetic equipment and education on its use.

## **FREEDOM TO WITHDRAW**

You are free to withdraw from the study at any time without penalty. You may also be asked to withdraw if it becomes evident that you have not followed the recommended guidelines, or you become ill. Remember, your compliance with the guidelines is essential to the success of the study.

## **CONFIDENTIALITY**

Names will not be used in the analysis of experimental results. All individual's information will be kept confidential, and will only be shared with you. Each individual will be assigned a number for identity.

## **SUBJECT'S RESPONSIBILITIES**

I know of no reason that I cannot participate in this study. I understand that I have the following responsibilities:

1. To advise the investigators of any pre-existing condition that may affect my participation, such as, but not limited to: AIDS, heart conditions, muscle, bone, or joint problems, hypertension, or major organ malfunctions.



2. To advise the researchers of any medical problems that might arise during the course of or upon completion of this experiment such as (but not limited to ) those illustrated in the RISKS OF PARTICIPATION section of this informed consent form.
3. To adhere to the conditions set forth in the PROCEDURES section of this form (including remaining in the laboratory for 20 minutes following each test).
4. Do not eat within an hour of the testing and training
5. Maintain bodyweight throughout testing and training.
6. No exercise within 24 hours of testing

#### **APPROVAL OF RESEARCH**

This project is under investigation by the committee members at present. Upon approval by committee members, it will be reviewed by the Institutional Review Board.

#### **SUBJECT'S PERMISSION**

I have read and understand the informed consent and conditions of this experiment. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this study.

Signature of participant:

Signature of Principal Investigator,  
Rodney P. Gaines, M.S. candidate:

\_\_\_\_\_

Date:

\_\_\_\_\_

Should I have any questions about this project or its conduct, I can contact:

Rodney P. Gaines, principal investigator: 951-8963

Don Sebolt, Ph.D., committee chairman: 231-8285

Ron Bos, Ph.D., committee advisor: 231-8286

Jay Williams, Ph.D., committee advisor: 231-8298

**Ernest Stout, Chairman of the Virginia Tech I.R.B: 231-9359**

**Shala Davis, Departmental Review: 231-8320**

**Marilyn Prchm, Departmental Review: 231-9359**

APPENDIX C  
HEALTH QUESTIONNAIRE

## VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

### Health Questionnaire for Participants of Investigative Projects

Please answer the following questions honestly and as accurately as possible. If you have any questions or concerns, please bring them to the attention of the examiner at this time. Also, if you answer "yes" to any of this form to explain your answer.

Circle One.

1. Are you currently involved in an exercise program?      Yes      No

2. If you answered "yes" to Question #1, please specify what types of activities you perform, how frequently, how long each session, and how many years you have been involved.

<u>type</u>	<u>frequency</u>	<u>duration of session</u>	<u>years involved</u>
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3. How many years or months have you been weightlifting? \_\_\_\_\_

4. When was your most recent physical examination? \_\_\_\_\_

5. Have you taken anabolic steroids within the last 2 years? Yes      No

6. Do you use any illicit drugs?      Yes      No

7. Are you currently taking any medications?      Yes      No

8. Do you use any nutritional supplements?      Yes      No

9. Have you ever been diagnosed with any of the following problems(If so give specifics and dates):

Cardiovascular disease	Yes	No
High Blood Pressure	Yes	No
Fractured or broken bones	Yes	No
Joint problems requiring medical attention	Yes	No
Kidney disorders	Yes	No
Stomach problems(ulcers, etc.)	Yes	No
Any other internal disorder	Yes	No

H.I.V. or Hepatitis  
Diabetes(in any form)

Yes    No  
Yes    No

10. Have you ever experienced unexplained weight loss?    Yes    No

11. Have you been ill recently?    Yes    No

12. Have you ever felt faint or dizzy during exercise?    Yes    No

13. Have you ever been hospitalized?    Yes    No

Please write  
comments \_\_\_\_\_

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I have answered the questions above honestly and accurately, have brought any questions or concerns to the attention of the examiner, and furthermore give my voluntary consent to participate in this experiment.

Signature of participant

Signature of Principal Investigator,  
Rodney P. Gaines, M.S. candidate

\_\_\_\_\_

\_\_\_\_\_

Date:

\_\_\_\_\_

## **APPENDIX D**

### **RAW DATA AND STATISTICAL ANALYSIS**

# RAW DATA

## SUBJECT'S DEMOGRAPHICS

COND	SUBJECT	HEIGHT (CM)	AGE (YRS)	GENDER
1	1	185.42	20	1
1	2	170.18	22	2
1	3	160.02	22	2
1	4	177.8	37	1
1	5	172.72	20	2
1	6	160	32	2
1	7	170.18	22	1
1	8	170	19	1
1	9	157.48	29	2
2	10	154.9	27	2
2	11	162.6	22	2
2	12	157.5	20	2
2	13	162.56	23	2
2	14	152.4	20	2
2	15	175.26	20	1
2	16	173.99	21	1
2	17	165.1	23	2
2	18	175.26	37	1
2	19	177.2	22	1
2	20	170	20	1
3	21	165.1	24	2
3	22	167.4	32	2
3	23	167.6	24	2
3	24	180	21	1
3	25	180.3	27	2
3	26	178.5	30	1
3	27	166.5	28	1
3	28	166	22	2
3	29	167.6	27	2
3	30	182.8	25	1

Condition 1= Slow group, 2= Fast group, 3= Control group

Gender 1= males, 2= females

# RAW DATA

## BODYWEIGHT

COND.	SUBJECT	PRE-BW (LBS)	POS-BW (LBS)
1	1	200	186
1	2	128	128
1	3	122	119
1	4	244	243
1	5	126	126
1	6	149	147
1	7	143	147
1	8	113	118
1	9	148	146
2	10	113	108
2	11	215	220
2	12	104	107
2	13	157	157
2	14	135	137
2	15	155	155
2	16	138	142
2	17	243	243
2	18	161	153
2	19	151	153
2	20	111	111
3	21	113	112
3	22	145	144
3	23	178	176
3	24	153	155
3	25	184	189
3	26	212	217
3	27	150	151
3	28	140	137
3	29	157	157
3	30	175	175

Condition 1= Slow group, 2= Fast group, 3= Control group



# RAW DATA

## TRAINED LIMB ABSOLUTE PEAK TORQUE AT 60 DEGREES-PER-SECOND

COND.	SUBJECT	PRE-60 (FT-LBS)	POST-60 (FT-LBS)
1	1	38.7	45
1	2	27	31
1	3	23.5	23
1	4	41.3	40
1	5	21.1	25.5
1	6	20.6	21
1	7	32.1	34.5
1	8	26	37.8
1	9	22.4	26.2
2	10	25.6	24.8
2	11	27.2	23.1
2	12	20	21
2	13	16.6	17.2
2	14	16.3	14.4
2	15	33.4	40.9
2	16	40.8	43.1
2	17	29	24
2	18	35.7	39.2
2	19	42.5	48.2
2	20	32.5	30.2
3	21	18.9	16
3	22	20.9	15.4
3	23	25.6	21.6
3	24	29	31.6
3	25	26.1	24.7
3	26	47	47.7
3	27	36.6	38.1
3	28	17.6	14.6
3	29	29.8	29.8
3	30	54.3	43.9

Condition 1= Slow group, 2= Fast group, 3= Control group

# RAW DATA

## TRAINED LIMB ABSOLUTE PEAK TORQUE AT 210 DEGREES-PER-SECOND

COND.	SUBJECT	PRE-210 (FT-LBS)	POST-210 (FT-LBS)
1	1	30.2	31.7
1	2	22.7	28.3
1	3	22.5	23
1	4	32.4	29.9
1	5	17.9	17.8
1	6	20.6	22
1	7	27.5	31.4
1	8	23.3	31.2
1	9	17.8	24.5
2	10	21.3	21.1
2	11	19.6	24.4
2	12	16.8	20.5
2	13	19.7	17.9
2	14	17.4	16.3
2	15	33	41.3
2	16	30.5	38.2
2	17	23.2	24
2	18	29.8	38.4
2	19	36.1	33.7
2	20	25.7	28
3	21	16.3	15.9
3	22	15.7	11.9
3	23	20.9	22.4
3	24	22	25.3
3	25	23.5	20.2
3	26	37.3	38
3	27	30.7	30.3
3	28	16.4	12.5
3	29	24.4	27.6
3	30	41.6	37.8

Condition 1= Slow group, 2= Fast group, 3= Control group

# RAW DATA

## TRAINED LIMB ABSOLUTE PEAK TORQUE AT 450 DEGREES-PER-SECOND

COND.	SUBJECT	PRE-450 (FT-LBS)	POST-450 (FT-LBS)
1	1	30.3	30.2
1	2	24	29.2
1	3	22.6	22.9
1	4	32.7	28.7
1	5	19.2	20.1
1	6	19.7	22.4
1	7	29.6	31.4
1	8	24.2	27.9
1	9	18.1	25.2
2	10	21.9	23.7
2	11	19.6	25.5
2	12	19	23.3
2	13	20.1	21.7
2	14	15.5	17.6
2	15	30.9	48.3
2	16	25.6	36.3
2	17	22.9	21.1
2	18	27.9	39.7
2	19	39	36.8
2	20	29.6	29.3
3	21	17.4	17.2
3	22	17.1	13.6
3	23	22.5	24.2
3	24	25.2	24.6
3	25	24.6	22.9
3	26	31.9	45.3
3	27	29.3	28.6
3	28	17.5	15
3	29	23.9	28.7
3	30	44.2	39.7

Condition 1= Slow group, 2= Fast group, 3= Control group

# RAW DATA

## UNTRAINED LIMB ABSOLUTE PEAK TORQUE AT 60 DEGREES

COND.	SUBJECT	PRE-60 (FT-LBS)	POST-60 (FT-LBS)
1	1	35.6	33
1	2	27.4	26.1
1	3	27.3	21.8
1	4	41.9	35.9
1	5	20.4	21.4
1	6	22.8	21
1	7	28.7	30.5
1	8	21.6	31.9
1	9	23.1	24.6
2	10	25.2	24.1
2	11	23.3	23.8
2	12	23.1	21.8
2	13	18	18.6
2	14	16.2	16.2
2	15	35.6	47.7
2	16	49.1	48.5
2	17	25.1	25.2
2	18	40.2	35
2	19	42.5	42
2	20	36.2	25.7
3	21	17.9	14.8
3	22	18.7	15.6
3	23	28.9	22
3	24	31.2	31.1
3	25	24.5	21.3
3	26	44	41.3
3	27	40.9	32.9
3	28	17.4	18.1
3	29	28.6	24.1
3	30	44.5	35.2

Condition 1= Slow group, 2= Fast group, 3= Control group

# RAW DATA

## UNTRAINED LIMB ABSOLUTE PEAK TORQUE AT 210 DEGREES

COND.	SUBJECT	PRE-210 (FT-LBS)	POST-210 (FT-LBS)
1	1	31	26.5
1	2	25.5	22.6
1	3	25.2	19.6
1	4	33.1	28.9
1	5	16.2	20.7
1	6	24.1	22
1	7	29.2	29.7
1	8	22.4	26.7
1	9	17.3	22.5
2	10	20.1	20
2	11	19.8	25
2	12	18.9	18.9
2	13	20.7	16.8
2	14	14.6	15.6
2	15	28.3	47.9
2	16	37	43.9
2	17	22.2	22.1
2	18	34	30.8
2	19	32.4	39.4
2	20	28.9	21.3
3	21	16.9	14.2
3	22	16.3	13.9
3	23	25.9	23.3
3	24	24.6	24.9
3	25	22.2	19.5
3	26	35	40.6
3	27	32.7	30.2
3	28	14.9	12.8
3	29	21.9	25.2
3	30	33.2	32.2

Condition 1= Slow group, 2= Fast group, 3= Control group

# RAW DATA

## UNTRAINED LIMB ABSOLUTE PEAK TORQUE AT 450 DEGREES

COND.	SUBJECT	PRE-450 (FT-LBS)	POST-450 (FT-LBS)
1	1	29.4	23.7
1	2	27	23.1
1	3	25.4	20.7
1	4	28.2	25.4
1	5	15.1	21.5
1	6	23.8	20.7
1	7	28.8	33.9
1	8	18.6	22.5
1	9	18.3	19.4
2	10	22.4	20.5
2	11	23.1	24.8
2	12	19.6	20.4
2	13	21.3	19
2	14	14.7	16.1
2	15	30.5	41.5
2	16	36	39.8
2	17	25.1	19.8
2	18	33.5	31.3
2	19	28.6	34.9
2	20	30.5	21.8
3	21	16.2	13.5
3	22	16.3	14.6
3	23	26.1	24
3	24	19.8	23.7
3	25	21	22.4
3	26	33	42.4
3	27	35.2	32.2
3	28	16.7	15.9
3	29	23.2	25.4
3	30	31	30.8

Condition 1= Slow group, 2= Fast group, 3= Control group

# RAW DATA

## ESTIMATED CROSS-SECTIONAL AREA OF THE UPPER ARM

COND.	SUBJECT	PRE-GIR (CM <sup>2</sup> )	POS-GIR (CM <sup>2</sup> )
1	1	42.08	49.71
1	2	22.56	29.35
1	3	24.5	27.84
1	4	34.28	30.86
1	5	25.85	29.5
1	6	18.86	21.32
1	7	30.96	31.95
1	8	31.05	29.79
1	9	24.66	31.94
2	10	26.97	28.95
2	11	21.35	18.69
2	12	23.4	21.47
2	13	24.67	18.93
2	14	20.08	25.3
2	15	50.87	51.61
2	16	45.98	42.58
2	17	27.07	33.4
2	18	34.93	40.78
2	19	42.35	43.42
2	20	35.67	39.01
3	21	21.47	18.12
3	22	22.09	23.03
3	23	22.83	29.36
3	24	30.06	33.12
3	25	21.62	25.17
3	26	41.93	46.08
3	27	55.93	53.71
3	28	22.33	27.45
3	29	28.05	26.27
3	30	52.51	57.64

Condition 1= Slow group, 2= Fast group, 3= Control group

TABLE 1

**Characteristics Of Slow Velocity, Fast Velocity, and Control Groups**

Variable	Slow (n=11)	Fast (n=9)	Control (n=10)
Age (years)	21.0 (0.5)	23.1 (1.0)	23.5 (1.0)
Height (cm)	166.1 (8.43)	169.3 (8.55)	172.1 (6.82)
Weight pretraining (kg)	84.1 (3.6)	80.6 (2.8)	81.4 (2.6)
Weight post-training (kg)	83.8 (3.5)	81.2 (2.6)	81.8 (2.5)

Numbers in parentheses represent standard deviations.



**Table 2****Reliability Estimates Of Trained Limb, Untrained Limb, And Cross-sectional Measures**

<b>Variables</b>	<b>Correlation Coefficients</b>
Trained Limb at 60 degrees-per-second	$r=.93$
Trained Limb at 210 degrees-per-second	$r=.91$
Trained Limb at 450 degrees-per-second	$r=.81$
Untrained Limb at 60 degrees-per-second	$r=.91$
Untrained Limb at 210 degrees-per-second	$r=.87$
Untrained Limb at 450 degrees-per-second	$r=.81$
Control Estimated cross-sectional measures	$r=.96$
Slow Estimated cross-sectional measures	$r=.92$
Fast Estimated cross-sectional measures	$r=.87$

TABLE 3

**Two Way ANOVA (Group\*Speed) with Repeated Measures of the Trained Limb**

<b>Source</b>	<b><u>DF</u></b>	<b><u>SS</u></b>	<b><u>MS</u></b>	<b><u>F</u></b>	<b><u>P</u></b>
A (Group)	2	241.76	120.88	3.09	.06
B(A)	27	1054.8	39.06		
C (Speed)	2	49.23	24.62	3.25	.046*
AC	4	81.18	20.29	2.68	.04*
BC (A)	54	409.64	7.58		
Total (Adjusted)	89	1847.51			
Total	90				

Asterisk denotes significant change ( $p < .05$ )

TABLE 4

Tukey-Kramer Multiple-comparison Test for Group\*Speed Interaction of the Trained Limb

GROUP	COUNT	MEAN	DIFFERENT FROM GROUPS
3, 60	10	-2.24	(1,450), (1,210), (2,210), (1,60), (2,450)
3, 210	10	-0.69	(1,60), (2,450)
3, 450	10	0.59	(2,450)
2, 60	11	.59	(2,450)
1, 450	9	1.95	(3,60)
1, 210	9	2.76	(3,60)
2, 210	11	2.79	(3,60)
1, 60	9	3.42	(3,60), (3,210)
2, 450	11	4.66	(3,60), (3,210), (3,450), (2, 60)

1= SLOW VELOCITY GROUP (60 DEGREES-PER-SECOND)

2=FAST VELOCITY GROUP (450 DEGREES-PER-SECOND)

3= CONTROL GROUP

TEST VELOCITIES= 60, 210, AND 450 DEGREES-PER-SECOND

**Table 5**

**Paired T-test Values For The Trained Limb**

	Mean (ft-lbs)	SEM	T-value	P-Value
Slow(60)				
pre 60	28.08	1.33	2.58	.033*
post 60	31.56			
pre 210	23.88	1.15	2.4	.043*
post 210	26.64			
pre 450	24.49	1.08	1.81	0.11
post 450	26.44			
fast (450)	29.05	1.19	0.5	0.63
pre 60	29.65			
post 60				
pre 210	24.83	1.24	2.25	.048*
post 210	27.62			
pre 450	24.73	1.88	2.48	.033*
post 450	29.39			
Control				
pre 60	30.58	1.22	-1.84	0.099
post 60	28.34			
pre 210	24.88	0.909	-0.76	0.47
post 210	24.19			
pre 450	25.36	1.62	0.36	0.72
post 450	25.98			

Asterisk denotes significant change ( $p < .05$ )

TABLE 6

Two Way ANOVA (Group\*Speed) with Repeated Measures of the Untrained Limb

Source	<u>DF</u>	<u>SS</u>	<u>MS</u>	<u>F</u>	<u>P</u>
A (Group)	2	69.48	34.74	.58	.57
B(A)	27	1628.32	60.31		
C (Speed)	2	69.44	34.72	6.35	.003327*
AC	4	82.27	20.57	3.76	.009004*
BC (A)	54	295.10	5.46		
Total (Adjusted)	89	2150.38			
Total	90				

Asterisk denotes significant change ( $p < .05$ )

TABLE 7

**Tukey-Kramer Multiple-comparison Test for Group\*Speed Interaction of the Trained Limb**

GROUP	COUNT	MEAN	DIFFERENT FROM GROUPS
3, 60	10	-4.02	(1,210), (2,60), (1,450), (1,60), (2,450), (3,450), (2,210)
3, 210	10	-0.68	
3, 450	10	-0.53	(3,60)
2, 60	11	-0.44	(3,60)
1, 450	9	-0.41	(3,60)
1, 210	9	-0.29	(3,60)
2, 210	11	0.42	(3,60)
1, 60	9	0.64	(3,60)
2, 450	11	2.25	(3,60)

1= SLOW VELOCITY GROUP (60 DEGREES-PER-SECOND)

2=FAST VELOCITY GROUP (450 DEGREES-PER-SECOND)

3= CONTROL GROUP

TEST VELOCITIES= 60, 210, AND 450 DEGREES-PER-SECOND

Table 8

Paired T-test Values For The Untrained Limb

	Mean (ft-lbs)	SEM	T-value	P-Value
Slow(60)				
pre 60	27.64	1.62	-0.18	0.86
post 60	27.36			
pre 210	24.89	1.42	-0.38	0.72
post 210	24.36			
pre 450	23.84	1.53	-0.27	0.8
post 450	23.43			
fast (450)				
pre 60	30.41	1.61	-0.28	0.79
post 60	29.87			
pre 210	25.17	2.21	1.02	0.33
post 210	27.43			
pre 450	25.94	1.64	0.25	0.8
post 450	26.35			
Control				
pre 60	29.66	1.02	-3.93	0.0035
post 60	25.64			
pre 210	24.36	0.92	-0.74	0.48
post 210	23.68			
pre 450	23.85	1.2	0.53	0.61
post 450	24.49			

\*asterisk denotes significant change ( $p < .05$ )

TABLE 9

**Changes In Estimated Cross-sectional Areas Among The Experimental Conditions**

<b>Source</b>	<b><u>DF</u></b>	<b><u>SS</u></b>	<b><u>MS</u></b>	<b><u>F</u></b>	<b><u>P</u></b>
A(condition)	2	21.46	10.73	0.74	.486
B(A)	27	391.25	14.49		
Total(Adjusted)	29	412.71			
Total	30				

Asterisk denotes significant change ( $p < .05$ )



**Table 10**

**Paired T-test For the Trained Limb (Estimated Cross-sectional Area Measures)**

	Mean (CM <sup>2</sup> )	SEM	T-value	P-Value
Slow(60) pre-girth post girth	28.31 31.36	1.28	2.38	.044*
Fast (450) pre-girth post girth	32.12 33.1	1.22	0.81	0.44
control pre girth post girth	31.88 33.99	1.11	1.91	0.08

**Asterisk denotes significant change (p<.05)**

Table 11  
Peak Torque Generation Pre- And Posttraining And Percent Changes At Various Velocities of the Trained Limb

	pre 60 ft-lbs	post 60 ft-lbs	% change	pre 210 ft-lbs	post 210 ft-lbs	% change	pre 450 ft-lbs	post 450 ft-lbs	% change
Slow(9)	28.08	31.56	12.39*	23.88	26.64	11.56*	24.49	26.44	8
Fast(11)	29.05	29.65	2.06	24.83	27.62	11.24*	24.73	29.39	18.34*
Control(10)	30.58	28.34	-7.3	24.88	24.19	2.77	25.36	25.98	2.44

asterisk denotes significant change ( $p < .05$ )

Table 12

## Peak Torque Generation Pre- And Posttraining And Percent Changes At Various Velocities Of The Untrained Limb

	pre 60 ft-lbs	post 60 ft-lbs	% change	pre 210 ft-lbs	post 210 ft-lbs	% change	pre 450 ft-lbs	post 450 ft-lbs	% change
Slow (9)	27.64	27.36	1.01	24.89	24.36	2.13	23.84	23.43	1.72
Fast (11)	30.41	29.87	-0.54	25.17	27.43	8.97	25.94	26.35	1.58
Control (10)	29.66	25.64	-13.55	24.36	23.68	2.79	23.85	24.49	2.68

asterisk denotes significant change ( $p < .05$ )

Table 13

Pre-test to Post-test Changes in the Estimated Cross-sectional Area of the Trained Limb

Group	Pre-test mean	Post-test mean	% Change
Slow (9)	28.31	31.36	10.77*
Fast (11)	32.12	33.1	3.05
Control (10)	31.88	33.99	6.6

asterisk denotes significant change ( $p < .05$ )

**APPENDIX E**  
**HUMAN SUBJECTS REQUEST AND APPROVAL**

## **REQUEST FOR APPROVAL OF RESEARCH PROPOSAL**

**Submitted to**

**Ernest Stout**

**Chairman, Division Human Subjects Committee and/or  
Chairman, Institutional Review Board**

**Rodney P. Gaines**

**Principle Investigator**

**TITLE:** Effects of slow(60 degrees/second) and fast(450 degrees/second) isokinetic elbow flexion training on peak torque/bodyweight, average power/bodyweight, girth measurements, and contralateral limb values.

**BACKGROUND/SCIENTIFIC JUSTIFICATION:** Many questions are still left unanswered in the best way to maximize strength and rehabilitation. Previous studies show that the velocity of movement is specific only to that velocity and movement velocities close to that particular velocity. There has been studies showing that those training at fast velocities increase strength over all other velocities, while slow velocities only increase strength at slow velocities, but not fast. Another area of research in strength training is the idea of cross education. Cross education research has shown that by training one limb over time without training the other limb, even the untrained limb will increase in strength. This study will look at the effects of slow and fast velocity training on cross education. Previous research indicate that in order for cross education to occur, high intensity weightlifting must occur.

**PURPOSE(S):** The purpose of this study is to evaluate the effects of slow(60 deg./sec.) and fast(450 deg./sec.) velocity training of elbow flexion on strength/bodyweight, average power/ bodyweight, girth measurements, and contralateral limb values. Other studies have looked at similar factors using knee flexion and extension. The six week study will be done on biodex isokinetic equipment. Hopefully, this study will answer some of the dilemma and unclear conclusions of whether it is better to train at slow velocity or fast movement velocity in order to maximize strength gains. Another issue that has yet to be looked into is the effect of movement velocity on cross education: does a slow or fast velocity training cause more changes in strength.

**EXPERIMENTAL METHODS AND PROCEDURES:** There will be approximately 20-30 male and female subjects between the age of 18-35 recruited from the Virginia Tech campus and surrounding areas. They will be interviewed and screened for previous

weightlifting experience, previous injuries, and contraindications to exercise. Subjects will be divided into experimental and control groups.

The length of the study will last a total of nine weeks, which includes a week of learning and practicing on the equipment. All testing and training will be supervised by the experimenter and/or other trained staff on the equipment. Only the flexion measurements will be used for the study. During this period, informed consent and morphological measurements (height, weight, and bicep skinfold) will be taken. The second week will consist of the pretesting at the various speeds, such as 60/sec, 250/sec, and 450/sec. During the next six weeks after the pretesting, participants will train at a workload of 2000 ft-lbs per session with an increase of 200 ft-lbs each week. This increase in workload is necessary for muscle hypertrophy, and to continue the level of stress to prevent adaptations of just 2000 ft-lbs. The sets or number of exercise bouts will consist of 3-6 sets with five minutes rests between each set. The number of repetitions or curls during a set will range between 4 and 30 repetitions, but the amount of work will be the same for everyone. We encourage you to maintain a similar weight throughout the study, and refrain from other similar upperbody exercises during the training period. At the end of the six weeks, post testing will be done to look at changes of peak torque and average power across various speeds over the six week period.

There will be three total groups in the study: a control group who will only do pre and post testing, a group training at 60 degree per second on the elbow flexion/extension for the nine weeks, and a group training at 450 degrees per second for the nine weeks. Each training session in the Human Performance Laboratory will begin with a warm-up period of 1 to 2 sets at the training speed. During pre and post testing there will be a warm up at all speeds before the test will proceed. A five minute rest period will be allotted between each exercise bout. The training session should last between 20-30 minutes. During the sets you will be asked to curl the bar as hard and fast as you can until the investigator says stop. This pattern will be repeated until the necessary work is completed for the training speed.

The initial week in the Human Performance Lab will be "treatment" and "placebo" tests, and will consist of three mock training sessions either on Monday, Wednesday, and Friday or Tuesday, Thursday, and Saturday. During this time you will become familiar with the laboratory (bathrooms, equipment, phone, etc.). The main purpose of this time is to familiarize you with the use and setup of the isokinetic equipment. You will be trained at the various speeds to get a feel for the different resistance levels. The equipment has an emergency stop button, which will stop all motion during anytime of the test. The range of motion of the curl lever arm will be the same for everyone, and you will be exercising in a safe and applicable range. After initial testing the next six weeks training will be as followed for slow or fast training:

Amount of Work	sets	reps	rest time	work
1. 60/sec group	3-6	3-15	5 minutes	2000 ft-lbs
2. 450/sec group	3-6	4-30	5minutes	2000 ft-lbs

Each week of the training period will consist of a 200 ft-lb increase to provoke hypertrophy and stress level.

We will ask you to refrain from a few things during the study, and they are as follows: alcohol consumption, tobacco or caffeine use, making any dietary changes, performance of other upperbody exercises and workouts, no supplementation during this period, eating immediately before the test, and other resistance exercise. Please feel free to ask questions about the test and training procedures. A final outline for test procedures is listed below:

Week 1:	Orientation, Informed consent, habituation and learning, 3 workouts
Week 2:	Pretesting at the various speeds
Week 3-8	Training at either 60/sec. or 450/sec.
Week 9:	Post testing at the various speeds, end of study

**STATEMENT DESCRIBING LEVEL OF RISK TO SUBJECTS:** The level of risk to the participants will be very low due to the nature of the study. In any type of strength testing and training, there is some risk of orthopedic sprain, strain, or muscle pull. The muscle involved in this study will be the bicep muscle, which is very hard to incur an injury to this muscle. There are possible injury to the wrist or elbow, but these injuries are unlikely.

This type of equipment is normally used by physical therapist, who use the equipment for testing, training, and rehabilitation. The instruction manual and operation are very user friendly, and there are automatic stop devices given to the participants if they want to stop operation at any time.

**PROCEDURES TO MINIMIZE SUBJECT RISK (IF APPLICABLE):** A major way of reducing risk in this project is the prescreening. The participant will be thoroughly interviewed, and asked of previous orthopedic and other medical problems(See interview and prescreening form). Another way to reduce risk is equipment familiarity. The subjects will practice with the equipment a week before the initial testing, and two weeks before training. Available in the room is a phone, and right next door in the Human Performance Laboratory is a first aid and CPR kit. Whoever is running the testing or training will be certified in adult CPR. The participants will be required to warm-up/stretch before getting on the machine, and they will be warmed up with light resistance before testing and training start. All participants will be given an orientation on their first day in the lab, and during this time they will become familiar with phone operation, the eye washout area, first aid and CPR kit, the bathrooms and sink, etc.

**RISK/BENEFIT RATIO (IF RISK PROJECT):** The benefits of performing the study far exceed the risk level. As mentioned above the risk level is very minimum, and



emergency procedures and room layout will be given to all participants. The benefits gained by the participants will be a better understanding of the use of biodex equipment, strength training and education, strength assessment and measurements, and a better appreciation for research. The study will contribute to rehabilitation and strength training, and resolve some of the unanswered questions in strength training and rehabilitation.

MEMORANDUM

TO: Rodney P. Gaines  
Human Nutrition and Foods

FROM: Ernest R. Stout *ERS*  
Associate Provost for Research

DATE: June 14, 1995

SUBJECT: IRB EXPEDITED APPROVAL/"Effect of Slow and Fast  
Isokinetic Training of Elbow Flexion and Cross Education  
Effects"  
Ref. 95-154

I have reviewed your request to the IRB for the above referenced project. I concur with Dr. Davis that the experiments are of minimal risk to the human subjects who will participate and that appropriate safeguards have been taken.

This approval is valid for 12 months. If the involvement with human subjects is not complete within 12 months, the project must be resubmitted for re-approval. We will prompt you about 10 months from now. If there are significant changes in the protocol involving human subjects, those changes must be approved before proceeding.

On behalf of the Institutional Review Board for Research Involving Human Subjects, I have given your request expedited approval.

Best wishes.

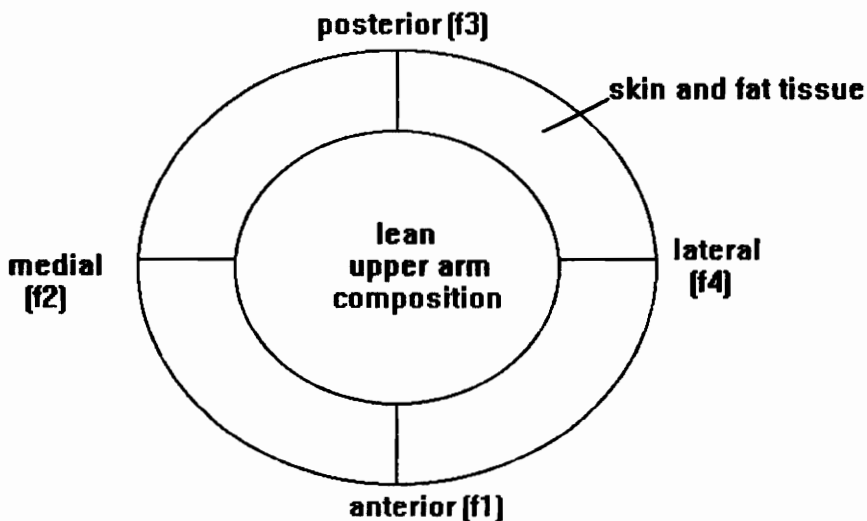
ERS/php

c: Dr. Davis

**APPENDIX F**  
**UPPER ARM GIRTH PROCEDURES AND FORM**

## **ESTIMATION OF CROSS-SECTIONAL AREA**

1. All subjects stood relaxed with their arms down by their side
2. Skinfolds were taken on both arms at the medial, lateral, anterior, and posterior sites at the middle portion of the upper arm.
3. Limb circumferences were taken at the middle portion of the upper arm.
4. All information was entered into a formula to find the area of the arm.



5. Limb circumferences(cm) and skinfolds(mm) were entered into the following formula:

$$A=3.14[c/2(3.14)-\text{sum of skinfolds}/4]^2$$

$f1+f2+f3+f4=$  sum of skinfolds

Correction for skin and subcutaneous fat dimension.

C= upper arm girth

**APPENDIX G**  
**PROCEDURES FOR TRAINING AND TESTING**

**VIRGINIA TECH MUSCULAR FUNCTION LABORATORY**  
**guidelines FOR BIODEX TESTING AND TRAINING**

1. Provide a general orientation to the subject regarding testing and training protocol
2. Subject signs informed consent form and health questionnaire  
-gather height, weight, and bicep skinfold
3. Determine limb preference and have subject warm-up on arm crank and stretch
4. warmup machine, setup machine for use, and balance input shaft
5. Position subject in appropriate test/training position to line up the input shaft with the the proper axis of rotation.
6. Secure subject for test and set elbow range of motion.
7. Inform subject of the automatic stop button.
8. Record subject set-up data.
9. Administer a test-speed-specific orientation and warm-up to subject. Using both submaximal and maximal trials, check for subject's ROM, total reciprocal muscle involvement, and proper reciprocal muscle timing.
10. Administer Biodex test or training protocol.
11. Give proper rest time between each test.
12. Check validity of data before continuing to next test or ending the test/training.
13. Once done, unstrap the subject from the chair and inform them to stretch.
14. Alert subject about potential arm soreness before they exit.
15. Obtained desired printed test report from the machine

**APPENDIX H**  
**WORKLOAD OF SUBJECTS**

## PROCEDURE FOR ASSIGNING WORKLOADS

1. Determine the maximum work repetition from the 5 repetitions done in the testing at 60 degrees-per-second

For example: 40 ft-lbs. is the maximum work repetition at 60 degrees-per-second for a subject.

2. Determine the maximum amount of work to be done in a session.

The training protocol for the slow velocity was 6 to 8 sets for 8 repetitions.

$$6 \text{ sets} \times 8 \text{ repetitions} \times 40 = 1920 \text{ ft-lbs}$$

3. Determine the maximum work repetition from the eight repetitions at 450 degrees-per-second.

For example: 25 ft-lbs

4. Determine the maximum amount of work to be done in a session if subject is in the fast velocity group.

The training protocol for the fast velocity group consisted of 8 to 10 sets for 10 to 12 repetitions.

$$8 \text{ sets} \times 10 \text{ sets} \times 25 \text{ ft-lbs} = 2000 \text{ ft-lbs}$$

5. Differences in workload was equated and repetitions were added as needed.
  - a. 60 degrees-per-second training workload=1920
  - b. 450 degrees-per-second training workload=2000
  - c. The difference is  $2000-1920=80$
  - d. Divide the difference  $(80)/40(\text{average work at this velocity})=2$
  - e. If the subject was randomly assigned to the slow group, they would have to perform 2 additional reps to equate with the fast velocity group.



# RAW DATA- TRAINING LOADS OF SUBJECTS-IN FT-LBS

SUBJECTS	70% max	80% max	90% max	100% max
1	1974	2256	2538	2820.4
2	1347.36	1539.2	1732.32	1924.8
3	1018.08	1163.2	1308	1454.4
4	1857.4	2122.4	2387.7	2653.4
5	872.9	1000	1122.3	1247.04
6	872.9	1000	1122.3	1247.04
7	1041.6	1190.4	1339.2	1488
8	1733	1980.8	2228.4	2476.8
9	1411.2	1612.8	1814.4	2016
10	1017	1162.4	1307.7	1453
11	1160	1324.8	1490.4	1656
12	926	1057.6	1190	1322
13	1357.3	1551.2	1745.28	1939.2
14	752.5	860	967.68	1075.2
15	1562	1785.6	2008.8	2232
16	2083	2380.8	2678.4	2976
17	1194.2	1364.8	1536.19	1706.88
18	1518.72	1736	1953	2170
19	2193.4	2506.4	2820.06	3133
20	1495.2	1708	1922.4	2136

1-9= SLOW VELOCITY GROUP

10-20= FAST VELOCITY GROUP

**APPENDIX I**  
**DATA COLLECTION FORMS**

## VIRGINIA TECH MUSCULAR FUNCTION LABORATORY

### Biodex Patient Information Sheet

Patient's Name \_\_\_\_\_  
(last) (first)

Social Security Number \_\_\_\_\_

Date \_\_\_\_\_

Age \_\_\_\_\_ Birthdate \_\_\_\_\_ Sex \_\_\_\_\_

Height(in) \_\_\_\_\_ Weight(lbs) \_\_\_\_\_

Bicep girth measurements: 1 \_\_\_\_\_ 2 \_\_\_\_\_ 3 \_\_\_\_\_ =Avg. \_\_\_\_\_

Bicep skinfold measurement: 1 \_\_\_\_\_ 2 \_\_\_\_\_ 3 \_\_\_\_\_ =Avg. \_\_\_\_\_

Dominant Limb(Uninvolved) \_\_\_\_\_ Involved \_\_\_\_\_

Limb used for study \_\_\_\_\_ Control \_\_\_\_\_

Joint tested \_\_\_\_\_

Mode \_\_\_\_\_

Clinician \_\_\_\_\_

Arm Length \_\_\_\_\_

Inside arm attachment \_\_\_\_\_

Arm Adjustment \_\_\_\_\_

Powerhead Shaft \_\_\_\_\_

Seat height \_\_\_\_\_

Range of motion \_\_\_\_\_

Back seat \_\_\_\_\_

Seat Cage setting \_\_\_\_\_

Limb weight \_\_\_\_\_

## VIRGINIA TECH MUSCULAR FUNCTION LABORATORY

### DAILY ENTRY AND LOG FORM OF SUBJECTS

SUBJECT #: \_\_\_\_\_ FILE # \_\_\_\_\_

DATE \_\_\_\_\_ TIME: \_\_\_\_\_

PERFORMANCE TRIAL # \_\_\_\_\_

LIMB(S) TRAINED OR TESTED \_\_\_\_\_

CLINICIAN \_\_\_\_\_

ARM LENGTH \_\_\_\_\_

INSIDE ARM ATTACHMENT \_\_\_\_\_

POWERHEAD SHAFT \_\_\_\_\_

SEAT HEIGHT \_\_\_\_\_

BACK SEAT \_\_\_\_\_

SEAT CAGE SETTING \_\_\_\_\_

RANGE OF MOTION \_\_\_\_\_

LIMB WEIGHT \_\_\_\_\_

	VELOCITY	WORK	POWER	TORQUE	C.V.	COMMENTS
SET#1						
SET#2						
SET#3						
SET#4						
SET#5						
SET#6						
SET#7						
SET#8						
SET#9						
SET#10						

## **VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY**

### **PRESCREENING INTERVIEW FORM?**

1. Please tell me of any hobbies and other interest you have.
2. What is your present major and occupation?
3. How did you find out about the study, and what interests you in strength training?
4. What is your current class schedule:
5. What is your current work schedule:
6. When is the best time for you to come to the laboratory?(M,W,F or Tu., Thur., Sat)
7. Are you planning to leave or take a vacation during June, July , or August?
8. How would you rate yourself in attendance, being on time, and following directions?
9. Missing an exercise session or dropping out of the study would really throw my thesis data off, what would be reasons that you would miss or drop out of the study?
10. What do you expect to gain from this study, and do you plan to start an exercise program after the study?
11. What is your current level of exercise(acrobic and weightlifting)?
12. Has your weight changed over the last few years?
13. Do you smoke or use caffeine products?
14. What is a typical daily diet that you follow?

At this time see if there are any more questions, and explain the importance of attendance and interests in the study. Inform the subject that the participation in the study is voluntary, and some gifts maybe rewarded.

**VIRGINIA TECH MUSCULAR FUNCTION LABORATORY**

**Estimated Cross-sectional Area of the Upper Arm**

SUBJECT# \_\_\_\_\_ FILE# \_\_\_\_\_

Patient's Name \_\_\_\_\_  
(last) (first)

Social Security Number \_\_\_\_\_

Date \_\_\_\_\_

Age \_\_\_\_\_ Birthdate \_\_\_\_\_ Sex \_\_\_\_\_

Height(in) \_\_\_\_\_ Weight(lbs) \_\_\_\_\_

Dominant arm: \_\_\_\_\_

Left Arm girth measurements:

f1 \_\_\_\_\_, \_\_\_\_\_, \_\_\_\_\_ = \_\_\_\_\_

f2 \_\_\_\_\_, \_\_\_\_\_, \_\_\_\_\_ = \_\_\_\_\_

f3 \_\_\_\_\_, \_\_\_\_\_, \_\_\_\_\_ = \_\_\_\_\_

f4 \_\_\_\_\_, \_\_\_\_\_, \_\_\_\_\_ = \_\_\_\_\_

Circumference= 1 \_\_\_\_\_ 2 \_\_\_\_\_ 3 \_\_\_\_\_ = \_\_\_\_\_ area= \_\_\_\_\_

Right Arm skinfold measurement:

f1 \_\_\_\_\_, \_\_\_\_\_, \_\_\_\_\_ = \_\_\_\_\_

f2 \_\_\_\_\_, \_\_\_\_\_, \_\_\_\_\_ = \_\_\_\_\_

f3 \_\_\_\_\_, \_\_\_\_\_, \_\_\_\_\_ = \_\_\_\_\_

f4 \_\_\_\_\_, \_\_\_\_\_, \_\_\_\_\_ = \_\_\_\_\_

Circumference= 1 \_\_\_\_\_ 2 \_\_\_\_\_ 3 \_\_\_\_\_ = \_\_\_\_\_ area= \_\_\_\_\_

## SCHEDULE FOR BIODEx TRAINING \_\_\_\_\_

8:00-8:30am \_\_\_\_\_

8:30-9:00am \_\_\_\_\_

9:00-9:30am \_\_\_\_\_

9:30-10:00am \_\_\_\_\_

10:00-10:30am \_\_\_\_\_

10:30-11:00am \_\_\_\_\_

11:00-11:30am \_\_\_\_\_

12:00-12:30pm \_\_\_\_\_

1:00-1:30pm \_\_\_\_\_

1:30-2:00pm \_\_\_\_\_

2:00-2:30pm \_\_\_\_\_

2:30-3:00pm \_\_\_\_\_

3:00-3:30pm \_\_\_\_\_

3:30-4:00pm \_\_\_\_\_

4:00-4:30pm \_\_\_\_\_

4:30-5:00pm \_\_\_\_\_

5:00-5:30pm \_\_\_\_\_

5:30-6:00pm \_\_\_\_\_

6:00-6:30pm \_\_\_\_\_

6:30-7:00pm \_\_\_\_\_

7:00-7:30pm \_\_\_\_\_

Other Appointments:

\_\_\_\_\_

\_\_\_\_\_

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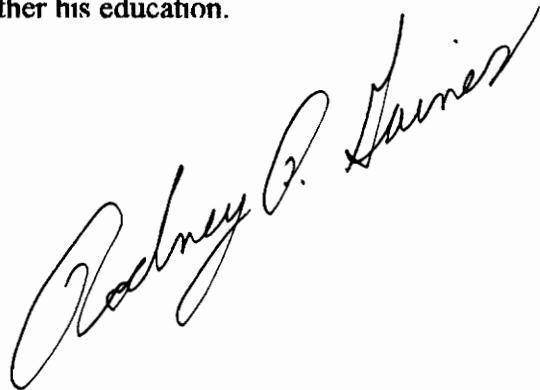
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## VITA

Rodney P. Gaines was born in Richmond, Virginia on June 6, 1967. He grew up in Tappahannock, VA, and attended Essex County Public Schools. He graduated as the Senior class President at Essex High School, and he finished 3rd in the class out of 105 students. He attended Virginia Tech from 1985 to 1989, and he received a degree in Business Finance from Virginia Tech in 1989. He worked for three years as a human resources coordinator for SouthTech, Inc. (subsidiary of Canon, Inc.) in Tappahannock, Virginia, and he switched careers and came back to school. He came back to Virginia Tech in August 1993 with hopes of getting into the graduate program of exercise science. After one more year of coursework, he was accepted into the master's program of exercise science. He taught weightlifting for two years, and in 1995 he captured his dream of winning the Mr. Virginia bodybuilding championship after four previous shortcomings of winning the title.

Rodney's future plans are to stay in the field of exercise science, and his next goal is to pursue a PhD. in Exercise Physiology. He also wants to continue his hobby as a bodybuilder, and promote drug free competition. Rodney hopes to complete his m.s. degree in May 1996, and he hopes to further his education.

A handwritten signature in black ink, reading "Rodney P. Gaines". The signature is written in a cursive, flowing style with a large initial 'R' and 'G'.