2016

Maximal Strength Effects of Cross Education Training on the Elbow Flexors

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Maximal Strength Effects of Cross Education

Training on the Elbow Flexors

(TITLE)

BY

Molly Dyer

THESIS

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF

Master of Science

IN THE GRADUATE SCHOOL, EASTERN ILLINOIS UNIVERSITY
CHARLESTON, ILLINOIS

2016

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Maximal Strength Effects of Cross Education Training on the Elbow Flexors Muscles

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Abstract

The purpose of this study was to compare the absolute and relative changes in maximal bilateral elbow flexion strength increase after a four-week intervention protocol between a unilateral and bilateral resistance training program in college age females. **Methods:** Five non-athlete females, with a mean age of 21.6 years, completed the study. Eligible subjects were randomly assigned to one of two groups; unilateral elbow flexion resistance training (n=2) or bilateral elbow flexion resistance training (n=3). Both groups completed a four-week resistance training three days per week using three sets of ten repetitions at 65% of their predicted one repetition maximum. Maximal strength increase was measured before and after intervention. The test arm (TA) was the untrained arm in the unilateral resistance training group (URT) and the designated arm in the bilateral resistance training group (BRT). The training arm in the unilateral group and the designated arm in the bilateral group were referred to as the control arm (CA). All subjects were permitted to continue regular exercise excluding any upper body exercises for the duration of the study. **Results:** Maximal elbow flexion strength increased by 16.7 ±11.8 pounds in CA and by 8.3 ±5.9 pounds in TA in the bilateral resistance training group. Comparatively, the unilateral resistance training group experienced a 17.5 ±12.4 pound increase in the CA in this group, and along with a 15 ±10.6 pound increase in strength in the TA. Percent crossover (PC) was calculated by dividing the change in pounds lifted by the TA by the change in pounds lifted by the CA and multiplying by 100. Compared to the control arm of unilateral resistance training protocol the percent cross over of the test arm was 85.71%. The percent cross over in the test arm in the bilateral resistance training group was 49.7%. There was no significant change in mid arm circumference or skin fold thickness from pre to post testing in either group. This eliminated the possibility of hypertrophy as this was a key aspect to the findings of neural mechanisms. **Conclusion:** In non-athlete, college age females unilateral resistance training caused a greater percent cross over in the test arm compared to the training arm, than bilateral resistance training following the same protocol. Both groups experienced bilateral maximal strength increases as previous studies have found. However, the magnitude of cross over demonstrated in the unilateral resistance training protocol was greater than previous studies that followed a similar protocol. In conclusion, this study found a greater percent cross over strength in the test arm following a unilateral resistance training protocol when compared to a bilateral resistance training protocol.

Acknowledgements

Firstly, I would like to express my sincere gratitude to my chair advisor, Dr. Jake Emmett, for the continued support of my master's study and continued research, for his vast knowledge within our field of study, and motivation, patience and guidance during the process of writing this thesis.

Additionally. I would like to thank my thesis committee, Dr. Stacey Ruholl and Dr. Brian Pritschet for their encouragement and enthusiasm, patience, and knowledgeable comments. Their suggestions and input were greatly appreciated during this educational process.

Most importantly, I would like to give a special thank you to my family and friends. Without their support, encouragement, and much needed distraction at times, I wouldn't have been able to complete my master's degree in such a short amount of time with my sanity intact. In particular, this thesis is dedicated in memory of my Grandpa Birdie for his constant support, comedic relief and for believing in me every step of the way.

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Definition of Terms

Hypertrophy: increase in size of cells

Rating of Perceived Exertion: a scale used to measure a client's subjective rating of exercise intensity. (Heyward, 2006)

Concentric contraction: type of dynamic muscle contraction in which muscle shortens as it exerts tension. (Heyward, 2006)

Eccentric contraction: type of muscle contraction in which the muscle lengthens as it produces tension to resist gravity or decelerate a moving body segment. (Heyward, 2006)

Isometric contraction: type of muscle contraction in which there is no visible joint movement; static contraction. (Heyward, 2006)

Isokinetic contraction: maximal contraction of a muscle group at a constant velocity throughout entire range of motion. (Heyward, 2006)

One repetition maximum: measure of intensity for resistance exercise expressed as maximum weight that can be lifted for a given number of repetitions. (Heyward, 2006)

Chapter I

Introduction

Statement of the Problem

The activation of muscle fibers post-injury is crucial in regaining strength and staving off atrophy. For example, Farthing, et al. (2011) found that activation of the elbow flexor muscle group post-injury can help stabilize the elbow joint and decreases the effect of atrophy (Farthing, et al., 2011). However, immediately following an injury active muscle movements are typically avoided in an attempt to encourage healing and prevent additional injury to the area. Also, the patient may not possess the ability to move through an active range of motion for musculoskeletal, and nervous system, such as stroke or nerve damage, or pain reasons (Lepley, & Palmieri-Smith, 2014). A newly emerging concept called cross education could change the treatment protocol for exercise therapy. Cross education is commonly defined as the phenomenon of unilateral resistance training that produces strength grains in the untrained limb (Lepley, & Palmieri-Smith, 2014). Cross education produces strength gains without training on one side of the body because of training the same muscle group on the opposite limb. According to Farthing & Magnus (2012), there is a "growing interest in the potential for cross-education to be used in rehabilitation settings" which is a step towards changing the protocol for rehabilitation therapy.

A cross education rehabilitation protocol allows the patient to maintain strength and experience less weakening in the musculature of an injured limb during the healing process (Farthing, et al., 2011). Attenuating strength loss allows the patient to maintain activities of daily living and improve overall quality of life after a muscular injury. Given these benefits, cross education has important implications for therapeutic exercise rehabilitation. Comparing the absolute and relative strength gains of the untrained limb to not only the training limb on the same person but also to a bilaterally trained limb in another person will provide information on the effectiveness of cross education as an option for rehabilitation protocols .

Cross education is theorized to be the result of neural adaptations that lower the inhibition of the motor units to the inactive, muscle that would allow for mild force activation of the opposite, non-exercised muscle. Over time, this can maintain or even increase muscular force production without traditional overload training to the injured limb. This is especially useful when traditional overload training is contraindicated or cannot be performed due to tissue injury or debilitating conditions such as a stroke (Lepley, & Palmieri-Smith, 2014). Although the mechanisms have not been identified, cross education has been demonstrated in both upper and lower body muscle groups including ankle dorsiflexors and plantar flexors (Dragert and Zehr 2011; Fimland, et al., 2009; Lagerquist, et al., 2006), and quadriceps (Coratella, et al., 2015; Lepley and Palmieri-Smith 2014) rotator cuff (Magnus, et al., 2013), forearm ulnar deviation (Farthing, et al., 2005; Farthing, et al., 2009), finger flexors (Farthing, et al., 2011; Miyamura and Yasuda 1983),and wrist flexors (Sariyildiz, et al., 2011).

More studies have investigated the effects of cross-education in lower limb muscles compared to upper extremity muscles. Upper extremity muscles are used in everyday tasks and require a certain level of stability and strength to complete these tasks. They are also utilized in everyday tasks and are commonly affected by strokes and other injuries affecting a person's quality of life. Unfortunately, injuries to the upper extremities can hinder activities of daily living. At times, it can be contraindicated to begin necessary resistance training exercises post injury due to the risk of re-injury and delay in healing (Lepley, & Palmieri-Smith, 2014).

The elbow flexor muscles are an important muscle group to test for the cross education phenomena because of the prevalence of injuries to the elbow flexor muscles. In addition, this muscle group is especially influential in completing activities of daily living. The results of this study will provide information about the effectiveness of cross education as a therapeutic modality.

Significance of the Study

No studies have examined the magnitude of cross over training induced strength changes in the elbow flexor muscles following a concentric resistance training protocol in college age females with no known musculoskeletal or neurological deficits. This study compared pre and post training changes in the untrained limb of unilaterally trained subjects as well as the changes compared to the bilateral strength gained in bilateral subjects. Furthermore, fewer studies have compared the percent of crossover of the strength gains in to the testing limb following a unilateral resistance training protocol to the testing limb following a bilateral resistance training protocol. The magnitude of crossover effects leads to the main findings of this study. This calculation represents how much strength was gained in the untrained limb in comparison to the trained limb in both the unilateral and bilateral resistance training groups. Comparing the strength gains resulting from unilateral and bilateral resistance training allows researchers to assess the value of cross education compared to therapies that are more traditional. The results from this study will assist in validating cross education as an exercise rehabilitation technique specifically for those suffering a unilateral musculoskeletal injury or deficit.

Purpose and Hypothesis

The purpose of this study was to compare the strength gains between bilateral and unilateral elbow flexion resistance training. It was hypothesized that unilateral resistance training program would produce similar elbow flexion strength gains in the untrained arm with unilateral training similar to the gains from bilateral training.

Limitations and Assumptions

A limitation to this study was the small sample size (n=5) from a mid-western university. Another limitation is the intensity of the training intervention. Increasing the training intensity from 60% of the one repetition maximum to near 85% of the one repetition maximum may have caused a greater strength gain, but also would increase the risk for injury in the subjects.

The first assumption was that the subjects were truthful when denying any musculoskeletal or neurological deficits in the upper extremities specifically. Another assumption was that the subjects completed the training protocol as prescribed with proper technique and rest periods and achieved 80% compliance throughout the four-week protocol. A final assumption was that the subjects did not engage in any other upper extremity resistance training outside activities of daily living for the duration of the study.

Chapter II

Numerous studies have tested the effects of cross education on various muscle groups with special interest in the mechanisms and the magnitude of the effect. To better understand how cross education can be fully utilized as a therapeutic exercise tool, its effects on different muscular groups need more investigation. This chapter reviews the current, relevant research on cross education and its possible effects on various muscle groups.

Cross education is can be defined as the phenomenon of unilateral, or single limb, resistance training that produces gains in strength in the opposite, untrained limb.

Cross education can be an important training technique in rehabilitative exercise. The activation of muscle fibers post injury is crucial in regaining strength and staving off atrophy. For example, activation of the quadriceps muscle group post-injury is important in stabilizing the knee joint. Farthing & Magnus (2012) see cross education as a modality with great potential and value in rehabilitation efforts and a type of therapy that could change current treatment protocols for rehabilitative exercise therapy. For example, unilateral resistance training of a non-injured limb can increase, or at least maintain strength and muscle mass in the opposite but injured limb (Damiano, Dodd & Taylor, 2005). If the body is able to adapt similarly on the injured or untrained side with cross education, full rehabilitation of the injured limb could occur faster and progress more aggressively than other rehabilitation protocols that do not incorporate cross education.

Background

Cross education was first described in 1895 and was noted to occur when, "an increase in steadiness is not limited to the muscles immediately trained, it affects the control of the corresponding muscles on the opposite side of the body…" and the increase in muscular power is in part transferred bilaterally without training the opposite side of the body (Scripture, E.W., 1895, p. 380).

The mechanisms responsible for cross-education training in the untrained limb are not fully understood. It has been hypothesized that it may be due be neural adaptations originating in either supraspinal (Lagerquist, Zehr, Paul, Docherty, David, 2006) or spinal areas (Dragert, & Zehr, 2010) resulting in greater motor cortex stimulation (Farthing, et al., 2011; Farthing, Chilibeck, & Binsted, 2005) or an increased neural drive (Fimland, et al., 2009) to the muscle groups of the untrained limb. Also, it may involve lowered inhibition and heightened sensory receptor excitability leading to activation of the motor units to the untrained limb (Coratella, Milanese, & Schena, 2015; Lee & Carroll, 2007; Lepley, & Palmieri-Smith, 2014; Sariyildiz, Karacan, Rezvani, Ergin, & Cidem, 2011; Shima, Ishida, Katayama, Morotome, Sato, & Miyamura, 2002). Other less supported hypotheses include vascularity changes (Yasuda, & Miyamura, 1983) and visual mirroring and imagery training (Zult, Howatson, Kádár, Farthing, & Hortobágyi, 2013).

Cross education mechanisms

Supraspinal mechanisms have been hypothesized as being responsible for cross educational adaptations. Farthing, et al. (2011) suggest that during a period of immobilizing to simulate an injury the contralateral motor cortex is stimulated during unilateral resistance training producing greater neural drive to the untrained limb and thus maintenance of strength. Functional magnetic resonance imaging was used to measure changes in activation of the motor cortex, specifically cortical motor activation, before and after the unilateral isometric ulnar deviation protocol was implemented. The imaging displayed an increase in activation in the contralateral motor cortex for both the right and left arm during unilateral exercise (Farthing, et al., 2011). These findings suggest that the cross education effect, in some part, can be attributed to an increased activation from within the contralateral motor cortex.

Lee and Carroll (2007) suggested that during unilateral training the "…organization of the central nervous system creates increased excitability of spinal and cortical motor pathways…" which can be translated to an increased neurological fitness. Neurological fitness could explain cross educational strength advances because a more efficient neurological system could allow action potentials to be activated easier. An increase in muscle force output can be attributed to lowering the inhibition of sensory receptors (Gabriel, Frost & Kamen, 2006). Increases in strength due to greater neural drive occurs in a resistance training program before strength gains due to muscle fiber hypertrophy. This has been shown through use of surface electromyography and its ability to illustrate neurological activity. Increased amplitude on the surface electromyography has been interpreted as magnitude of efferent neurons to activate muscle fibers therefore increasing the likelihood of doublet firing and motor unit synchronization (Gabriel, Frost & Kamen, 2006). Neurological pathways impact force production in the muscle by increasing motor units activation and the firing rate of the motor neurons. Increasing neural drives allow for more muscle fibers to depolarize and to depolarized more frequently resulting in higher force production. Therefore, the increased activation of the neurological pathways to the untrained limb are at least partially responsible for the initial strength gains described in previous cross educational studies (Coratella, Milanese, & Schena, 2015; Dragert, & Zehr, 2010; Farthing, Krentz, Magnus, Barss, Lanovaz, Cummine, Borowsky, 2011; Farthing, Krentz, & Magnus, 2009; Farthing, Chilibeck, & Binsted, 2005; Fimland, Helgerud, Solstad, Iversen, Leivseth, & Hoff, 2009; Lagerquist, Zehr, Docherty, David, 2006; Shima, Ishida, Katayama, Morotome, Sato, & Miyamura, 2002; Tabak, & Plummer-D'amato, 2010).

Another possible cross education mechanism hypothesis is the mirror effect, which is the influence, watching one side of the body doing a task and the other non-training side responds without training. Zult, Howatston, Kadar, Farthing and Hortobagyi (2013) found that performing cross education in conjunction with mirror training increased the overall strength increase in the untrained limb. The authors explained that overlapping areas of the brain containing mirror neurons are stimulated causing the untrained limb to experience similar adaptations to the trained limb. Watching the training limb complete the exercise stimulates the overlapping areas in the mirroring neurons found in several cortical areas. They believed that several bouts of the same unilateral exercise provide greater cross education due to the activation of the same brain areas repeatedly allowing for greater accessibility to the motor units controlling the untrained homologous muscle. It was felt that the mirror neuron system is an important part of the cross education phenomenon due to the involvement of the opposite temporal lobe during contraction of the homologous muscle and the increase in the contralateral motor cortex activation (Zult, et al., 2013).

Changes in blood flow may also contribute to the cross-education effect. During exercise fatigue is reduced by increasing blood flow to an area that can increase muscular endurance by allowing necessary energy and waste products to be brought to and taken away from the working muscle, respectively. While testing the effect of venous occlusion plethysmography on forearm strength, Miyamura and Yasuda (1985) found that muscular endurance increased in both the trained and untrained arm. It was thought that this increase in muscular endurance is partly attributed to increased blood flow (Miyamura and Yasuda, 1985). Blood flow to both the untrained and trained arm increased over the 6-week study (Miyamura and Yasuda, 1985). This led the researchers to speculate the effect of increased blood flow in the trained limb also occurred in the untrained limb (Miyamura and Yasuda, 1985).

Cross education benefits

Cross education is thought to produce strength, hypertrophy, and stave off atrophy in the untrained limb following an injury. Bilateral strength gains have been found in several studies of various muscular groups. Lepley, & Palmieri-Smith, (2014) found increased bilateral strength in the untrained quadriceps following an isokinetic eccentric unilateral resistance training program. The researchers found a significant increase in eccentric strength at both 60°/s and 30°/s (Lepley, & Palmieri-Smith, 2014). Although not statistically significant, they also found a positive trend toward an increase in bilateral concentric strength despite training eccentrically at 60°/s. Similarly, bilateral strength was found following a unilateral wrist flexion protocol utilizing electrical muscle stimulation (Sariyildiz, Karacan, Rezvani, Ergin, & Cidem, 2011).

Increases in bilateral hypertrophy are not as common as bilateral strength following cross education training. In fact, only one study could be found that showed evidence of bilateral hypertrophic gains. Magnus et al (2012), found hypertrophic gains in the untrained limb as well as strength following an at home resistance training program of the rotator cuff. Although hypertrophy is not commonly noted following cross educational training, decreased atrophy has been found (Farthing, et al., 2011). Other studies found bilateral strength gains without hypertrophy providing support to neural mechanisms being responsible for cross educational adaptations (Dragert & Zehr, 2010; Fimland, et al., 2009; Sariyildiz, et al., 2011).

Cross education has the potential for being a very valuable exercise rehabilitation treatment which can be utilized to increase strength and minimize atrophy during in the immobilization of an injured and untrained limb. Research has shown that a decline in strength after a rotator cuff injury can reach 15-36% even 5 years after the injury (Binet, Forthomme, Bierlaire, Meurant, Crielaard, & Croisier, (2003); Rokito, MD, Cuomo, MD, Gallagher, Ph. D., & Zuckerman, MD. (1999)). Farthing, et al. (2011) showed an increase of 0.8% in handgrip strength in the untrained, casted limb suggesting the activation of the opposite motor cortex during unilateral training. Similarly, three weeks of immobilization of one arm by casting to simulate an injury did not decrease strength or muscle cross sectional area despite the immobilization and lack of training to the injured arm (Farthing, et al., 2009). Although these subjects were not injured at the time of casting, these results show that the use of cross education has the ability to prevent muscle atrophy in an arm immobilized for three weeks.

Hand dominance

In the upper extremities, where hand dominance is evident, researchers have investigated the influence of handedness on the effects of cross education (Farthing, J. P. 2011; Farthing, et al., 2009; Farthing, et al., 2005). Current research suggests that training the dominant hand or arm results in greater cross education effects in the untrained, non-dominant hand compared to training the cross education effects from training the non-dominate hand (Farthing, et al., 2011; Farthing, et al., 2009; Farthing, et al., 2005). Farthing, Chilibeck, & Binsted, (2005) found that training the dominant arm resulted in a 23.7% greater increase in strength in the untrained, non-dominant arm resulting from unilateral hand grip strength, 39.2% increase in the dominant training protocol and 9.3% increase in the non-dominant training protocol. They attributed the adaptations to neural coordination.

Muscle groups previously tested

Cross education has been tested with several different muscle groups of the upper body including the rotator cuff (Magnus, et al., 2013), forearm ulnar deviation (Farthing, et al., 2005; Farthing, et al., 2009), finger flexors (Farthing, et al., 2011; Miyamura and Yasuda 1983),wrist flexors (Sariyildiz, et al., 2011), ankle dorsiflexors and plantar flexors (Dragert and Zehr 2011; Fimland, et al., 2009; Lagerquist, et al., 2006).

An increase in bilateral hand grip strength or the finger flexor muscles strength was found following a unilateral resistance training program (Farthing, et al., 2011; Magnus, Boychuk, Kim, & Farthing, 2013; Yasuda, & Miyamura, 1983). The rotator cuff has also been studied using an at home resistance training protocol with therapeutic resistance bands (Magnus, Boychuk, Kim, & Farthing, 2013). An increase in external rotation, internal rotation, and retraction strength in the untrained shoulder occurred after a 4 week at-home unilateral resistance training protocol (Magnus, et al., 2013). An increase in ulnar deviation strength was found following a unilateral resistance training protocol of the same muscle group (Farthing, et al., 2005; Farthing, et al., 2009). Unilateral wrist flexion resistance training resulted in bilateral strength in the untrained homologous muscle (Sariyildiz, et al., 2011). Overall, the majority of cross education studies show evidence of increased strength in the untrained limb. The current study is unique due to the concentric modality and the use of the elbow flexors.

Cross education has also been tested on major muscle groups of the lower extremities including the gastrocnemius and soleus, (Fimland, et al., 2009; Lagerquist, et al., 2006; Shima, et al., 2002), tibialis anterior (Dragert, & Zehr, 2010) and quadriceps group (Coratella, et al., 2015; Lepley, & Palmieri-Smith, 2014). Unilateral plantar flexion exercise increased maximal voluntary isometric contractions by 44% in the training leg and 32% in the untrained, cross education exhibiting limb following a 4 week protocol (Fimland, et al., 2009). The surface electromyogram showed a similar increase in activity in the trained and untrained limb after the intervention of 42% and 45%, respectively (Fimland, et al., 2009). Other studies have investigated the cross over effect in the gastrocnemius and soleus muscles and found increased strength and surface electromyogram activity in the untrained limb after following a unilateral isometric plantar flexion training protocol (Lagerquist, et al., 2006; Shima, et al., 2002).

Cross education in the dorsiflexion muscles was researched for the possible implications for stroke hemiparesis damage (Dragert, & Zehr, 2010). A five week, high intensity isometric program elicited an increase in maximal voluntary isometric contraction of 14.7% in the trained limb and 8.4% in the untrained limb. Furthermore, increases in maximal strength in both plantar flexion and dorsiflexion have been found with cross education (Lagerquist, et al., 2006; Dragert, & Zehr, 2010; Shima, et al., 2002). Increases in strength in the untrained limb following a unilateral isokinetic, eccentric and concentric protocol was found in the quadriceps muscle with a trend toward greater quadriceps activation after the intervention (Coratella, et al., 2015; Lepley, & Palmieri-Smith, R. 2014). It was thought that greater quadriceps motor unit activation allowed the muscle to exert more force as evident in the increased strength after the intervention. Training had no effect on cross sectional area, fascicle length, fat mass or angle of insertion suggesting that cross education did not have any structural effect on the quadriceps (Coratella, et al., 2015) and is primarily the result of neurological adaptations.

Training Modes

A specific training protocol for cross-educational training has not been identified. Eccentric, concentric, isokinetic and electrical stimulation are common practices in the research community but isometric exercise/contraction seems to be the most commonly used therapy/treatment.

Isometric training has been used in both the upper and lower extremities in various muscle groups including finger flexors, ulnar deviation, knee extension, plantar flexion and dorsiflexion (Coratella, et al., 2015; Farthing, et al., 2005; Farthing, et al., 2009; Farthing, 2011; Fimland, et al., 2009; Lagerquist, et al., 2006; Dragert, & Zehr, 2010; Lepley, & Palmieri-Smith, 2014; Shima, et al., 2002). Isometric tests measure maximal voluntary contraction through a torque assessment and have been shown to elicit increases in strength in the untrained contralateral limb following a unilateral resistance training protocol. Cross-education adaptations were found in the ankle dorsiflexors after a five-week high intensity unilateral isometric dorsiflexion intervention with significant strength increases in both the trained and untrained limb of 14.7% and 8.4% respectively (Dragert and Zehr, 2011).

Although less common and applicable than concentric protocols, eccentric protocols have also been studied in cross education studies. Using isokentic exercise, Coratella, Milanese, & Schena (2015) compared the effects of an eccentric protocol to a concentric protocol of unilateral knee extension and found significant increases with eccentric strength of 28.5 newton meters (N/M) with an isokinetic unilateral protocol compared to strength increases of 46.0 N/M with a dynamic constant external resistance unilateral protocol.

Also used in cross education research are isokinetic protocols. These protocols measure the force produced when attempting to move a joint through a specified range of motion at a predetermined speed. Isokinetic protocols used to measure the cross education effect in the quadriceps produced significant increases in strength and maximal velocity in the untrained limb (Coratella, et al., 2015; Lepley, & Palmieri-Smith, 2014).

Finally, protocols using concentric contractions have also been used in cross education research. Increases in bilateral external and internal rotation strength and retraction were found following an at home unilateral concentric resistance training protocol (Magnus, et al., 2013).This study had subjects complete at- home unilateral resistance training exercises for all planes of motion for the shoulder joint with increasing resistance throughout the study to stimulate overload. This study is especially applicable for rehabilitative exercise treatments because of the frequent use of at home exercise programs in conjunction with therapist based exercise. For control purposes, concentric exercises are not a commonly used protocol in cross-educational research yet concentric exercise are very common in the general population and are used often in normal daily routines. Therefore, more research is needed investigating the effectiveness of concentric protocols on cross-education.

Involuntary muscle contraction through electrical stimulation has also been utilized in cross education research. For example, Sariyildiz, Karacan, Rezvani, Ergin, & Cidem, (2011) used an electrical involuntary muscle stimulation protocol that included hand dominance testing, isokinetic strength and torque assessment and passive wrist extension simultaneous to the electrical stimulation of the agonist wrist flexor muscles following a six week training protocol. This protocol required the researcher to passively extend the wrist while the electrostimulation contracted the wrist into flexion for a total of 30 sessions over six weeks. As a result of the training protocol, there was a 46.5% cross-over of strength in the untrained muscle and a significant increase in strength in the contralateral wrist extensors (Sariyildiz, et al., 2011). These results suggest that the effects of cross education can be utilized through therapeutic electrical muscle stimulation combined with passive stretching of the antagonist muscle in the forearm.

Strength Cross Over

The relative increase in strength from cross education in the untrained limb range from 8- ~52% (Farthing, J.P. et al., 2005; Farthing, et al., 2009; Farthing, et al., 2005). After unilateral isokinetic eccentric training Lepley, & Palmieri-Smith, (2014) found a 46% increase in strength in the untrained limb compared to an 80% increase in strength in the trained limb. Similarly, Fimland, Helgerud, Solstad, Iversen, Leivseth, & Hoff,

(2009) found an increase in untrained plantar flexion strength of 32% and a 44% increase in the trained leg after following a unilateral concentric resistance training program. The increase in the untrained limb was 72.7% of the trained leg increase. Similarly, Magnus, Boychuk, Kim, & Farthing, (2013) found a 16.6% and 9.6% increase in muscle strength for external rotation and internal rotation strength, respectively, in the untrained limb. However, Coratella, et al., (2015) only found a 7.8% increase in strength in the untrained limb following a unilateral eccentric isokinetic knee extension resistance-training program. The authors thought that the magnitude of cross over may be dependent upon the specificity of training since there was a greater increase in strength and torque following eccentric training compared to concentric and isometric training in terms of maximal strength and torque (Coratella, et al., 2015). Similarly, Farthing, Krentz, Magnus, Barss, Lanovaz, Cummine, Borowsky, 2011 found in the untrained limb a strength increase of only 10.7% of the trained limb following a unilateral isometric ulnar deviation resistance training program. The small percent cross over could be attributed to the small muscle group and the type of training.

Conclusion

Cross education has large potential for exercise rehabilitation. The use of cross education in the clinical setting is not commonly utilized due to the lack of a precise understanding of the mechanisms and an accepted protocol. Although it is commonly understood that a neurological adaptation can be attributed to the cross educational phenomena, further research is needed to pin point the exact mechanism. Continual research should also address the best prescriptive protocol to make the use of cross education a more wide spread tool for combatting atrophy, beginning strengthening sooner and recovering from injury. The current study will add to the body of knowledge and offer more evidence of the cross educational phenomenon as well as increase the understanding of the possible percent cross over in strength to the untrained limb following a concentric protocol.

Chapter III

Methods

The purpose of this study was to compare the strength gains between bilateral and unilateral elbow flexion resistance training. It was hypothesized that unilateral resistance training program would produce similar elbow flexion strength gains in the untrained arm with unilateral training similar to the gains from bilateral training.

Subjects

Subjects were recruited from a Midwestern university's undergraduates by flyers distributed by professors to their students. In order to participate subjects needed to be college age females with no history of upper extremity injuries or pathologies including ligament repair or fracture met the inclusionary criteria. Subjects were excluded if they were currently a collegiate athlete. Also, subjects had to be willing to temporarily refrain from upper extremity resistance training for the duration of the study or not initiate any new exercise regimen. Continuing any current exercise program that did not include upper body resistance training was permitted. Finally, subjects had to commit to completion of all sessions of the program to the best of their ability. Exclusionary criteria were explained and applied to each volunteer prior to their inclusion in study.

This study was approved by the university institutional review board and considered to be of low risk to the subjects. Five females who met the requirements volunteered to participate in the study. Experimental design, risks, confidentiality and subject requirements were described in an informed consent document (Appendix A) signed by all subjects. Confidentiality was ensured by referring to the results in terms of the subjects training group (bilateral group and unilateral group) and in all analysis, numbers rather than names identified subjects. All notes and findings were stored at the university and will remain there for seven years for record keeping and confidentiality. After that time period, the records will be shredded. Only the lead researcher and faculty advisor to the study had access to these records.

Anthropometric Measurements

Anthropometric measurements and maximal strength were assessed at the beginning and the end of the four-week intervention periods. Age was recorded in years from self-report data. Height was measured using a stadiometer to the nearest half inch. Subjects stood, with their head in the Franklin plane, feet together with hands on the hips and shoes removed against a wall with the stadiometer. Their heels, low back, head and shoulders were pressed against the stadiometer. Instruction was given to inhale and lengthen the spine during recording. Weight was measured to the nearest pound using a standing, manual scale (Detecto, 439). The subjects were weighed without shoes, wearing non-baggy or heavy tops, bottoms, and socks for clothing. Body mass index was calculated for each subject using the following equation: weight (kg) ÷ height (m^2). Percent body fat was measured using a handheld bioelectrical impedance device with both hands holding at the active sites of the device.

Mid-arm circumference and mid-arm skin fold thicknesses were measured at baseline and post experiment using a retractable fiberglass measuring tape to the nearest millimeter. Mid-arm anterior skin folds were assessed using an SH5020 SAEHAN Skinfold Caliper following the ACSM protocol (Kaminsky, 2010, p. 64). These measurements were performed by a trained researcher and repeated twice. If the two recorded values were not within 0.5 cm (circumferences) or 1 mm (skinfolds) a third measure was taken and the closest two averaged in accordance with the American College of Sports Medicine (ACSM) protocol. The arm being measured was relaxed and in the anatomical position as the skin fold was taken and at 90 ° abduction as the circumference, measurements were taken. This information was compiled to include in the final data analysis. All pre- and post-intervention measurements were taken by the same trained researcher.

Muscular Strength

Each subject's baseline elbow flexion maximal strength was assessed using a one-repetition maximum on an elbow flexion machine in the university recreation center. The subjects were instructed on the use of the elbow flexion machine prior to testing. The one repetition maximum was determined using the ACSM protocol (Kaminsky, 2010). Subjects began a warm up set of 6-8 repetitions with resistance. Warm up resistance was determined to be 30%-40% of the estimated maximum, or a 9-11 on the RPE Scale. Subjects were asked to self-report their one repetition max on the biceps curl if known through regular exercise. If the estimated maximal amount was unknown, the subject attempted a resistance and assessed difficulty using the Borg Rate of Perceived Exertion (RPE) scale to determine warm up resistance based on the difficulty. One repetition maximum testing began immediately after the warm up set. The researcher chose a weight representing 50%-70% of the subjects estimated one repetition maximum if known by the subject. If the maximum was unknown, a weight was chosen based on perceived ability. Each repetition was completed through a normal range of motion and the subjects were instructed to exhale during the lifting phase and inhale during the relaxation phase. The researcher requested an RPE number between 6-20 from the subject and the added resistance for the next attempt was chosen based on the previously reported RPE. If necessary, the resistance was increased by 2.5- 20 kilograms after each trial based on the rating from the RPE scale given after each attempt as suggested by the ACSM fitness testing protocol. Weight was increased based on the subject's ratings and was variable with each subject. Resistance was increased in five pound increments and was increased based on the RPE reported by the subject after each lift until nearing maximal lifting capacity then an increase of 2.5 kg to end the protocol. The maximal lift was reported as when the subject reported a 19 or 20 on the RPE scale or the next weight could not be completed. The maximal lifting capacity (1 repetition maximum resistance) was achieved within four trials. A 3-5 minute rest period followed each trial and was completed on each arm to achieve baseline measurements and again post experiment. No verbal encouragement was given to the subjects during the maximal strength testing.

Intervention Protocol

Subjects were randomly assigned to either the unilateral resistance training group (URT) or the bilateral resistance training group (BRT) with three in URT and three in BRT. Also, all subjects were randomly assigned a designated test arm to simulate an injury, as injuries are random in nature. In the URT, the designated test arm was the untrained arm, which became the cross education demonstrating arm for comparison purposes. For BRT the test arm was trained and used as a control arm (CA) to be compared to the URT test arm (TA). Both groups completed the pre and post intervention testing and followed the same 4-week training protocol except that the test arm for URT was not used while both arms for the BRT were used. The training protocol was conducted on a biceps curl machine one arm at a time for the BRT and only unilaterally for the URT. All subjects completed three sets of ten repetitions at 65% of their predicted one repetition maximum with a two minute rest period between sets. The non-exercising arm was left in the anatomical extended position while lifting with no tension applied. All subjects were given a training log to be filled out after each session documenting the number of reps, sets and rest. The log was turned in to the lead investigator at the end of the intervention. This log served as an alternative to supervised exercise sessions as the subjects were completing the training without supervision by the researcher. Although self-reported compliance is not as accurate as supervised exercise, this was chosen to resemble an at home resistance training protocol. Unsupervised exercise was chosen to emulate an at home exercise program that cross education has been suggested. The subjects were given contact information for the primary researcher as well as the faculty supervisor for questions and concerns throughout the intervention.

Percent Cross Over Calculations

Cross over refers to the amount of strength increase in the test arm from the training arm. This strength comparison represents the phenomena of cross education as the increase in strength in the untrained arm cannot be explained by over load. Comparing the percent strength cross over in test arm of unilateral resistance training group to control arm of bilateral resistance training group shows how strength increases compare without training to a limb that did train. The percent cross over was calculated as the percent of strength increase between TA and its opposite limb and CA to its opposite limb on the same person. Calculating the percent strength rather than only having absolute increases in strength gives information of how effective each training protocol is in producing bilateral strength. Although even if an absolute increase in strength is present, the percentage increase indicates how well cross education performs in increasing bilateral strength when compared to a traditional, bilateral protocol.

Data Analysis

Descriptive statistics including means and standard deviations were calculated for all variables. Maximal strength increase, percent change, and magnitude of crossover as well as circumference and body composition for the test and control arms were calculated. A mixed ANOVA was used to determine if there was a significant difference, ($p<0.05$), between the dependent variables.

Chapter IV

Results

The purpose of this study was to compare the strength between bilateral and unilateral elbow flexion resistance training. It was hypothesized that unilateral resistance training program would produce similar elbow flexion strength gains in the untrained arm with unilateral training similar to the gains from bilateral training.

Descriptive Characteristics of Subjects

Seven college age females volunteered to participate in the study. One subject withdrew from the study and another was non-compliant leaving five to complete the study with two in URT and three in BRT. The mean age for all subjects was 21.6 ±0.55. Subjects were eligible to complete the study if they were currently not training the elbow flexor muscles, had no history of upper extremity pathologies or injuries and were not a current collegiate athlete. All subjects were randomly assigned to a training group and also a designated test arm. The unilateral resistance training group, (n=2), and bilateral resistance training group, (n=3), and test arm right (n=4) and test arm left (n=1) completed the study.

Anthropometric Measurements

Anthropometric measurements were completed pre- and post- intervention. Height in inches, weight in pounds, body composition and body mass index (weight (kg) ÷ height (m^2)) were measured and calculated (Table 1). Chronological age was also recorded from self-report information. There was no significant difference between the two groups or between pre and posttest anthropometrics. Mid-arm circumference and skinfold thickness were measured bilaterally pre- and post- intervention. Mid-arm circumference showed no significant change in all the subjects in the test arm (p=0.941) or the training arm (p=0.913) (Table 2).There was no significant difference between pre- and post- intervention skin fold thickness in the test arm (p=0.920) or training arm (p=0.872) for all subjects (Table 3).

Table 1.

Anthropometric Measurements

Group	Number of subjects	Mean Age (yrs)	Mean Height (inch)	Mean Weight (pound)	Mean BMI (kg/m²)	Mean Body Fat Percentage
Bilateral Training	3	21.67 ±0.58	66.01 ±1.53	163.33 ±10.69	26.60 ±2.91	30.30 ±4.96
Unilateral Training	2	21.50 ±0.71	64.96 ±1.39	116.5 ±2.12	19.35 ±0.49	16.80 ±0.42

Table 2. *Mid-Arm Circumferences Before and After Intervention*

Group	Pre Circumference Training Arm (cm)	Post Circumference Training Arm (cm)	Pre Circumference Test Arm (cm)	Post Circumference Test Arm (cm)
Bilateral Training	30.5 ±2.18	30.47 ±1.93	30.37 ±1.71	30.73 ±2.97
Unilateral Training	23.85 ±2.33	23.15 ±1.48	22.85 ±1.06	22.85 ±0.92

Table 3. *Mid-Arm Skin Fold Thickness Before and After Intervention*

Group	Pre Skinfold Thickness Training Arm (mm)	Post Skinfold Thickness Training Arm (mm)	Pre Skinfold Thickness Test Arm (mm)	Post Skinfold Thickness Test Arm (mm)
Bilateral Training	14.50 ±1.8	15.33 ±2.93	14.83 ±1.76	15.17 ±2.31
Unilateral Training	5.00 ±1.41	5.25 ±1.77	4.00 ±0.00	4.50 ±0.71

Maximal Strength

Maximal elbow flexion strength was assessed before and after the four-week intervention period for all subjects using a one repetition maximum test. Both the unilateral resistance training group and the bilateral resistance training group displayed increases in strength in both arms (Figure 1). The bilateral resistance training group showed an increase of 16.7 ±11.8 pounds in the control arm and an increase of 8.3 ±5.9 pounds in the test arm. Comparatively, the unilateral resistance training group showed a 17.5 ±12.4 pounds increase in the control arm and a 15 ±10.6 pounds increase in strength in the test arm.

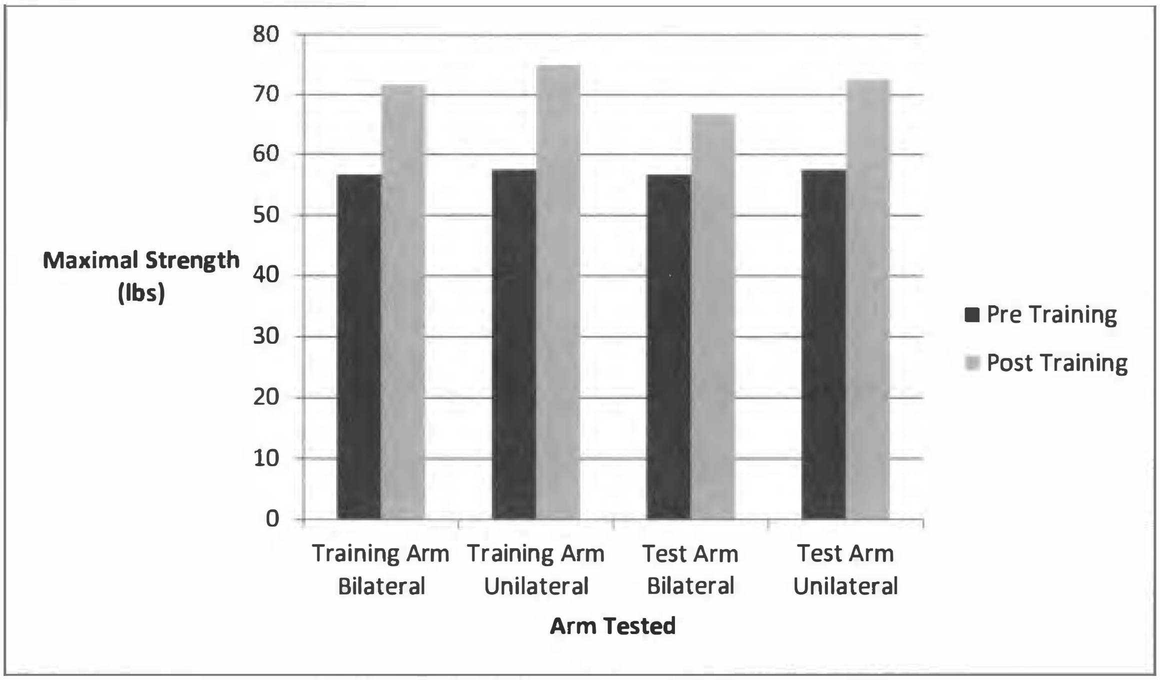

Figure 1. *Comparisons of Maximal Strength Increase Because of Bilateral or Unilateral Training.*

Percent Cross Over

The percent of cross-over was calculated by dividing the maximal strength increase (lbs) in the TA by the maximal strength increase in the control arm expressed as a percentage (Table 4). The bilateral resistance training group demonstrated a percent cross-over strength gain of 49.7% of the training arm compared to the unilateral resistance training group of 85.71% of the training arm. This comparison shows how much strength was gained in the test arm because of either cross education, the URT, or traditional overload, BRT, in a percentage.

Table 4. *Changes in Maximal Strength in terms of Absolute Strength and Percent Cross Over*

Group	Strength increase in control arm (lbs)	Strength increase in test arm (lbs)	Percent strength cross over
Bilateral Training	16.7±11.8	8.3±5.9	49.70
Unilateral Training	17.5±12.4	15±10.6	85.71

Chapter V

Discussion, Conclusions, and Recommendations

The purpose of this study was to compare the strength gains between bilateral and unilateral elbow flexion resistance training. It was hypothesized that unilateral resistance training program would produce similar elbow flexion strength gains in the untrained arm with unilateral training similar to the gains from bilateral training. The results of this study found that the unilateral resistance training group URT elicited relatively greater cross over effect in the TA than the bilateral resistance training group (BRT).

This study is unique in that no previous research compared cross education effects in the elbow flexors following a four-week, concentric unilateral resistance training protocol. Other studies have investigated the effect of unilateral resistance training and the cross education phenomena on other upper extremity muscle groups and found positive percent cross overs in the rotator cuff, 16.6% external rotation, 9.6% internal rotation, and 9.6% retraction (Magnus, et al., 2013). Forearm ulnar deviation was found to have a 9.24% (Farthing, et al., 2009) and a 39% cross over effect (Farthing, et al., 2005). The percent cross over in the finger flexors was found to be 10.7% in this immobilization study focusing on reducing atrophy (Farthing, et al., 2011). Also, the wrist flexors were found to have a percent cross over of 44.1% (Sariyildiz, et al., 2011). Lower extremity muscle groups have also been studied and percent cross over calculated. The ankle dorsiflexors and plantar flexors 57.14% and 69% and 116% respectively (Dragert and Zehr 2011; Fimland, et al., 2009; Lagerquist, et al., 2006). The plantar flexors experienced a large difference between the two reported groups. This could be because of the smaller sample size in the study by Dragert and Zehr or other outside influences. Both protocols were of similar length and protocol. The quadriceps were measured as well and found a percent cross over of 57.5% following an eccentric protocol and 7.8% isokinetic protocol (Coratella, et al., 2015; Lepley and Palmieri-Smith 2014).

After the intervention period, there were no significant changes in anthropometric measurements for either group. However, the four-week, unilateral, concentric, elbow flexion resistance training protocol produced greater strength increases in the untrained arm in the URT group compared to the strength gains in the BRT group. The results of this study indicate that cross education is a useful exercise rehabilitation tool for the elbow flexor muscles and produces greater strength gains as bilateral training. URT test arm increased in strength by 85.71% of the test arm while the control arm increased strength 49.70% of the training arm. This means that the URT test arm had a greater strength cross over than the BRT group in the test arm. These results are similar to Fimland, et al., (2009) who found a magnitude of cross over at 69% in the plantar flexion muscle group following a four-week, unilateral, maximal isometric exercise intervention and Dragert & Zehr, (2010) who found a 57.14% cross over effect following a five week, unilateral, maximal isometric protocol. Sariyildiz, et al.,(2011) found a 44.1% cross over post intervention of six week electrical stimulation protocol. Although the modes, intensity and intervention duration differ, the results of the present study produced similar cross educational strength increases.

The variability in findings of these previous studies leaves room for speculation as to which mode of training is best. The present study utilized a concentric resistance training protocol at 65% of the predicted maximal contraction but similar findings were found utilizing other modes such as maximal isometric (Fimland, et al., 2009) and involuntary electrical stimulation (Sariyildiz, et al., 2011). Even with the addition of the present study to the current body of research, it is impossible at this point to predict the best mode of cross education training and effectiveness. It does appear, however, that cross education does occur with concentric and isometric training and with electrical stimulation.

It is worth noting that Farthing, et al., (2011) reported a 10.7% magnitude of cross over, lower than found in the current study. Isometric grip strength was tested in both hands following an immobilization of one hand for three weeks while the other hand completed maximal isometric hand grip. The difference in cross over strength could be attributed to the total immobilization of the untrained hand. However, in normal daily living, both arms are utilized which does not allow for complete immobilization of the test arm therefore the results of Farthing, et al., (2011) could be more applicable to an actual rehabilitative situation.

There were no significant differences in strength gain in the control arm between groups. The large standard deviation shown in the strength gains in both groups of this study could be attributed to the small sample size. The small sample size makes it impossible to conclude why one subject responded to training to a certain degree while the others did not. Increasing the sample size could have reduced the standard deviation and therefore give more valid results. Additional investigation within this area of study is recommended to give more credibility to cross educational intervention.

The lack of variability in mid arm circumference and skin fold thickness is important to mention. The training duration was chosen to lessen the possibility of hypertrophy occurring. This typically occurs around eight weeks, and would have skewed the results as well as adding possible discomfort to the subject. The lack of hypertrophic size change indicates that no muscular overload occurred and the cross over occurred through neural mechanisms. The lifting intensity was chosen as the ACSM recognizes that a lower intensity, 65% rather that upwards of 80% of one repetition maximum, is capable of inducing strength in new exercisers. This was sufficient and safer for the subjects.

Summary of Findings

The purpose of this study was to evaluate the changes in strength in college age females after participation in a four-week unilateral resistance training protocol compare to the strength response of traditional, bilateral resistance training protocol. The hypothesis that similar strength increases in both the unilateral and bilateral resistance training groups would be found in the untrained or designated test arm was supported. Unilateral resistance training produced similar absolute strength increases in the untrained limb as bilateral resistance training.

Conclusion

In conclusion, a four-week elbow flexion, unilateral resistance training protocol at 65% of the predicted maximal strength in college age females lift elicited similar increases in absolute strength in the untrained arm than the bilateral resistance training protocol. Further, the relative magnitude of cross-over in the unilateral resistance training group was greater than the bilateral resistance training group. This finding supports the evidence of an increase in strength in an untrained limb due to cross education and demonstrates the effectiveness of unilateral training compared to bilateral training.

Recommendations for Future Research

Future research should focus on finding the best prescription and modality for unilateral resistance training cross over and research the application to actual injuries. Also, future studies should use a larger subject pool in order to increase statistical power. To move the cross education phenomena to the mainstream rehabilitation plan, more studies should be conducted using injured subjects. Cross education could change the rehabilitative exercise prescriptive protocol, but continued research is needed on different exercise prescriptions and modes as well as on subjects of all levels of ability, age, health and gender.

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APPENDIX A

Informed Consent for Participation in Research

CONSENT TO PARTICIPATE IN RESEARCH

Effects of Cross Education Training on the Elbow Flexors

You are invited to participate in a research study conducted by Molly Dyer, student, and Jake Emmett, Professor, from the Kinesiology and Sports Studies Department at Eastern Illinois University.

Your participation in this study is entirely voluntary. Please ask questions about anything you do not understand, before deciding whether or not to participate.

You have been asked to participate in this study because you are a college age female not currently following an exercise training program with no previous injuries to the knee extensor muscles or joint.

- **PURPOSE OF THE STUDY**

The purpose of this study is to determine the impact of cross education unilateral resistance training on the biceps as an anchor to the elbow joint during elbow flexion.

- **PROCEDURES**

If you volunteer to participate in this study, you will be asked to:

Attend initial and final biometric and strength measurements including height, weight, body composition and maximal strength

Attend initial training of proper exercise form, safety and completion prior to beginning

Be assigned to either the control group or experimental groups. Experimental groups will complete an experimental unilateral or bilateral training program 3 days per week for four weeks

Abstain from all other exercise for the duration of the study

Complete an exercise log for the duration of the study as well as attend supervised sessions

- **POTENTIAL RISKS AND DISCOMFORTS**

As the program involves resistance training, there is a possibility of soreness or tenderness in the exercising muscles and joint. Unilateral resistance training poses a risk for unilateral muscular strength and size gains. Efforts to prevent or limit soreness will be managed by prescribing resistance at a pre-determined percentage of your one repetition maximum. There are no significant psychological, social legal or financial risks involved in participating in this study. The researcher may terminate participation if you are non-compliant for 80% of the exercise sessions, experience an injury or excessive painful range of motion or if you wish to terminate your participation. Participation in this study is completely voluntary with no compensation for participation. The researcher may terminate the study if injuries or excessive symptoms of over training occur.

- **POTENTIAL BENEFITS TO SUBJECTS AND/OR TO SOCIETY**

You may experience mild strength and size gains in the elbow flexors as well as a greater joint stability in both limbs. You may benefit from adding resistance training to your routine.

Through the results of this study, training implications can be made to better care for patients and clients suffering from deficits following an injury or pathology affecting the elbow joint.

- **CONFIDENTIALITY**

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission or as required by law. Confidentiality will be maintained by means of coding results with a numerical code rather you're your name. Access will be granted to the researcher and the faculty advisor and will be ensured by keeping all data in the university documents for seven years. After the seven years, the data will be destroyed.

- **PARTICIPATION AND WITHDRAWAL**

Participation in this research study is voluntary and not a requirement or a condition for being the recipient of benefits or services from Eastern Illinois University or any other organization sponsoring the research project. If you volunteer to be in this study, you may withdraw at any time without consequences of any kind or loss of benefits or services to which you are otherwise entitled.

There is no penalty if you withdraw from the study and you will not lose any benefits to which you are otherwise entitled.

- **IDENTIFICATION OF INVESTIGATORS**

If you have any questions or concerns about this research, please contact:

Molly Dyer, primary investigator, madyer@eiu.edu

Jake Emmett, Faculty Sponsor, jemmett@eiu.edu

If you have any questions or concerns about the treatment of human subjects in this study, you may call or write: Institutional Review Board, Eastern Illinois University, 600 Lincoln Ave., Charleston, IL 61920, Telephone: (217) 581-8576, E-mail: eiuirb@www.eiu.edu

You will be given the opportunity to discuss any questions about your rights as a research subject with a member of the IRB. The IRB is an independent committee composed of members of the University community, as well as lay members of the community not connected with EIU. The IRB has reviewed and approved this study.

I voluntarily agree to participate in this study. I understand that I am free to withdraw my consent and discontinue my participation at any time. I have been given a copy of this form.

____

Printed Name of Subject

____________________________________ ______________________

Signature of Subject Date

APPENDIX B

Exercise Log

Date	Weight	Reps	Sets