2019

Effects Of Unilateral Resistance Training Of The Biceps Brachii With And Without A Mirror On Maximal Isometric Voluntary Contraction And Muscle Activation

Brendon David Truax
Indiana State University

EFFECTS OF UNILATERAL RESISTANCE TRAINING OF THE BICEPS BRACHII WITH AND WITHOUT A MIRROR ON MAXIMAL ISOMETRIC VOLUNTARY CONTRACTION AND MUSCLE ACTIVATION

A Master's Thesis

Presented to

The College of Graduate and Professional Studies

Department of Kinesiology, Recreation, and Sport

Indiana State University

Terre Haute, Indiana

In Partial Fulfillment

Of the Requirements for the Degree

Master of Arts in Physical Education: Exercise Science

---

by

Brendon David Truax

August, 2019

Keywords: Cross-education, mirror training, maximal isometric voluntary contraction, muscle activation

COMMITTEE MEMBERS

Committee Chair: Alfred Finch, Ph.D.

Professor of Kinesiology, Recreation and Sport Department

Indiana State University

Committee Member: Heather Abbott, Ph.D.

Assistant Professor of Kinesiology, Recreation and Sport Department

Indiana State University

Committee Member: Alberto Friedmann, Ph.D.

Assistant Professor of Kinesiology, Recreation and Sport Department

Indiana State University

ABSTRACT

Regular unilateral resistance training of an exercising limb has been shown to induce strength gain in both the exercised limb and the contralateral, unexercised limb. This phenomenon is called cross-education. Recent evidence has suggested that unilateral training combined with mirror training, practiced by imposing a reflective image of the exercising limb over the resting limb, may enhance the strength increase transferred from the trained limb to the untrained limb. However, this evidence has only been shown to occur in small, distal muscles within the forearm. The purpose of this study was to determine whether four weeks of unilateral resistance training with a mirror augmented the cross-education effect within the biceps brachii by assessing changes in maximal, isometric biceps strength, biceps activation and triceps antagonistic activation. Six healthy, non-strength trained adult participants were randomly assigned into the mirror training group (n = 3; age = 27 ± 5 yrs.) and the non-mirror training group (n = 3; age = 25 ± 3 yrs.). Maximal voluntary isometric contractions (MVICs) measured with a Dillon Strain gauge were used to assess changes in the trained and untrained biceps strength across five weekly assessments (ex. Pre-, Week 2, Week 3, Week 4, and Post-assessment) throughout the four-week program. Surface electromyography (sEMG) was recorded during bicep MVICs on each arm using a Delsys TRIGNO^{TM} wireless system to assess changes in biceps and triceps activation across the four-week program in the trained and untrained arms. Each week of the program contained three exercise sessions consisting of three working sets of ten repetitions of dumbbell curls for the right arm only. A One-way ANOVA was conducted for the trained and untrained arms between the mirror training group and non-mirror training group at .05 level to determine if there were any significant differences between biceps MVIC, biceps sEMG and triceps EMG from pre- to post-assessment. The means and standard deviations of each variable were calculated, and a qualitative analysis of the results was used to compare the mirror and non-mirror groups. Further, biceps electrical efficiency was calculated to evaluate the contributions of neurological adaptations involved in the changes associated with MVIC both arms of the mirror and non-mirror group. There were no significant differences between the mirror group and non-mirror group in biceps MVIC, biceps sEMG, or triceps EMG in either the trained or untrained arms. This lack of significance may be attributed to the small sample size used in this study (n = 6). Mirror group biceps MVIC was shown to increase in the trained and untrained limbs by 5.2 kg (22% of initial strength) and 4.3 kg (24% of initial strength), respectively. Non-mirror group biceps MVIC was shown to increase in the trained and untrained limbs by 5.13 kg (19% of initial strength) and 4.5 kg (23% of initial strength), respectively. Mirror group trained and untrained biceps sEMG both shown increasing trends across the five weekly assessments, while the untrained arm of the non- mirror group showed an increasing trend from the pre-assessment to the week four. Non-mirror group trained biceps sEMG presented no trends in the trained arm and a steady increase from week three to post-assessment in the untrained arm. Training had no noticeable effects on triceps or antagonistic activation during biceps MVIC. Despite the limitations, this study affirmed that the biceps unilateral training paradigms used in this study may be effective in enhancing strength in the trained and untrained biceps within its sample. Further studies with greater sample sizes are needed to investigate the differences between mirror and non-mirror unilateral training on MVIC, and agonist and antagonist muscle activation.

ACKNOWLEDGEMENTS

This work would not have been possible without the support provided to me throughout its completion. I am grateful to my committee members who have provided time, guidance, and valuable feedback toward this project. I would especially like to thank Dr. Alfred E. Finch, the chairperson of my research committee. His research expertise and many hours spent working with me were essential in the completion of this thesis. Thanks to him and this project, I have learned a great deal more about preparing and conducting research.

I wish to thank my family and colleagues who have supported me throughout schooling and life. Thank you to my parents (Eric and Cindy Truax, and Kelly and Richard Lyons) and my dear friend Carla Lima for their ongoing encouragement and boundless support for me and my education.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Resistance training is an increasingly popular form of exercise in both clinical and recreational settings. It involves repetitive muscular contractions against an external resistance to increase muscular strength, endurance, size and overall function (Hendy & Lamon, 2017). The increase in strength or force output of a muscle is facilitated by neurological and morphological adaptations. Neurological adaptations that increase force output may include an increase in the recruitment, firing rate and synchronization of motor units (Folland & Williams, 2007), which are single motor neurons that innervate up to 1000 muscle fibers each (Moritani, 1993). Each motor unit recruited at a constant discharge frequency is estimated to produce approximately two to five kg of muscle force per cm^2 of muscle and is independent of age, gender, and training status (Alway et al., 1990; Close, 1972; Ikai & Fukunaga,1970). The greater the number of motor units recruited, the higher their firing rate, and or the more synchronously two or more motor units discharge, the greater the sum force output of the innervated muscle. A muscle's motor unit recruitment, firing rate and synchronization translates to its electrical activity when viewed through surface electromyography (sEMG) (Moritani & DeVries, 1979; Folland & Williams, 2007). Therefore, force output is directly proportional to sEMG activity or muscle activation (Moritani, 1993).

Morphological adaptations associated with enhanced force output include an increase in muscle size (hypertrophy), change in muscle fiber typing (Type IIx → Type IIa), an increase in muscle pennation angle, and change in muscle enzyme concentration (Carroll, Herbert, Munn, Lee & Gandevia, 2006; Coratella, Milanese & Schena, 2015; Hendy & Lamon, 2017). Muscular strength has been shown to increase in the first three to five weeks of progressive resistance training without noticeable hypertrophy (Moritani & DeVries, 1979). This would suggest the initial change in strength is facilitated by neuromuscular mechanisms such as motor unit recruitment and firing rate. Repetitive, unilateral resistance training (URT) of one side/limb of the body has been shown to increase strength in both the trained and untrained side in the absence of muscle hypertrophy on the untrained side. This phenomenon was termed bi-lateral transfer of motor learning, or more commonly referred to as cross-education (Moritani & deVries, 1979). The cross-education effect involves the transfer of muscular strength and motor skill learning to the opposite, untrained, homologous muscle following repetitive unilateral training (Farthing et al., 2005). Cross-education has alternatively been documented as cross exercise, cross training effect, and contralateral strength transfer (Zhou, 2000; Carroll et al., 2006).

Cross-education was first documented in 1894 by the Yale Physiological Laboratory. A participant was instructed to squeeze a rubber bulb ten times as hard as she could with her right hand. A manometer measuring grip strength was connected to the bulb. On eight occasions over a 13-day period, she would repeat squeezing the bulb ten times with her right hand only. On the thirteenth day, her left grip strength was measured. Despite training only her right arm, her left-hand grip strength increased approximately 43%. Many studies since then have documented the cross-education effect following URT to determine the underlying mechanisms as well as quantify the amount of strength transfer (Zhou, 2000; Hendy & Lamon, 2017). Current evidence suggests that neurological adaptations in the motor pathway, particularly the motor cortices, are responsible for the strength transfer between limbs (Carroll et al., 2006; Fimland et al., 2009).

There is potential for cross-education to be applied in clinical settings. It can be integrated into rehabilitative strategies that treat unilateral injuries and disorders (i.e. fractured arm) by reducing strength loss or atrophy during limb immobilization (Farthing, Chilibeck, & Binsted, 2005; Hendy & Lamon, 2017); though, it may be less effective in stroke treatment which may benefit greater from constraint induced movement therapy (Farthing, 2009). Another rehabilitative approach that may augment the cross-education effect is mirror training (Zult, Goodall, Thomas, Solnik, Hortobagyi, & Howatson, 2016).

Mirror training involves the projection of a superimposed, reflective image of the exercising limb onto or over the non-exercising limb (Howatson, Zult, Farthing, Zijidewind, & Hortobagyi, 2013). This would make it seem as if the non-exercising limb is moving with the exercising limb. Evidence suggests that the additional sensory input from mirror training can potentiate the contralateral limb's motor pathway (Lagerquist, Zehr, & Docherty, 2006; Howatson et al., 2013, Zult et al., 2016; Hendy & Lamon, 2017). Increased potentiation of the contralateral limb's motor pathway, including the ipsilateral motor cortex, may enhance the overall magnitude of cross-education.

Even though there is a large body of literature detailing the mechanisms modulating cross-education, less is known about its application with mirror training (Howatson et al., 2013). A recent study reported a dynamic strength increase of nearly 30% greater in one group using URT with a mirror compared to the non-mirror trained group (Zult et al., 2016); however, this involved the wrist flexors which are small, distal muscles. It is possible that larger, proximal musculature such as the biceps brachii, may also experience an enhanced strength transfer effect following URT with a mirror.

Purpose

The purpose of this study was to compare maximal voluntary isometric contraction and muscle activation of the biceps brachii and muscle activation of the triceps brachii following four weeks of biceps URT between a mirror training group and a non-mirror training group.

Statement of the Problem

The problem of this study was to determine whether or not mirror training augments the cross-education effect on maximal isometric strength and sEMG generated by the biceps brachii.

Operational Definitions

1. <u>Maximal Voluntary Isometric Contraction (MVIC):</u> measurement of maximal, isometric muscle strength at a preset joint angle.
2. <u>Surface Electromyography (sEMG):</u> measurement of muscle electrical activity through electrodes affixed to the skin above or near the muscle.

Delimitations of the Study

1. Six adult volunteers (two males and four females), with a background of little to no resistance training, no contraindications to exercise, and with biceps skinfold measurements below 21 mm participated in this study. Excessive skinfold thickness has been shown to impair electrical signals from contracting muscle to sEMG electrodes; therefore, a skin thickness of the biceps was limited to ≤ 21 mm (De la Barrera & Milner, 1994).
2. Participants were randomly assigned into either the mirror or non-mirror training group.

3. Participants engaged in a four-week training program of the right biceps brachii including three sessions per week, a duration that has be shown to be sufficient for primarily inducing neurological adaptations (Moritani & deVries, 1979), and either used a mirror image during URT or the non-reflective side of the mirror.
4. Assessments for the trained and untrained arms of each participant were taken at the beginning of each week throughout the program to determine baseline strength and assess changes in MVIC and biceps and triceps sEMG.
5. Each MVIC and sEMG assessment included three trials per arm.
6. MVIC was assessed using a strain gauge equipped with a handle to perform elbow flexion.
7. sEMG was assessed using Delsys wireless electrodes and analyzed through EMGworks (version 4.0.9).
8. The changes in the mirror and non-mirror training group across five assessments were analyzed and compared to determine whether or not significant training differences existed. The changes in strength (MVIC) and muscle activation (biceps and triceps sEMG) in the trained and untrained arms of each group before and after training were compared.
9. Participants were required to not resistance train outside this study's training program.

Assumptions

1. Participants exerted maximal effort for each MVIC trial.
2. Participants adhered to the four-week training program and attended a total of 12 exercise sessions.

3. Participants did not engage in any resistance training beyond what is required for this study.

Statistical Hypotheses

1. There will be significant differences in MVIC and biceps and triceps sEMG between the mirror training group and non-mirror training group in the untrained arms following the four-week URT program.
2. MVIC and biceps and triceps activation of the trained arms in both the mirror and non-mirror training groups will be not be significantly different following the four-week URT program.
3. Triceps brachii activation will not differ significantly between the mirror training and non-mirror training groups trained and untrained arms.

CHAPTER 2

LITERATURE REVIEW

This literature review was delineated into the following categories: characteristics of cross-education, muscular mechanisms, neurological mechanisms and the mirror neuron system.

Characteristics of Cross-education

The cross-education effect is the transfer of muscular strength and motor skill learning from the trained homologous muscles to the resting, untrained limb following a period of URT (Farthing et al., 2005). The strength transfer and increased EMG activity associated with cross-education has been observed primarily in homologous muscle groups that share the same dimensions and position on each side of the body. Hortobágyi and colleagues (1999) evaluated knee extensor and grip-strength on the untrained side of the body when the contralateral knee extensors were trained to determine if the effect is limited to the homologous knee extensors only, or if it transferred to the flexor muscles of the hand. They found that the untrained knee extensor strength noticeably increased while grip strength involving distal arm musculature did not, affirming that the strength transfer is homologous specific. Multiple studies have indicated that cross-education is independent of age and gender (Zhou, 2000; Howatson et al., 2013). Moritani and DeVries (1979) reported that the neural strength gain during progressive URT of the elbow flexors was similar between males and females during the first three to five weeks of training. Another study found that after two weeks of maximal, isometric elbow flexor training, similar strength gains were observed in both young and elderly adult men and women (Ehsani, Nodehi-Moghadam, Ghandali, & Ahmadizade, 2014). Additionally, unilateral strength transference has been exhibited going from the dominant to non-dominant limb and vice-versa (Hortobagyi et al., 1999; Zhou, 2000; Shima, 2002; Farthing, Borowsky, Chilibeck, Binsted, & Sarty, 2007). Though, it has been suggested that strength and motor skill transfer is greater when the dominant limb is unilaterally trained due to the greater potential for improvement remaining in the non-dominant limb (Farthing, 2009).

Typical Cross-education Experimental Study Design

Most cross-education studies share similar, between-group study designs. They measure left and right limb strength prior to the program and then randomly assign those limbs to training and control conditions. Cross-education is then measured afterwards by subtracting the mean strength of the control group's untrained limbs from the untrained limbs of the training group. Strength is usually assessed using MVIC or a one-repetition maximum (1RM). These studies primarily used proximal and distal limb musculature (Carroll et al., 2006). These muscles are then trained isometrically or isokinetically using either voluntary or electrically stimulated contractions (Zhou, 2000; Carroll et al., 2006). Before pre-assessments, familiarization protocols are often implemented to reduce error in estimating strength transfer which can account for approximately 3% of strength gains (Carroll et al, 2006).

Strength Transfer

The amount of strength transfer involved in cross-education varies between studies. These variances are largely due to differences in training paradigms such as exercise complexity, contraction type, volume, intensity, and duration. Additional factors include targeted muscle characteristics, strength testing methodology and participant training status (Hendy & Lamon, 2017). In their meta-analysis, Carroll and colleagues (2006) analyzed sixteen cross-education studies and found that the strength transfer was ~7.6% of initial strength or roughly half of the trained side when completed over a four to 12-week period at an intensity of 55-100% 1RM. Zhou (2000) concluded a similar degree of strength transfer after analyzing previous studies. He concluded a strength increase of five to 25%, equating to ~60% of the trained side between four to 12 weeks at 60% 1RM minimum intensity.

Other studies have shown greater results. Following five weeks of submaximal (three sets at 10RM), unilateral, and isometric plantar flexion training. Lagerquist and colleagues (2006) found that the strength of the trained leg increased 15.31% while the untrained leg increased 17.83%. They speculated that the greater increase in strength of the untrained limbs might be attributed to a lesser initial strength level; therefore, the untrained side had more potential for gain. Another study involving the maximal strength training (five sets at 5RM) of the right elbow flexors of 10 women for two months (three sessions/week) resulted in an increase in peak force of 37 and 35% in the trained and untrained arms, respectively (Adamson, Macquaide, Helgerud, Hoff, & Kemi, 2008). The differences among these latter studies in comparison to the aforementioned meta-analyses are likely training variables such as program duration and training intensity (Hendy & Lamon, 2017).

Contraction Type Specificity

Evidence shows that adaptations in the contralateral limb are dependent on the training paradigms used on the trained, ipsilateral side (Hortobágyi, Scott, Lambert, Hamilton, & Tracy, 1999). Contraction type is one training paradigm that has been manipulated frequently in cross-education studies. There are three principle types of muscle contractions including concentric (muscle shortening), eccentric (muscle lengthening) and isometric (no change in muscle length).

Eccentric training has been shown to maximize the cross-education effect (Howatson et al., 2013; Coratella, Milanese, & Tracy, 2015; Hendy & Lemon, 2017). Hortobágyi and colleagues (1999) conducted a study that used electrically stimulated contractions and different contraction types to determine if these different paradigms affected cross-education and carried over any specificity to the untrained side. Following six weeks of knee extensor training, the eccentric, concentric, and isometric trained groups increased strength by 104%, 77%, and 66% respectively; showing that eccentric URT may induce greater strength transfer than other contraction types. Additionally, it was found that each group performed better when the testing procedures matched their training conditions, indicating testing specificity. The concentrically trained group performed better than the eccentrically trained group during concentric testing (30% versus 18%), while the opposite was true during eccentric testing (10% versus 77%). These results would support the notion that CE is contraction, or test specific (Hortobágyi et al., 1999; Zhou, 2000).

Muscular Mechanisms

It has been speculated that muscular adaptations, or adaptations within the muscle itself, may be partially responsible for the increased strength from cross-education. These can include muscle hypertrophy, and changes in muscle architecture, muscle fiber typing, and muscle enzyme concentration (Carroll et al., 2006; Folland & Williams, 2009; Hendy & Lamon, 2017). Measurements of these adaptations may include anthropometrical, histological, and imaging such as (i.e. magnetic resonance imaging and ultrasound) (Carroll et al., 2006). Changes in muscle cross-sectional area (CSA) are atypical in the untrained limb following URT. In one early study, 14 elderly males underwent a URT program of the elbow flexors at near maximal intensities that increased CSA of the type II, fast twitch muscle fibers in both the trained and untrained biceps brachii (Brown. McCartney, & Sale, 1990). In contrast to this, another study also training the elbow flexors at maximal intensity for eight weeks did not induce changes in muscle CSA in its sample (Adamson et al., 2008). Coratella and colleagues (2015) reported similar findings following five weeks of unilateral, isokinetic, eccentric knee extension training, observing no changes in muscle CSA, pennation angle or fiber orientation. Despite the findings by Brown and colleagues (1990), studies conducted since then using similar parameters have not been able to replicate those results (Hendy & Lamon, 2017).

Hendy and Lamon (2017) suggested that URT may induce changes in systemic blood hormone levels that may promote muscle anabolism or anti-catabolism (i.e. testosterone and growth hormone). Significant hormone release and changes are associated with larger muscle group resistance training and potentially may facilitate cross-education; though, it is unlikely the critical mechanism underlying the strength transfer. This is due to cross-education also observed occurring in small, distal musculature (i.e. intrinsic muscles of the hand) which would not produce adequate systemic hormonal changes (Carroll et al., 2006; Hendy & Lamon, 2017). One study by Beyer and colleagues (2016), examined the hormone levels of participants following four weeks of large muscle group training consisting of unilateral leg press and leg extension training. They measured blood levels of testosterone, growth hormone, insulin, and insulin-like growth factor before exercise, immediately following exercise, and 30- and 60-minutes post-exercise. Only acute responses were recorded, and no chronic adaptations were observed despite leg press strength increasing by 55.5% and 40.4% in the trained and untrained limb, respectively. This suggests that cross-education is not facilitated by hormonal/endocrine responses (Beyer et al., 2016).

It is possible that morphological changes were not observed due to limitations in equipment (Hendy & Lamon, 2017). Hendy and Lemon (2017) indicated that more accurate methods of measuring changes in muscle mass such as magnetic resonance imaging and peripheral quantitative computed tomography are not used often and might explain the lack of evidence for morphological changes following URT. Despite this, evidence supports cross-education being largely mediated by neurological rather than morphological mechanisms (Moritani & deVries, 1979; Carroll et al., 2006; Farthing, 2009; Hendy & Lamon, 2017).

Neurological Mechanisms

The Cross-activation theory and Bilateral Access theory are two possible explanations of the neurological involvement underlying cross-education. The Cross-activation theory states that bilateral cortical activity occurring in both the ipsilateral and contralateral motor cortices during unilateral contraction produces lasting neuroplasticity in both cortices (Hendy & Lamon, 2017). Dual activation of the trained and untrained motor cortices during unilateral contractions, also known as cross-activation, may cause control system adaptations for both limbs (Carroll et al., 2006). Unilateral movement has been shown to induce cross-activation by activating both the ipsilateral (same side as moving limb) and contralateral (opposite side of moving limb) motor cortices (Zhou, 2000). Kristeva and colleagues (1991) analyzed movement-related magnetic fields in the cerebral cortex during left and right, unilateral and bilateral finger flexion and found that both motor cortices were active during unilateral movement; indicating that bi-lateral activation during unilateral movement does occur.

Unilateral movements can lead to the development of motor engrams which are then stored in the control system of the trained limb (Farthing, 2009). Motor engrams are motor patterns that are used to perform movement or skills. These engrams can later be accessed by both the trained and untrained limbs; this is functioning underlying the Bilateral Access Theory. (Hendy & Lamon, 2017). Farthing (2009) proposed that the Bilateral Access Theory is contingent on cross-activation of both motor cortices. Farthing elaborated that unilateral motion is stored in the contralateral motor cortex (cM1) and sensorimotor information is stored in the temporal lobe of the ipsilateral side. The combination of these sensory and motor storage mechanisms may increase motor drive descending from the motor command level to the activated muscle of the untrained limb, modulating the strength transfer of cross-education. The cross-activation and bilateral access theories, exclusively or mutually, may modulate cross-education following URT (Carroll et al., 2006).

Role of the Motor Cortices

In both the Cross-activation and Bilateral access theories, key roles are assigned to the motor cortices; however, current literature proposes that the ipsilateral motor cortex (iM1) is the primary mediator of cross-education (Lee, Hinder, Gandevia, & Carroll, 2010; Hendy & Kidgell, 2014; Hendy, Teo, & Kidgell 2015; Zult et al., 2016; Hendy & Lamon, 2017). Lee and colleagues (2010) assessed unilateral ballistic motor contractions while the iM1 was down regulated using repetitive transcranial magnetic stimulation to examine the roles of the motor cortices during unilateral training. Performance gains and changes in neural excitability were abolished in the contralateral, untrained limb only. In contrast, when the cM1 was down regulated, performance was reduced in the trained limb only. However, the strength transfer to the untrained limb was unaffected. Moreover, another study found an increase in 1RM strength, corticomotor excitability, and reduced corticomotor inhibition of the contralateral limb when stimulation was applied to the iM1 (Henry & Kidgell, 2014). Similar results were found in a two-week study involving stimulation to the iM1 during URT of the right elbow flexors. The group receiving iM1 stimulation had greater strength gain and neural adaptations compared to the sham stimulation group (Hendy et al., 2015). Increased excitability and reduced corticomotor inhibition between the two motor cortices enhance the communication between them, allowing the iM1 to access motor engrams in the cM1 more effectively (Hendy & Lamon, 2017).

Studies implementing volitional wave (V-wave) and Hoffman reflex (H-reflex) measurements further support the role of the motor cortices in cross-education. V-wave amplitudes can be used to assess efferent neural drive originating from the supraspinal, or cortical pathway (Fimland, Helgerud, Solstad, Iversen, Leivseth, & Hoff, 2009). On the other hand, the electrically evoked H-reflex can be used to assess reflex excitability of the 1a afferent motor neuron pathway, indicating a change in the spinal pathway (Aaagard et al., 2002). An increased reflex excitability is associated with greater motor unit recruitment and force generating capacity (Lagerquist et al., 2006).

Fourteen weeks of heavy resistance training in one study, led to a V-wave amplitude increase of 50%, H-reflex amplitude increase of 20%, and 30% increase in strength (Aaagard et al., 2002). This evidence suggests that both enhanced neural drive and spinal excitability are associated with increased strength when both limbs are trained together at near maximum intensity. Fimland and colleagues (2009) found that after four weeks of maximal, isometric plantar flexor training, V-wave amplitude increased by 72 and 24% in the trained and untrained soleus muscles, respectively; although, there was no change in H-reflex amplitude. Lagerquist and colleagues (2006) observed a significant increase in the H-reflex amplitude of the trained limb only following five weeks of URT of the legs. The increase in V-wave, but not H-reflex amplitude indicates that cross-education may not be heavily modulated by changes in spinal circuitry; rather it is a result of increased motor drive stemming from the motor cortices (Lagerquist et al., 2006; Fimland et al., 2009; Hendy & Lamon, 2017). Ultimately, evidence supports than an increase in descending motor drive and communication between the motor cortices modulates cross-education.

MNS and Cross-education

Viewing a mirror image has been shown to disinhibit the iM1 cortex, potentiating motor pathway excitability and increasing motor drive (Lagerquist et al., 2006). In one study involving the wrist flexors being unilaterally and concentrically trained for three weeks, participants that used a mirror-imposed image had almost double the dynamic strength transfer (61% versus 34%) compared to those without a mirror during training (Zult et al., 2016). This enhanced strength effect was attributed to the activation of mirror neurons.

The complex of mirror neurons in the brain is known as the mirror neuron system (MNS). The MNS connects neurons that discharge action potentials and initiate movement, with those that respond to visual properties of an observed task (Howatson et al., 2013). The MNS is thought to be essential in developing motor behaviors. In other words, mirror neurons provide a neuroanatomical link between visual input from observing a movement and motor neurons that are involved with that movement, without practicing that movement beforehand (Hendy & Lamon, 2017). The MNS can be found throughout the visual areas of the brain including the parietal, occipital, and temporal lobes and has connections to motor areas of the brain including the inferior parietal, pre-central, and inferior frontal gyri (Howatson et al., 2013). Following cross-education, functional magnetic resonance imaging has shown enlarged regions of activation in the contralateral, trained left temporal lobe, premotor and visual cortices, and the untrained sensorimotor cortex and primary motor cortex during unilateral contraction (Farthing, 2009). It is plausible that because there is overlapping neuroanatomy used in both mirror training and cross-education, that mirror training may enhance cross-education (Howatson et al., 2013; Zult et al., 2016).

Summary

Cross-education is mediated by neurological mechanisms rather than muscular mechanisms (Carroll et al., 2006; Folland & Williams, 2007; Farthing, 2009; Hendy & Lamon, 2017). These mechanisms are primarily modulated by adaptations within the motor cortices. Mirror training may augment the strength transfer associated with unilateral training; however, this has only been documented in small, distal forearm musculature (Zult et al., 2016). More research using larger limb musculature such as the elbow flexors is necessary to determine if mirror training significantly augments the cross-education following URT.

CHAPTER 3

METHODOLOGY

Methodological aspects of this research project are discussed in this section. These topics include participant selection, participant screening questionnaire, instruments, testing protocols, and statistical analysis.

Participant Selection

Participants were characterized as individuals who were healthy adults ($\geq$18 years of age), possessed little to no resistance training experience, and had no contraindications to resistance training. Prior to evaluation of the study's exclusion criteria, all volunteers were fully informed of the testing and training protocols involved in this study. Participants then read and signed an informed consent document (APPENDIX A) approved by the Indiana State University Institutional Review Board.

Exclusion criteria for this study included having considerable resistance training experience, possessing one or more exercise contraindications, having a biceps skinfold of 21 mm or greater, and being unable to commit to a four-week URT program. Considerable resistance training experience was determined using the American College of Sport's medicine's guidelines on sedentary behavior where a resistance trained individual would have resistance trained at minimum three times per week within three months prior to participating in the study (ACSM, 2018). Exercise readiness was assessed using a PAR-Q+ questionnaire (APPENDIX B), which helps identify any existing contraindications to exercise. Regarding the biceps skinfold, individuals with biceps skinfolds measured at ≥ 21 mm were excluded from the study due to evidence supporting an impedance of EMG signal these values (De la Barrera & Milner, 1994). Lastly, participants who were required to commit to three sessions of URT per week for four weeks (12 total sessions) were included in the study. Resistance training of this duration has mainly been shown to produce neurological adaptations that enhance muscle force production. Volunteers who have met the inclusion criteria and completed the informed consent were randomly inserted into the mirror training group or the non-mirror training group. A coin was flipped to randomly determine which group a participant was assigned to (heads → mirror group, tails → non-mirror group).

Participant Screening Questionnaire

Physical Activity Readiness Questionnaire (PAR-Q+): the 2018 edition of the pre-participation screening tool containing a seven-question battery that determines if an individual may safely participate in exercise. If they answered yes to one or more of the questions, he or she was excluded from this study. If answered no on all the questions, he or she would then move forward in the screening process. The objective of this screening questionnaire was to exclude moderate to high risk volunteers from participating in this exercise study. Participants completed the PAR-Q+ (APPENDIX B) during their first visit.

Instruments

1. Dillon FI-90 strain gauge: used to measure the peak force (±.001 kg) exerted during the MVIC flexion task of the biceps brachii. A padded strap was attached to the participant's arm while the opposite arm rested at his/her side. The participant's arm was placed inside

the strap which was attached to the Dillon strain gauge load cell. The other end of the load cell was anchored with an adjustable chain to the base of a padded strength testing table. The adjustable chain allowed the investigator to adjust length to where the elbow was positioned at 90° flexion. 90° elbow flexion was measured with a goniometer. The force indicator was zeroed prior to each MVIC attempt by pressing ZERO/CLEAR. Peak force was recorded when the digital arrow was set to PEAK, then MVIC was attempted. That value remained on the screen until ZERO/CLEAR was pressed again for the next attempt.

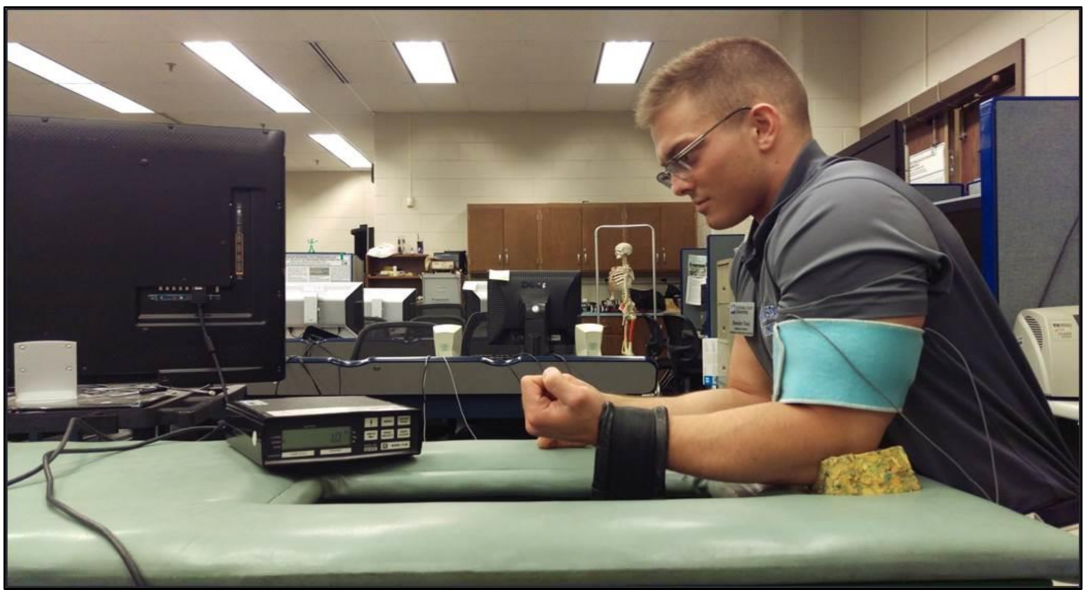

Figure 3.1. Displays Strain Gauge and MVIC Set-up.

2. Delsys TRIGNO™ Wireless System (Model PM-W01): surface electromyography (sEMG) unit was used to measure muscle activation of the biceps brachii and antagonistic activation of the triceps brachii during the biceps MVIC. Electrodes for the biceps and triceps brachii were affixed onto the belly of the muscles, sites shown to record adequate muscle activation during elbow flexion (Magnus, Barss. Lanovaz, & Farthing, 2010). The belly of the muscle was estimated to be half the length of the upper

arm on the anterior and posterior side. Halfway length of the upper arm was determined using the ACSM guidelines for locating the biceps and triceps brachii skinfold sites (ACSM, 2018). This was determined by measuring the halfway distance between the acromion and olecranon processes using a Gulick tape measure (.1 cm). Each sensor contains two silver contact bars (10 mm x 1 mm diameter) that are spaced 10 mm apart with a common mode rejection ratio of 92 dB and has a maximal sampling rate of 2000 samples per second. A hypo-allergenic adhesive was applied onto the conducting surface of each sensor to allow it to stick to the skin. Prior to placing the sensors, an isopropyl alcoholic swab was used to clean the skin of any dry skin cells, oil or other contaminants. If excessive body hair existed on the sensor site, the area was shaved before placement. Muscle activation data was collected and analyzed using EMGworks (version 4.0.9) software. Sensor placement sites for right, training arm and the Delsys unit is displayed in Figure 3.2.

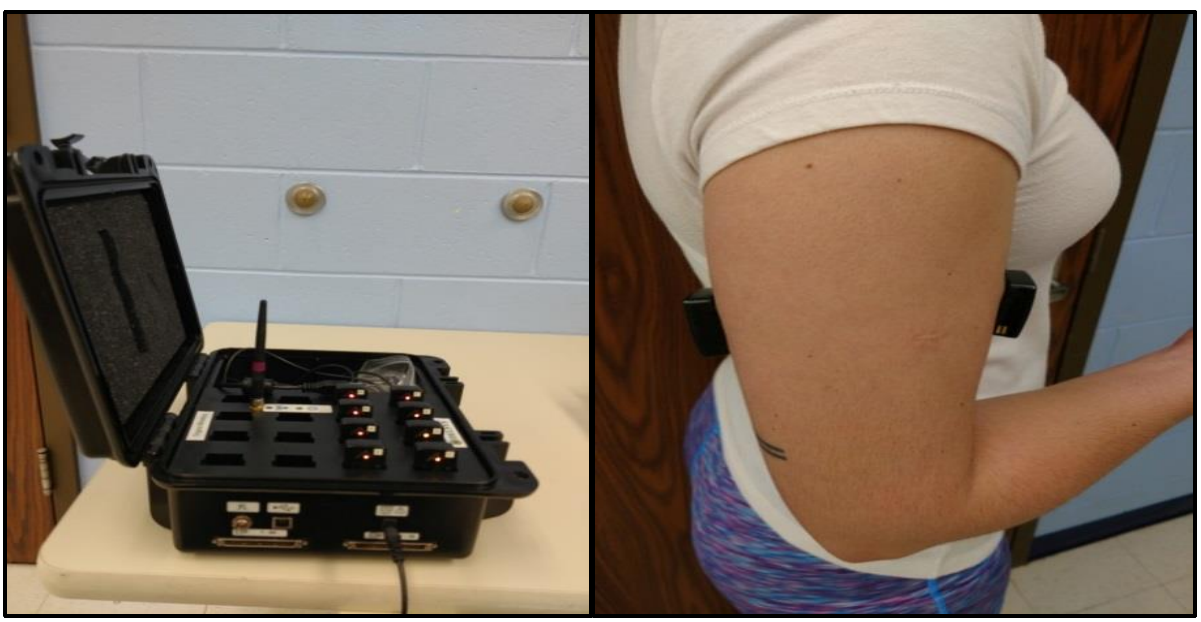

Figure 3.2. Displays Delsys and sEMG Sensor Sites

Testing Protocols

Testing protocols were delineated into the pre-training meeting, weekly and post-assessment protocols, and the progressive resistance training protocol.

Pre-training Meeting

1. The first meeting occurred one week prior to the progressive URT program in the Indiana State University Biomechanics Lab located in Arena room A-129. Interested volunteers were asked to schedule, via phone or email, this meeting with the investigator prior to arrival.
2. At the beginning of the first meeting, the volunteer was informed of the study's purpose, testing procedures and training program. Once fully informed, the volunteer was given an informed consent document (APPENDIX A) to read, sign, and return to the investigator.
3. The investigator then determined the resistance training background of each volunteer. If he/she had not resistance trained within the past three months, he/she completed a PAR-Q + questionnaire. Afterwards, the investigator reviewed the questionnaire to make certain that it was signed and completed. If at least one yes was answered on any of the seven questions, the volunteer was excluded. The questions inquired for existing medical risks that were contraindicative to exercise.
4. Following completion of the PAR-Q+, a skinfold test was measured on the right biceps brachii. Skinfold site placement and testing resembled the methods used in the ACSM guidelines book (ACSM, 2018). The midway point was measured between the olecranon and acromion processes on the anterior of the right arm and a horizontal line was marked on the biceps site using a dry-erase marker. A vertical pinch was used on the biceps and measured with a skinfold caliper in millimeters (mm). Each skinfold assessment was

given at minimum two trials. If there was a difference of two mm or greater between trial one and two, a third trial was needed. The average of the two closest trials must have been < 21 mm to include he/she in the study.

5. Following skinfold testing, the investigator recorded the participant's name, body mass (kg) and age (years) for later data analysis; then randomly inserted the participant into either the mirror group or non-mirror group using a coin flip toss.
6. Three weekly training sessions for the next four weeks were scheduled afterwards, as well as dates for the weekly assessments for MVIC and sEMG. Training sessions and assessments were separated by a minimum of 48 hours to ensure adequate post-exercise recovery.

Weekly and Post Assessment Protocols

1. Weekly assessments for MVIC and sEMG activation were recorded in the ISU Biomechanics Lab. Assessments pre- through week four were recorded during the first session of each week throughout the training program. The post-assessment was recorded within one week following the end of the training program. There were five assessments total.
2. To begin an assessment, the Delsys equipment was turned on and the EMGworks program was opened. The investigator designated the sites for sEMG sensor placement including the bellies of the biceps and triceps brachii on the right and left arm. Halfway distances between the olecranon and acromion processes were measured on both arms with a Gulick tape to identify the bellies of the biceps and triceps. Once all sites were designated, isopropyl alcohol swabs were used to clean the skin site prior to sensor placement. The area was shaved if there was excessive body hair. If needed, the

investigator provided the metal razor. After the sites were cleaned, a hypo-allergenic adhesive was used to affix the sensors to their sites. Resting sEMG was viewed to insure adequate signaling, but not recorded.

3. After obtaining a strong signal, the participant warmed-up the biceps brachii by performing elbow flexion (arm curls) for three sets of 10 with resistance bands he/she considered light to moderate resistance. The arm curl involved gripping the resistance band handle with a supinated grip and shortening the distance between the forearm and upper arm using elbow flexion. Arm curls were selected as a warm-up for the biceps brachii because it has the most translation to the testing movement. One minute of rest was given between each warm-up set prior to the MVIC. Two minutes of rest was provided before MVIC testing.
4. The investigator randomly selected either the left (untrained) or right (trained) arm to perform the MVIC first using a coin toss (heads → right arm, tails → left arm). The participant was seated at the end of the bench on near the force indicator; then instructed to place their elbow onto a cushion at a 90° angle with the hand positioned over the load cell connected to the force indicator. 90° elbow flexion was affirmed by the investigator using a goniometer and chain length was adjusted accordingly to the height of the flexed arm. The participant’s forearm was parallel to the bench with the upper arm perpendicular to the bench. Each participant gripped the handle with a supinated grip. Each MVIC was attempted in this position.
5. Participants were cued to attempt three MVIC arm curls. Each attempt lasted three seconds and was recorded to the nearest .05 kg. The MVIC was described to the participants as curling the handle maximally upward trying to bring it shoulder level

without lifting the elbow off of the bench. One minute of rest was used between each attempt. Following the completion of one arm, the participant switched to his/her other arm for identical testing.

6. MVIC attempts and corresponding muscle activation were recorded three times and listed as trials one through three. The greatest MVIC on each arm and its corresponding maximal activation was used for data analysis. An example data sheet is shown in Table 3.1.

Table 3.1.

Example Data sheet for recording MVIC, biceps activation and triceps activation during a Pre-assessment of the MG.

Date: xx/xx/xxxx		Participant: xx	Assessment: Pre
Right Arm			
Trials	MVIC (kg)	Biceps sEMG (mV)	Triceps sEMG (mV)
1			
2			
3			
Left Arm			
1			
2			
3			

Progressive Resistance Training Protocol

1. Training sessions took place in the Biomechanics Laboratory. The investigator scheduled three training sessions per week for the next four weeks with each participant (12 total sessions) for URT of the right biceps only. Cross-education has been shown to occur in from the dominant limb to non-dominant and vise-versa (Hortobagyi et al., 1999; Zhou, 2000; Shima, 2002); though, the right biceps were selected for training due to the

majority of previous cross-education studies using right limb training and right-arm dominant participants (Farthing, 2007).

2. Each session consisted of three warm-up sets of ten repetitions of arm curls using light to moderate resistant bands and one minute of rest between each set. Following the warm-up, three working sets of six to 10 repetitions using a weight estimated at roughly 65-75% 1RM for the right arm only. This training intensity has been shown in previous studies to produce noticeable strength gain in the biceps (Moritani & deVries, 1979; Cerir-Sastre, Beltran-Garrido, & Corbi, 2017). During the arm curl, the upper arm remained perpendicular to the ground and the elbow flexed until the hand and weight reached shoulder level. Two minutes of rest were used between each working set. The mirror group used a large mirror separating their right and left arm during the warm-up and exercising sets.
3. Mirror group participants viewed the mirror image of their right arm superimposed over their left as if it was their left arm exercising synchronously with the right. They were asked to visualize the left arm contracting as the right arm flexes in the mirror. In contrast, the non-mirror group used the non-reflective rear side of the mirror used for the mirror group. The non-mirror group was asked to visualize their left arm contracting as the right arm contracts without a reflection. This provided further control on the experimental conditions allowing the only difference in the training protocol being the use of a mirror reflection; an approach similarly used by Zult and colleagues (2016).
4. Resistance was expected to increase throughout the resistance training program. The ‘two for two’ rule recommended by the ACSM’s Resources for an Exercise Physiologist was used to determine when resistance should be increased (Magyari et al., 2018). This rule is

applied when the participant can lift two consecutive repetitions above ten before fatiguing and does this for two consecutive workouts; resistance is then increased to promote progressive overload. Weight was increased in increments of approximately two kilograms until six to 10 repetitions were achieved before muscle fatigue.

5. For both groups, training sessions were approximately 15 minutes in duration and separated by at least 48 hours for both groups. Sessions including assessments were approximately half hour. Participants were required not to resistance train outside this exercise program.

Statistical Analysis

IBM® SPSS® statistics software package, version 24 (SPSS Inc., Chicago, USA) was used to conduct all statistical analysis. A One-way Analysis of Variance (ANOVA) with repeated measures was used to determine any significant differences at .05 level between the mirror group and the non-mirror group for MVIC, biceps activation and triceps activation from pre to post-assessment. Baseline comparisons of the trained and untrained arms of both groups were assessed for each variable using independent t-tests assuming unequal variances. Descriptive statistics including the mean ± standard deviation (mean ± SD) for biceps MVIC, biceps and triceps activation and biceps electrical efficiency were conducted to numerically and graphically compare change over time between the mirror group and non-mirror group. Difference scores were calculated by subtracting the pre-assessment values from each weekly assessment for biceps and triceps activation to identify any discrepancies between sEMG assessments.

CHAPTER 4

RESULTS AND DISCUSSIONS

In this section of the research project, we describe the participant characteristics, the statistical analysis results and the discussion of those results based on the current literature.

Participant Characteristics

A total of six (Mirror: n = 3; Non-mirror: n = 3) participants volunteered for this study. Four females and two males participated; each group contained two females and one male. The mean age for the mirror group was 27 ± 5 years; while the mean age for the non-mirror group was 25 ± 3 years (Table 4.1). The mean body weight in kilograms (kg) was 80.6 ± 6 kg for the mirror group and of 99 ± 7.4 kg for the non-mirror group (Table 4.1). The mean skinfold was 9 ± 6.4 millimeters (mm) for the mirror group and of 15 ± 8 mm for the non-mirror group (Table 4.1). The participant pool was determined to be homogenous and normally distributed.

Table 4. 1

Participant Characteristics.

Characteristic	Mirror Group	Non-Mirror Group
Total	n = 3	n = 3
Age (yrs.)	27.0 ± 5.0	25.0 ± 3.0
Height (m)	1.79 ± .08	1.71±.12
Weight (kg)	80.6	99.0 ± 7.40
Skinfold (mm)	9	15.0 ± 8.0
Male	n = 1	n = 1
Age (yrs.)	32	25
Height (m)	1.79	1.84
Weight (kg)	85.3	92.3
Skinfold (mm)	5	6
Female	n = 2	n = 2
Age (yrs.)	24.5 ± 3.5	25 ± (4.24)
Height (m)	1.66 ± .05	1.64 ± 1.6
Weight (kg)	78.3 ± 6.2	102.1 ± 6.7
Skinfold (mm)	10.5 ± 7.8	19.5 ± .7

MVIC Results

Baseline t-test comparisons found that there were no significant differences in either the trained (*p* = .86) or untrained (*p* = .81) arms between both groups' biceps MVIC. A One-way ANOVA with repeated measures was conducted at .05 level for the trained and untrained arms between the mirror group and non-mirror group to determine any significant differences in MVIC from pre- to post-assessment. These results are compared in Table 4.2 and 4.3. There were no significant differences in the trained (*p* = 0.86) or untrained arms (*p* = 0.83) between the mirror group and non-mirror group.

Table 4.2

ANOVA analysis on trained arm MVIC strength for mirror and non-mirror groups.

	df	Mean Square	F	*p*
Mirror vs. Non-mirror	1	22.7	0.035	0.86

Note: MVIC = maximum voluntary isometric contraction; df = degrees of freedom; F = F-statistics; *p* = significance value.

Table 4.3

ANOVA analysis on untrained arm MVIC strength for mirror and non-mirror groups.

	df	Mean Square	F	*p*
Mirror vs. Non-mirror	1	29.01	0.054	0.83

Note: MVIC = maximum voluntary isometric contraction; df = degrees of freedom;
F = F-statistics; *p* = significance value.

Descriptive statistics including mean ± SD were also conducted to provide a numerical and graphical representation of the change in MVIC for both group’s trained and untrained arms. The trained arm and untrained arm mean ± SD values are displayed in Table 4.4 and graphically illustrated in Figure 4.1. The untrained arm mean ± SD values are displayed in Table 4.5 and graphically illustrated in Figure 4.2. MVIC was recorded in kilograms (kg).

Table 4.4

Descriptive statistics on trained arm MVIC strength for mirror and non-mirror groups.

	Mirror Group				Non-Mirror Group			
	Mean	±	SD	(kg)	Mean	±	SD	(kg)
Pre	23.80	±	14.70		22.00	±	5.44	
Week 2	25.33	±	16.00		23.70	±	4.80	
Week 3	26.63	±	15.00		25.60	±	3.84	
Week 4	28.50	±	15.13		25.83	±	3.61	
Post	29.00	±	16.60		27.13	±	3.90	

Note: MVIC = maximum voluntary isometric contraction; SD = standard deviation; kg = kilograms;
Pre = pre-assessment; Post = post-assessment.

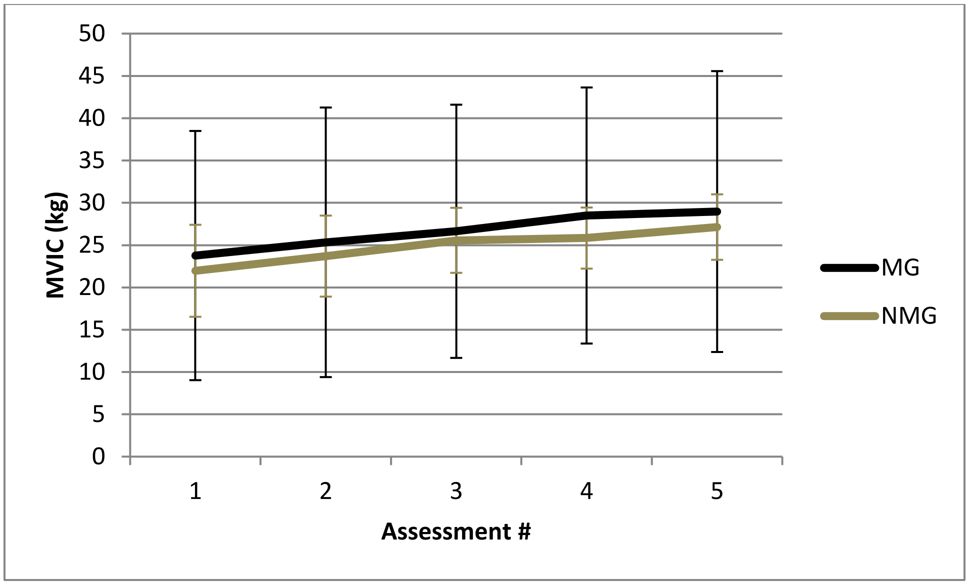

Figure 4.1. Trained biceps MVIC across 5 weekly assessments.

Table 4.5

Descriptive statistics on untrained arm MVIC strength for mirror and non-mirror groups.

	Mirror Group			Non-Mirror Group		
	Mean (kg)	±	SD (kg)	Mean (kg)	±	SD (kg)
Pre	22.40	±	14.30	20.03	±	5.20
Week 2	23.00	±	14.04	22.20	±	5.80
Week 3	25.13	±	12.44	23.20	±	5.21
Week 4	27.00	±	12.80	24.23	±	6.20
Post	26.70	±	14.11	24.53	±	6.20

Note: MVIC = maximum voluntary isometric contraction; SD = standard deviation; kg = kilograms; Pre = pre-assessment; Post = post-assessment

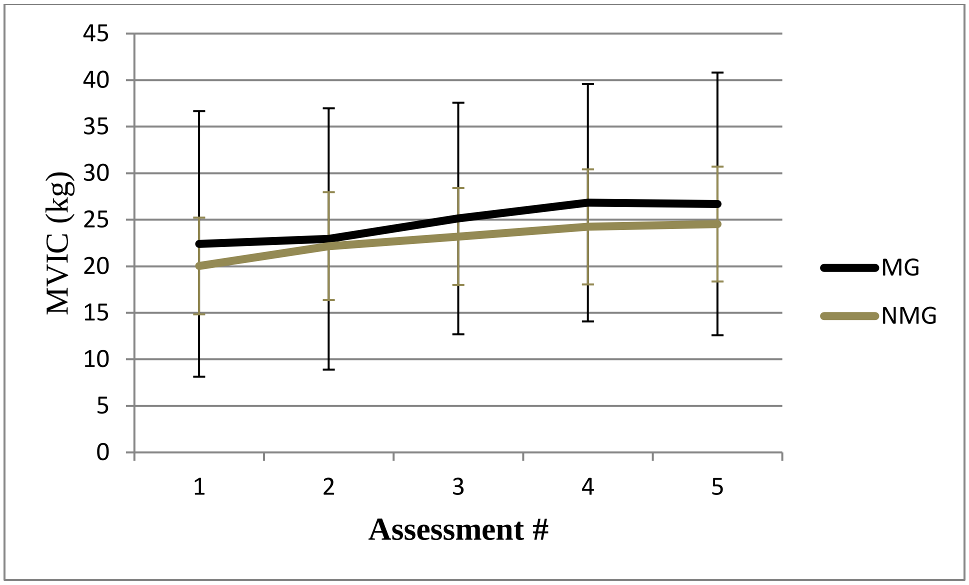

Figure 4.2. Untrained biceps MVIC across 5 weekly assessments.

MVIC Discussion

Enhanced MVIC force production in both arms of the mirror group and non-mirror group suggest that the training paradigms employed in this study (volume, intensity, frequency and duration) were effective in enhancing isometric strength in the trained biceps and in eliciting a strength transfer to the contralateral, untrained biceps within this sample. After conducting a One-way ANOVA comparing the mean MVIC of both arms for both groups, it was shown that there were no statistically significant differences between either in the trained ($p = 0.86$) or untrained arms ($p = 0.83$). The lack of significance may be attributable to low statistical power due to the small sample size used in this study (mirror group: $n = 3$, non-mirror group: $n = 3$). There were observable changes in mean MVIC force including an increase of 5.2 kg (22% of initial strength) and 5.13 kg (19% of initial of strength) in the trained mirror group and non-mirror group biceps, respectively shown in Figure 4.3.

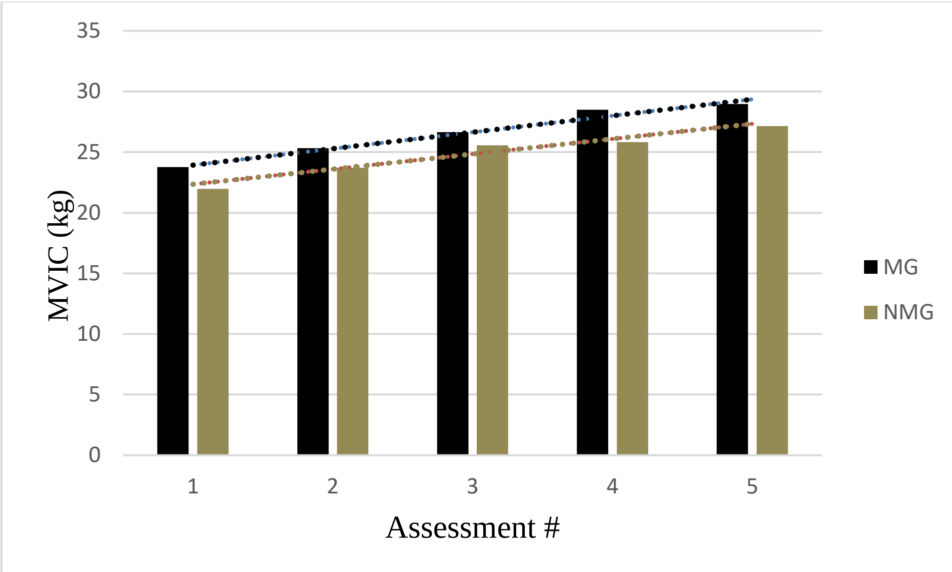

Figure 4.3. Trained arm biceps MVIC improvements.

There were also increases of 4.3 kg (24% of initial strength), and 4.5 kg (23% of initial strength) in the untrained biceps of the mirror group and non-mirror group, respectively shown in Figure 4.4. Further, the increase in mean MVIC in the mirror group's untrained arm was 82.6% of that observed in the trained arm. In contrast, the mean force production of the non-mirror group's untrained biceps was 87.1% of that observed in the trained biceps. Despite no statistical significance or observable differences between either group, there were observable changes from pre- to post-assessment in both arms of both groups.

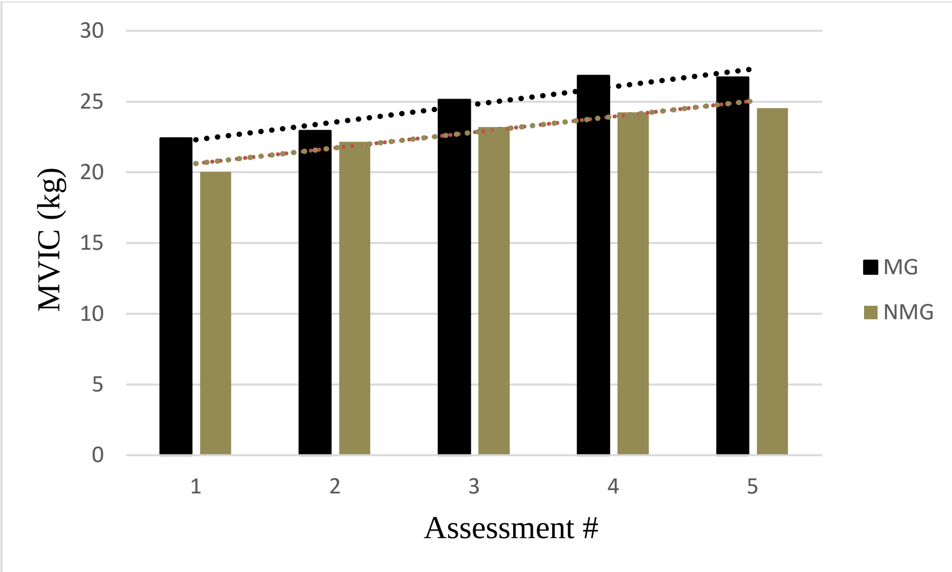

Figure 4.4. Untrained arm biceps MVIC improvements.

Current versus Previously Reported Changes in Strength

The changes in initial strength and percentage of strength transfer for the mirror group and non-mirror group were greater than was previously reported in Carroll and colleagues' (2006) meta-analysis (approximately 7.6 % of initial strength; this represented approximately half of the trained side's gain). In comparison to the systematic review conducted by Zhou (2000), MVIC values in this study were within the range of reported initial strength changes (5-25% of initial strength) but differed in the approximation of strength transfer from the trained to untrained sides (approximately 60% of trained side). The differences in strength gain among these studies may be attributable to differences in training paradigms such as the training intensity and volume (Hendy & Lamon, 2017), and the contraction types used for testing (i.e. isometric vs dynamic) (Zhou, 2000). Interventions utilizing eccentric contractions have been shown to induce the greatest cross-education and overall strength gain compared to concentric and isometric contractions alone (Hortobagyi et al., 1999). The majority of studies included in the 2006 meta-analysis were primarily isometric and isokinetic movements, which may have lowered the overall strength gain compared to the program used in this study which used both concentric and eccentric training movements. This current study also prescribed an exercise intensity of 65 to 75% 1RM which was suggested by Cerir-Sastre and colleagues' (2017) in their meta-analysis discussing training paradigms that have been shown to produce the most robust increase in strength transfer following URT. The meta-analysis by Carroll and colleagues (2006) included intensities ranging from 55 to 100%. To employ greater intensities, would consequently reduce training volume (i.e. less repetitions per set and/or less sets per exercise session). It is possible that this current study's volume and intensity intervention was more ideal for inducing cross-education rather than that used in the studies analyzed by Carroll and colleagues, producing greater overall changes in strength gain and transfer.

Contraction Specificity and Strength Gain

The similarity in both arms' strength gain in the mirror group and non-mirror group may be explained by contraction specificity. Zult and colleagues (2016) conducted a study where participants were divided into either a mirror or non-mirror training group and underwent 15 sessions of dynamic wrist flexor training at 80% 1RM. Dynamic wrist torque was reported to have increased 61% in the mirror group and 34% in the non-mirror group during a dynamic MVC; however, the MVIC between these groups showed no significant changes. The authors speculated that the dynamic rather than the isometric tests improved because they simulated the training movement (Zult et al., 2016). Other studies have also shown that greater cross-education was observed when the testing conditions matched the training modalities (Hortobagyi et al., 1999; Zhou, 2000; Lagerquist et al., 2006; Folland & Williams, 2007; Beyer et al., 2016). This evidence supports that strength transference is task or skill specific. The training method used in this study was dynamic biceps curls with or without a mirror; however, the testing movement used was isometric. It is possible that mirror training may enhance the strength transfer from the trained to untrained biceps; though a dynamic rather than isometric movement, should be used to elucidate this.

Biceps Activation Results

Baseline t-test comparisons resulted in no significant differences in either group's trained (p = .20) or untrained (p = .29) arms biceps activation (sEMG). A One-way ANOVA with repeated measures using a significance level of .05 significance was performed comparing bicep activation between the trained and untrained arms of the mirror group and non-mirror group from pre- to post-assessment. The results of these comparisons are shown in Table 4.6 and 4.7. There were no significant differences observed in the trained (p = 0.57) or untrained arms (p = 0.56) between the mirror group and non-mirror group.

Table 4.6

ANOVA analysis on trained arm biceps EMG for mirror and non-mirror groups.

	Df	Mean Square	F	*p*
Mirror vs. Non-mirror	1	0.03	0.391	0.57

Note: EMG = electromyography; df = degrees of freedom; F = F-statistics;
p = significance value.

Table 4.7

ANOVA analysis on untrained arm biceps EMG for mirror and non-mirror groups.

	Df	Mean Square	F	*p*
Mirror vs. Non-mirror	1	0.03	0.395	0.56

Note: EMG = electromyography; df = degrees of freedom; F = F-statistics;
p = significance value.

Descriptive statistics including mean ± SD were also conducted to provide a numerical and graphical representation of the change across the five assessments in biceps activation for both group's trained and untrained arms. The trained arm mean ± SD and differences scores are presented in Table 4.8 and displayed in Figure 4.5. The untrained arm mean ± SD and difference scores are presented in Table 4.9 and displayed in Figure 4.6. Surface EMG values were recorded in millivolts (mV).

Table 4.8

Descriptive statistics on trained arm biceps EMG for mirror and non-mirror groups.

	Mirror Group				Non-Mirror Group			
	EMG Mean	±	SD (mV)	Diff	EMG Mean (mV)	±	SD (mV)	Diff
Pre	0.28	±	0.18	------	3.32	±	2.45	------
Week 2	0.34	±	0.20	0.069	0.53	±	0.12	0.049
Week 3	0.37	±	0.20	0.094	0.32	±	0.15	-0.156
Week 4	0.40	±	0.19	0.094	0.30	±	0.20	-0.189
Post	0.40	±	0.19	0.126	0.31	±	0.21	-0.168

Note: EMG = electromyography; SD = standard deviation; Diff = differences scores; mV = millivolts; Pre = pre-assessment; Post = post-assessment.

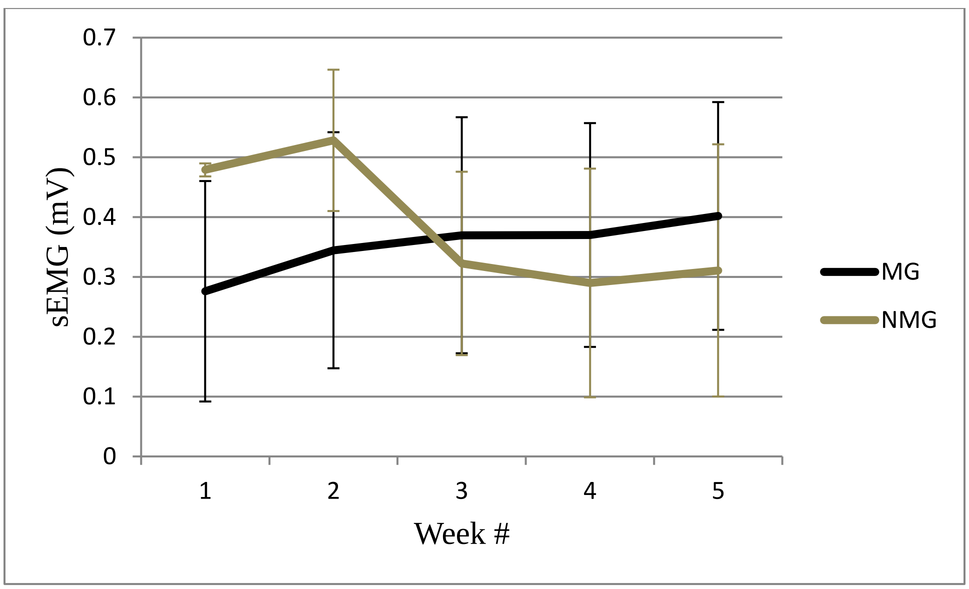

Figure 4.5. Trained biceps EMG across 5 weekly assessments.

Table 4.9

Descriptive statistics on untrained arm biceps EMG for mirror and non-mirror groups.

	Mirror Group				Non-Mirror Group			
	EMG Mean	±	SD (mV)	Diff.	EMG Mean	±	SD (mV)	Diff
Pre	0.18	±	0.10	------	1.91	±	1.34	------
Week 2	0.21	±	0.10	0.029	2.03	±	2.98	0.085
Week 3	0.23	±	0.10	0.046	0.24	±	0.11	-0.064
Week 4	0.26	±	0.15	0.079	0.24	±	0.15	-0.064
Post	0.13	±	0.09	-0.050	0.26	±	0.16	-0.050

Note: EMG = electromyography; SD = standard deviation; Diff = difference scores; mV = millivolts; Pre = pre-assessment; Post = post-assessment.

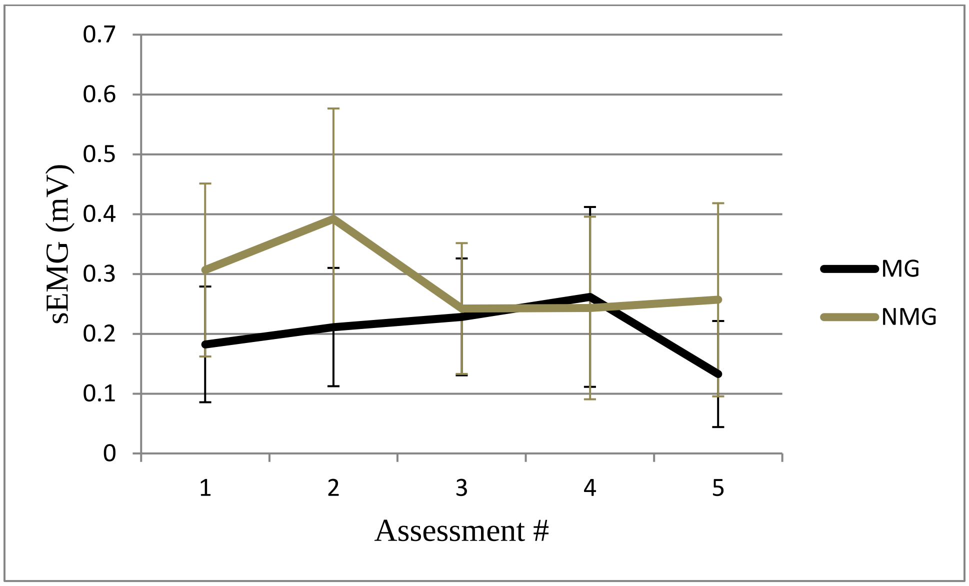

Figure 4.6. Untrained biceps EMG across 5 weekly assessments.

Biceps Activation Discussion

The results of the One-way ANOVA between the mirror group and non-mirror group found no significant differences in the mean biceps sEMG in the trained (p = .57) and untrained (p = .56) arms, respectively. However, large variability and a limited number of subjects may have prevented significant differences from occurring. When the data was graphed visually, the mirror group's trained arm mean sEMG activity was shown to steadily increase by 45.6% from the pre- to post-assessment. The trained arm biceps sEMG mean of the non-mirror group showed no trend to be increasing or decreasing; a noticeable difference existed between week two and week three (Difference = -0.156 mV). The untrained arm of the mirror group showed an increase of 43.5% in biceps activation from the pre-assessment to week four, and then decreased towards the post assessment period. An unusually large difference score of -.050 mV corresponded to this decrease. The untrained arm of the non-mirror group showed no trend until week three and then it steadily increased towards the post-assessment by 6%; a noticeably high difference score existed at week three (-.064 mV). The lack of noticeable change, changes from pre- to post-assessment, and large variance in the difference scores and standard deviations among both groups may be explained by low statistical power attributable to the small sample size used.

Surface EMG has been applied in research to record changes in muscle activation due to its association with neural drive changes within agonist muscles (Folland & Williams, 2007). Numerous studies have reported significant increases in agonist muscle sEMG with strength training, especially within the first three to five weeks in the trained and contralateral, untrained limbs (Häkkinen & Komi, 1983; Aagard et al., 2002; Shima, Ishida, Katayama, Morotome, Sato, & Miyamura, 2002; Magnus et al., 2010); though, some studies have reported no significant changes in contralateral, untrained limb sEMG following 3-8 weeks of URT (Moritani & DeVries, 1979; Farthing et al., 2005; Lagerquist et al., 2006; Beyer et al., 2016). Surface EMG was used in this study to measure biceps activation during a MVIC biceps curl before, throughout, and after a four-week URT biceps program. Although no significant differences were found between groups, there were inconsistencies found within the data collected during the non-mirror group's trained arm during the pre-assessment biceps sEMG and the non-mirror group's untrained arm during the pre- and week two assessments. These inconsistencies may have been caused by a variety of factors that have been reported in previous studies including variable impedance of the skin, hydration levels, distribution of subcutaneous tissue, muscle morphology changes, or contraction velocity during MVIC testing.

Prior to affixing the sEMG sensor onto the bellies of the biceps and triceps, the skin was wiped with an isopropyl alcohol swab to remove any dead skin cells, loose hair, and other contaminants that could impede EMG signal. The electrode was affixed after the skin dried; however, it is possible the area was not adequately dried or cleaned and caused electrical impedance to the sensors. Hydration levels may have also affected the EMG signal. If a participant was dehydrated, the electrical signal from the muscle to the sensor may have been reduced due to lower subcutaneous water content (Folland & Williams, 2007). Water was offered at libitum during this study and the participant was encouraged to have eaten and hydrated themselves at least two hours prior to his/her session; though, hydration was not an implemented measurement in this study and thus could have influenced the EMG results. Differences in subcutaneous tissue content between the trained and untrained arms could have also produced the biceps sEMG inconsistencies. A bicep skinfold assessment was administered as an inclusion criterion (< 21 mm → inclusion criterion met) to reduce potential outliers in EMG data on the training (right) arm only. It is possible that subcutaneous tissue was unequally distributed between the training and non-training limbs and caused the non-trained arm to have additional data inconsistencies than the training arm.

Another possibility includes changes in muscle morphology (i.e. muscle hypertrophy) that could have shifted the bellies of the trained biceps brachii, altering the strength of the signal to the sensors (Folland & Williams, 2007). Though, this possibility was unlikely due to muscle hypertrophy being the predominant factor in strength increases following five weeks of training (Moritani, 1993), exceeding the length of this training program and the duration where the inconsistencies were found. Contraction velocity could have also influenced the results of the sEMG recordings. Participants were instructed to exert maximal force against the strain gauge handle keeping the elbow fixed at 90º flexion; however, they were not required to do the contraction slowly or explosively. An explosive or more powerful contraction may have caused greater activation of the Type II muscle fibers situated in the periphery of biceps (Lexell & Taylor, 1989; Fuentes, Cobos, & Segade, 1998), producing greater spikes in muscle activation. If a participant approached the MVIC with an explosive, high speed contraction one week and switched to a slower contraction speed the next, this could explain the large differences among measurements. Low sample size and the previously mentioned variables may have contributed to the inconsistencies found within this study's sEMG data.

Triceps Activation Results

After conducting baseline t-test comparisons, no significant differences were found between both groups in either the trained (p = .43) or untrained (p = .06) arms for triceps EMG. A One-way ANOVA with repeated measures using a .05 level of significance was performed on triceps activation comparing the trained and untrained arms of the mirror group and non-mirror group from pre- to post-assessment. Results of these comparisons are shown in Table 4.10 and 4.11. There were no significant differences in the triceps sEMG activity values in the trained (p = 0.86) and untrained (p = 0.54) arms in either group.

Table 4.10

ANOVA analysis on trained arm triceps EMG for mirror and non-mirror groups.

	df	Mean Square	F	*p*
Mirror vs. Non-mirror	1	0.001	0.037	0.86

Note: EMG = electromyography; df = degrees of freedom; F = F-statistics;
p = significance value.

Table 4.11

ANOVA analysis on untrained arm triceps EMG for mirror and non-mirror groups.

	df	Mean Square	F	*p*
Mirror vs. Non-mirror	1	0.12	7.27	0.54

Note: EMG = electromyography; df = degrees of freedom; F = F-statistics;
p = significance value

Descriptive statistics including the mean ± SD were conducted to provide a numerical and graphical representation of change across the five assessments in triceps activation for both groups trained and untrained arms. The trained arm mean ± SD for triceps sEMG are presented in Table 4.12 and displayed in Figure 4.7. The untrained arm triceps sEMG mean ± SD are presented in Table 4.13 and displayed in Figure 4.8. Difference scores representing the difference between each weekly assessment triceps activation and baseline activation is shown in Table 4.12 and 4.13 for the trained and untrained arms, respectively.

Table 4.12

Descriptive statistics on trained arm triceps EMG for mirror and non-mirror groups.

	Mirror Group				Non-Mirror Group			
	EMG Mean	±	SD (mV)	Diff	EMG Mean	±	SD (mV)	Diff
Pre	0.09	±	0.06	------	0.37	±	0.49	------
Week 2	0.23	±	0.14	0.139	0.09	±	0.02	-0.222
Week 3	0.23	±	0.02	-0.045	0.24	±	0.07	-0.147
Week 4	0.14	±	0.16	-0.052	0.04	±	0.01	-0.072
Post	0.04	±	0.02	-0.047	0.05	±	0.01	-0.065

Note: EMG = electromyography; SD = standard deviation; Diff = difference scores; mV = millivolts;
Pre = pre-assessment; Post = post-assessment.

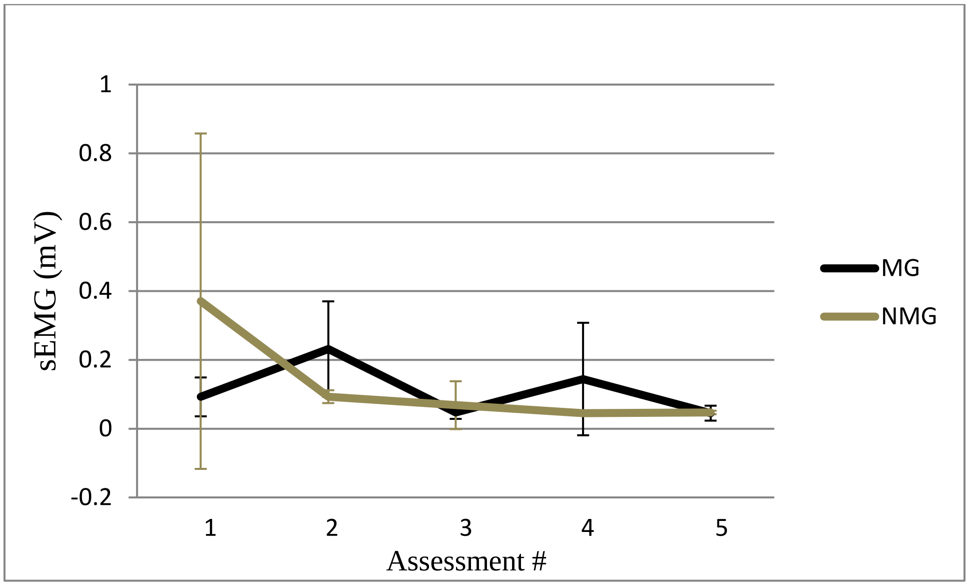

Figure 4.7. Trained triceps EMG across 4-week program.

Table 4.13

Descriptive statistics on untrained arm triceps EMG for mirror and non-mirror groups.

	Mirror Group				Non-Mirror Group			
	EMG Mean	±	SD (mV)	Diff	EMG Mean	±	SD (mV)	Diff
Pre	0.09	±	1.73	------	0.59	±	0.23	------
Week 2	0.05	±	0.20	-0.010	0.04	±	2.33	-0.222
Week 3	0.04	±	0.004	-0.019	0.09	±	0.11	-0.147
Week 4	0.04	±	0.01	-0.016	0.14	±	0.16	-0.072
Post	0.18	±	0.24	-0.120	0.17	±	0.16	-0.065

Note: EMG = electromyography; SD = standard deviation; Diff = difference scores; mV = millivolts; Pre = pre-assessment; Post = post-assessment.

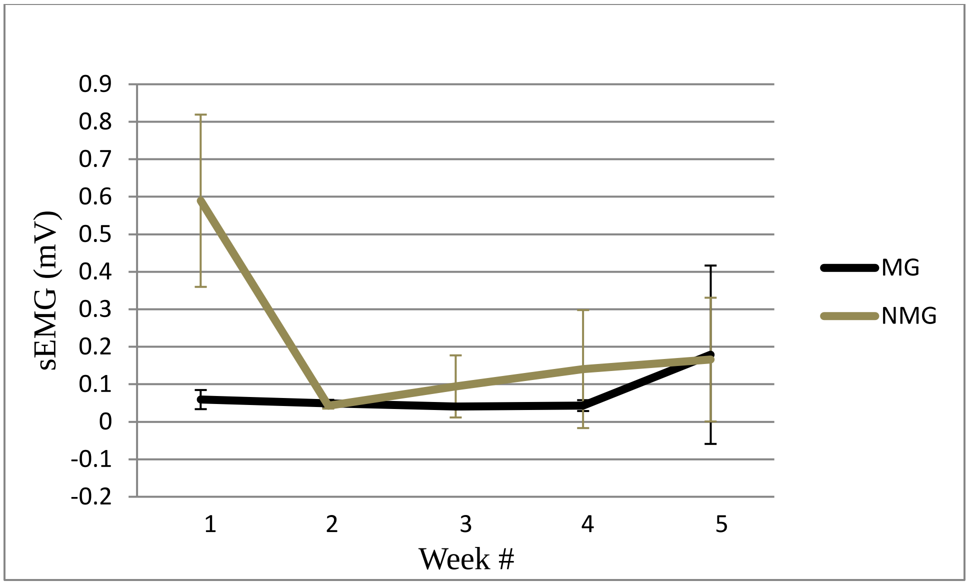

Figure 4.8. Untrained triceps activation across 5 weekly sessions.

Triceps Activation Discussion

Triceps activation was measured during the biceps MVIC across the five weekly assessments to compare any changes in antagonistic activation between the mirror and non-mirror groups in the trained and untrained arm. After analyzing the data, it was found that there were no significant differences between the mirror group and non-mirror group in the trained arm (p = 0.86), nor in the untrained arms (p = 0.54). The lack of significance found between both groups may be attributable to low statistical power caused by the small sample size used. After viewing the data visually, the mirror group presented a decreasing trend in the right arm by 51.3% and the non-mirror group by 49.5%. The trained arm of the non-mirror group had a noticeably large difference score of -.222 mV at week two. The untrained limbs of both groups showed no apparent trends of increasing or decreasing, though large difference scores appeared at week two for the non-mirror group (-.222 mV) and week five (-.120) for the mirror group.

Neurological adaptations that occur early in resistance training include an increase in descending neural drive to the agonistic muscle (i.e. biceps brachii) and a corresponding decrease in activation of its antagonistic muscle (i.e. triceps brachii) (Folland & Williams, 2007). During agonist and antagonist co-contraction, the agonist force output is reduced due to the resistive force of the antagonist muscle (i.e. muscle drag); furthermore, the agonist's ability to fully activate is impaired through reciprocal inhibition facilitated by the myotatic reflex of the opposing muscle. Strength trained individuals have been shown to have lower co-activation between agonist and antagonist muscles compared to untrained controls due to spinal reflex adaptations that reduce the activation of the myotatic reflex in antagonist muscles during agonist contraction (Osternig, Hamill, Lander, & Robertson, 1986; Häkkinen et al., 1998). This decrease in antagonist activation has been reported to be greatest within the first week of strength training (Carolan & Cafarelli, 1992). Reduced muscle temperature (~2ºC) through cool environmental conditions or inadequate warming up of the exercising muscle can also increase co-contraction by reducing contraction velocity of the agonist and slowing the relaxation rate of the antagonist, effectively reducing overall agonist force output (Oksa, Rintamaki, Makinen, Hassi, & Rukso, 1995). It remains unclear if reduced antagonistic activation via reciprocal inhibition contributes to the increase in agonistic force output observed in the untrained limb following URT. Previous cross-education studies investigating agonist and antagonist activation reported no significant differences in antagonistic activation in the untrained limb following six weeks of ulnar deviation training and four weeks of elbow flexion training (Farthing et al., 2005; Magnus et al., 2010).

The trend and larger difference scores observed in the non-mirror group's trained and untrained triceps activation between the pre- and second week assessments suggests that any adaptations in antagonistic activation took place primarily within the first week of biceps training, corroborating Carolan and Cafarelli's (1992) report. Though, this is contradicted by the increase in antagonistic activation within both arms of the mirror group from pre- to second week assessment. The triceps sEMG mean ± SD values of the non-mirror group for the trained (0.37 ± 0.49 mV) and the untrained arms (0.59 ± 0.23 mV) are shown to be abnormally greater than other recorded values within this group or within the mirror group. It is possible that one or more of the participants within the non-mirror group co-contracted their biceps and triceps during the biceps MVIC, causing spikes in both biceps and triceps activation. Co-contraction during agonist movement is common in individuals who are non-resistance trained, detrained, or are unfamiliar with that motor task (Osternig et al., 1986; Häkkinen et al., 1998). Therefore, it is possible that because these testing procedures were still new to the participants and/or the participants had little to no resistance training experience, that co-contraction during the biceps MVIC may have occurred. It is also possible that the warm-up procedures involving three sets of ten repetitions with light to moderate resistance bands did not adequately warm up the participant's arms prior to MVIC testing, causing excessive antagonist activation. These possibilities may explain the abnormally high triceps activation mean ± SD recorded in the pre- and second week assessments for the non-mirror group.

Additional confounding factors that may have influenced triceps activation include the change in triceps activation was too minimal to be detected by the sEMG sensors and possible variability within the set of sensors themselves. It remains unclear if reduced triceps activation is a component of the strength gain observed in this study or if a difference existed between the mirror and non-mirror groups activation levels due to the inconsistencies observed. A greater sample size is needed to clarify this.

Biceps Electrical Efficiency

As was done in Moritani and DeVries' (1979) study, this study calculated electrical efficiency (EE) (kg/mV) of the biceps brachii across the five weekly assessments by dividing each weekly MVIC value (kg) by its corresponding biceps sEMG value (mV). EE can be used to determine the contributions of neurological adaptations involved in the strength increase following resistance training. The calculated biceps EE for each weekly assessment for the trained and untrained arms of the mirror and non-mirror training groups are listed in Table 4.14 and graphed in Figure 4.9.

Table 4.14
Displays biceps brachii force activation across five weekly assessments.

Biceps Force/EMG (kg/mV)				
Assessment	MT	MUT	NMT	NMUT
1	86.1	122.9	45.9	65.3
2	73.5	108.6	44.9	56.6
3	72.0	110.1	79.3	95.8
4	77.0	102.6	89.1	99.7
5	72.1	201.2	87.3	95.5

Note: MT = Mirror Group Trained Arm; MUT = Mirror Group Untrained Arm;
NMT = Non-mirror Group Trained Arm; NMUT = Non-mirror Untrained Arm;
EMG = electromyography; kg = kilograms; mV = millivolts

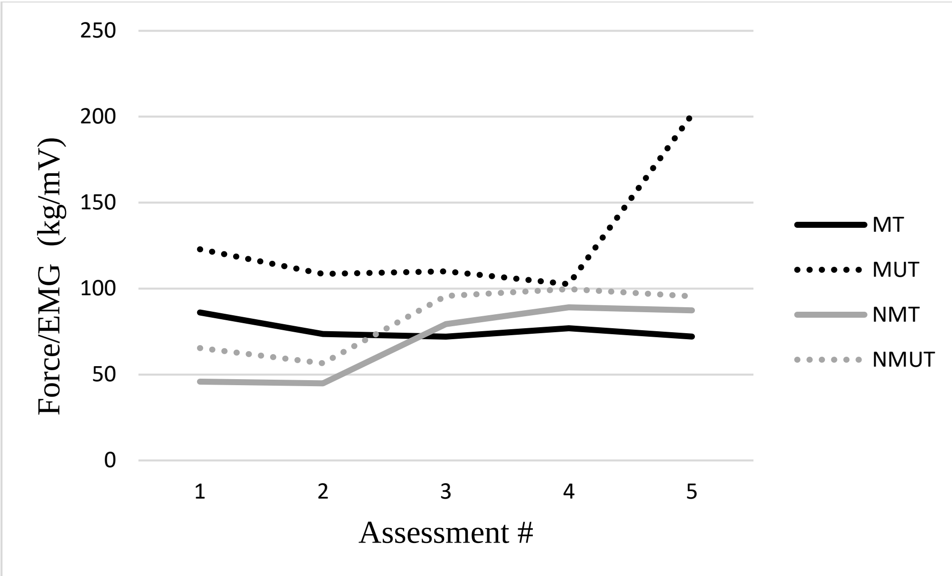

Figure 4.9. Bicep electrical efficiency across five weekly assessments.

There were substantial increases in EE within the untrained biceps of the mirror training group of 63.7% and within the trained and untrained biceps of the non-mirror training group by 90.2% and 46.2%. Because MVIC is a brief, maximal force test, the primary neurological adaptation underlying the improvement in strength was likely mediated by enhanced motor unit recruitment. During early strength training, the motor areas of the brain learn to increase descending drive (i.e. electrical signals) from the brain to the exercising muscle allowing for larger, higher threshold motor units to be recruited. As a result, these larger motor units, which generally innervate more high force/fast fatiguing Type II muscle fibers, summate with other motor units to produce greater force (Moritani, 1993). In the trained biceps of the mirror training group, there was a slight decrease of 16.3% in the EE from assessments one to five; this is likely due to variance in the sEMG data.

CHAPTER 5

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

URT has been shown to enhance strength in both the exercising and non-exercising, homologous limb (Farthing et al., 2005). Current evidence suggests that the mechanisms modulating this strength transfer from the training to non-training limbs occur in the motor cortices (Lee et al., 2010; Hendy & Kidgell, 2014; Hendy et al., 2015; Zult et al., 2016; Hendy & Lamon, 2017). When paired with mirror training, URT has been shown to greater increase dynamic maximal strength in the wrist flexors compared to URT without a mirror (Zult et al., 2016). It has been suggested that due to the overlapping neuroanatomy modulating both cross-education and the MNS (Farthing, 2009; Howatson et al., 2013), that enhanced sensory input from mirror training potentiates the motor pathway of the non-exercising limb (Lagerquist et al., 2006; Zult et al., 2016; Hendy & Lamon, 2017). Though mirror training has been shown to augment dynamic strength in the non-trained distal, wrist flexors (Zult et al., 2016), more research was needed to discern if this augmentation occurs in larger, proximal limb musculature.

Six healthy, non-strength trained men and women over 18 years of age participated in this study and were randomly assigned into either the mirror training or non-mirror training group. Baseline, independent t-tests at .05 level were conducted to compare pre-assessment values between the mirror group and non-mirror group trained and untrained arms and found there were no significant differences in bicep MVIC, biceps sEMG, or triceps EMG. The participant pool was determined to be homogenous and normally distributed. The mirror group underwent dynamic, unilateral training of the right biceps brachii while viewing a mirror image of that arm as it was exercising. The non-mirror group performed unilateral training of the biceps brachii without a mirror image. The duration of the unilateral training intervention was four weeks and each session consisted of only right arm, elbow flexion with a dumbbell for three sets of six to ten repetitions at approximately 65-75% 1RM. Changes in MVIC, biceps sEMG, and triceps sEMG of both the trained and untrained arms were measured across five weekly assessments. MVIC was measured using a Dillon FI-90 strain gauge. Biceps and triceps sEMG during biceps MVIC were measured using Delsys TRIGNO™ wireless sensors which were placed over the bellies of the biceps and triceps brachii on both arms.

Multiple One-way ANOVAs were conducted to determine if any significant differences existed between the mirror group and non-mirror groups trained and untrained limbs for MVIC, biceps sEMG and triceps sEMG from pre-to post-assessment. No significant differences were observed between the mirror group and non-mirror group in biceps MVIC, biceps activation or triceps activation. This lack of significance may be attributable to the small sample size used in this study and/or testing variability; because of this, the previously established hypotheses could not be evaluated. Instead, descriptive statistics were employed to visually compare the variables between the mirror group and non-mirror group including mean ± SD. Biceps MVIC was shown to increase in the trained and untrained biceps of the mirror group by 5.2 kg (22% of initial strength) and 4.3 kg (24% of initial strength) respectively. In the non-mirror group, biceps MVIC strength increased by 5.13 kg (19% of initial strength) and 4.5 kg (23% of initial strength) in the trained and untrained biceps respectively. Mirror group biceps activation in the trained arm was shown to steadily increase across the assessments by 45.6%, while the untrained arm showed an increasing trend from pre-assessment to week four by 43.5%. Lack of significant and noticeable changes in the triceps activation suggests that there was no training effect on antagonist activation. Biceps electrical efficiency (EE) representing the contributions of neurological adaptations in MVIC force output was calculated. EE decreased in the trained arm of the mirror training group by 16.3%. EE increased in the untrained arm of the mirror training group by 63.7% and in the trained and untrained arms of the non-mirror training group by 90.2% and 46.2%, respectively; indicating enhanced motor unit recruitment within the biceps. Despite limitations, the following meaningful insights were observed from the analyses in this study:

- Four weeks of dynamic biceps curl training at 65-75% 1RM for three sets of six to 10 repetitions, three times per week elicited observable strength gains in the trained and untrained biceps brachii within this sample;
- Isometric strength gain in both limbs between the mirror group and non-mirror group was not statistically or visually different during biceps MVIC testing;
- No significant differences were observed in biceps or triceps muscle activation in the trained and untrained arms between the mirror group and non-mirror group.
- EE noticeably increased in the untrained biceps of the mirror and non-mirror training groups, indicating neurological adaptations.

Conclusions

The resistance training paradigms employed in this study were effective in eliciting noticeable cross education between the trained, right and the untrained, left biceps brachii within the sample of this study. In this study, there were no statistically significant differences observed between the mirror trained and non-mirror trained groups in MVIC, biceps activation, triceps activation during the biceps MVIC. Due to the limitations within this study, further investigation is needed to elucidate if URT with a mirror enhances the strength transfer from the trained to untrained limb in the biceps brachii. This study, however, has laid additional groundwork for research investigating the effects of mirror and unilateral training on the cross-education of strength. With considerations of the results, suggestions and limitations of this study, later studies may be better equipped in determining the relationship and applications of combined mirror and unilateral training. The potential use of this study and further research within this field may benefit physical rehabilitation by quickening recovery and reducing muscle and strength loss in people living with conditions characterized by unilateral weakness including immobilized limb injuries, multiple sclerosis, and spinal cord injury (Magnus et al., 2010)

Recommendations

For the purpose of future research aiming to determine the effect of mirror training on cross-education in larger, proximal musculature, the following recommendations are suggested:

1. Use a larger sample size in order to conduct meaningful inferential statistical analysis;
2. Implement a match-group design to control for individual differences in training status, subcutaneous tissue distribution, baseline strength and baseline muscle activation;
3. Ensure full familiarization of motor task before beginning training intervention;
4. Ensure all participants are adequately hydrated prior to exercise training and testing through mandatory water consumption and urine analysis;
5. Employ maximal strength tests that match the contraction type used during training such as testing with a dynamic 1RM test following dynamic training;

REFERENCES

Aagard, P., Simonsen, E. B., Andersen, J. L., Magnusson, P. & Dyhre-Poulsen P. (2002). Neural adaptation to resistance training: Changes in evoked V-wave and H-reflex responses. *Journal of Applied Physiology*, 92(3), 2309-2318.

Adamson, M., Macquaide, N., Helgerud, J., Hoff, J., & Kemi, O. J. (2008). Unilateral arm strength training improves contralateral peak force and rate of force development. *European Journal of Applied Physiology*, 103(5), 553-559.

Alway. S., Stray-Gundersen, J., Grumbt, W. H. & Gonyea, W. J. (1990). Muscle cross sectional area and torque in resistance-trained participants. *European Journal of Applied Physiology*, 60, 86-90.

American College of Sports Medicine, In Riebe, D., In Ehrman, J. K., In Liguori, G., & In Magal, M. (2018). *ACSM's guidelines for exercise testing and prescription*.

Beyer, K. S., Fukuda, D. H., Boone, C. H., Wells, A. J., Townsend, J. R., Jajtner, A. R., & Stout, J. R. (2016). Short-term unilateral resistance training results in cross education of strength without changes in muscle size, activation, or endocrine response. *Journal of Strength and conditioning research*, 30(5), 1213-1223.

Brown, A. B., McCartney, N., & Sale, D. G. (1990). Positive adaptations to weight-lifting training in the elderly. *Journal of Applied Physiology (Bethesda, Md.: 1985)*, *69*(5), 1725-1733.

Carolan, B. & Cafarelli, E. (1992). Adaptations in co-activation after isometric resistance training. Journal of Applied Physiology, 73(3), 911-917.

Carroll, T. J., Herbert, R. D., Munn, J., Lee, M., & Gandevia, S. C. (2006). Contralateral effects of unilateral strength training: evidence and possible mechanisms. *Journal of Applied Physiology (Bethesda, Md.: 1985)*, 101(5), 1514-1522.

Cerir-Sastre, R., Beltran-Garrido, J., & Corbi, F. (2017). Contralateral Effects after Unilateral Strength Training: A Meta-Analysis Comparing Training Loads. *Journal of Sports Science and Medicine*, 16(2), 180-186.

Close, R. (1972). Dynamic properties of mammalian skeletal muscles. *Physiology Review*, 52, 129-197.

Coratella, G., Milanese, C., & Schena, F. (2015). Cross-education effect after unilateral eccentric-only isokinetic vs dynamic constant external resistance training. *Sport Sciences for Health*, 11(3), 329-335.

De la Barrera, E. J., & Milner, T. E. (1994). The effects of skinfold thickness on the selectivity of surface EMG. *Electroencephalography and Clinical Neurophysiology*, *93*(2), 91-99.

Ehsani, F., Nodehi-Moghadam, A., Ghandali, H., & Ahmadizade, Z. (2014). The comparison of cross-education effect in young and elderly females from unilateral training of the elbow flexors. *Medical Journal of The Islamic Republic of Iran*, *28*138.

Farthing, J. P., Chilibeck, P. D., & Binsted, G. (2005). Cross-education of arm muscular strength is unidirectional in right-handed individuals. *Medicine & Science in Sports & Exercise*, *37*(9), 1594-1600.

Farthing, J. P., Borowsky, R., Chilibeck, P. D., Binsted, G., & Sarty, G. E. (2007). Neuro-physiological adaptations associated with cross-education of strength. *Brain Topography*, *20*(2), 77–88.

Farthing, J. P. (2009). Cross-education of strength depends on limb dominance: implications for theory and application. *Exercise and Sport Sciences Reviews*, 37(4), 179-187.

Fimland, M. S., Helgerud, J., Solstad, G. M., Iversen, V. M., Leivseth, G., & Hoff, J. (2009). Neural adaptations underlying cross-education after unilateral strength training. *European Journal of Applied Physiology*, 107(6), 723-730.

Folland, J. P., & Williams, A.G. (2007). Morphological and neurological contributions to increased strength. *Journal of Sports Medicine*, 37(2), 145-168.

Fuentes, I. Cobos, A. R. & Segade, L. A. (1998). Muscle fibre types and their distribution in the biceps and triceps brachii of the rat and rabbit. *Journal of Anatomy*, 192(2), 203-210.

Häkkinen, K. & Komi, PV. (1983). Electromyographic changes during strength training and detraining. *Medicine and Science in Sports and Exercise*, 15(6), 455-460.

Häkkinen, K., Kallinen, M., Izquierido, M., Jokelainen, K., Lassila, H. Mälkia, E. Kraemer, W. J., Newton, R.U. & Alen, M. (1998). Changes in agonist-antagonist EMG, muscle CSA, and force during strength training in middle-aged and older people. *Journal of Applied Physiology*, 84(4), 1341-1349.

Hendy, A. M., & Kidgell, D. J. (2014). Anodal-tDCS applied during unilateral strength training increases strength and corticospinal excitability in the untrained homologous muscle. *Experimental Brain Research*, 232(10), 3243-3252.

Hendy, A. M., Teo, W., & Kidgell, D. J. (2015). Anodal transcranial direct current stimulation prolongs the cross-education of strength and corticomotor plasticity. *Medicine and Science in Sports and Exercise*, 47(9), 1788-1797.

Hendy, A. M., & Lamon, S. (2017). The cross-education phenomenon: Brain and beyond. *Frontiers in Physiology*, *8*297.

Hortobágyi, T., Scott, K., Lambert, J., Hamilton, G., & Tracy, J. (1999). Cross-education of muscle strength is greater with stimulated than voluntary contractions. *Motor Control*, 3(2), 205-219.

Howatson, G., Zult, T., Farthing, J. P., Zijdewind, I., & Hortobágyi, T. (2013). Mirror training to augment cross-education during resistance training: A hypothesis. *Frontiers in Human Neuroscience*, *7*396.

Ikai, M. and Fukunaga, T. (1970) A study on training effect on strength per cross-sectional area of muscle by means of ultrasonic measurements. *Internationale Zeitschrift für angewandte Physiologie einschließlich Arbeitsphysiologie*, 28, 173-180.

Kristeva, R., Cheyne, D., & Deecke, L. (1991). Neuromagnetic fields accompanying unilateral and bilateral voluntary movements: Topography and analysis of cortical sources. *Electroencephalography & Clinical Neurophysiology: Electromyography & Motor Control*, 81(4), 284-298.

Lagerquist, O., Zehr, E., & Docherty, D. (2006). Increased spinal reflex excitability is not associated with neural plasticity underlying the cross-education effect. *Journal of Applied Physiology*, 100(1), 83-90.

Lee, M., Hinder, M. R., Gandevia, S. C., and Carroll, T. J. (2010). The ipsilateral motor cortex contributes to cross-limb transfer of performance gains after ballistic motor practice. *Journal of Physiology*, 588, 201–212.

Lexell, J. & Taylor, CC (1989). Variability in muscle fibre area in whole human quadriceps muscle: How much and why? Clinical Physiology and Functional Imaging, 9(4), 333-343.

Magnus, C. A., Barss, T. S., Lanovaz, J. L., & Farthing, J. P. (2010). Effects of cross-education on the muscle after a period of unilateral limb immobilization using a shoulder sling and swathe. *Journal of Applied Physiology (Bethesda, Md.: 1985)*, *109*(6), 1887-1894.

Magyari, P., Lite, R., Kilpatrick, M., Schoffstall, J., & American College of Sports Medicine. (2018). *ACSM's resources for the exercise physiologist: A practical guide for the health fitness professional*.

Moritani T., & deVries H. (1979). Neural factors versus hypertrophy in the time course of muscle strength gain. *American Journal of Physical Medicine*, 58(3), 115-130. contributes to cross-limb transfer of performance gains after ballistic motor practice. *The Journal of Physiology*, *588*(Pt 1), 201-212.

Moritani, T. (1993). Neuromuscular adaptations during the acquisition of muscle strength, power, and motor tasks. *Journal of Biomechanics*, 26(1), 95-107.

Oksa, J., Rintamaki, H., Makenin, T., Hassi, J., & Rusko, H. (1995). Cooling-induced changes in muscular performance and EMG activity of agonist and antagonist muscles. *Aerospace Medical Association*, 66(1), 26-31.

Osternig, L. R., Hamill, J., Lander, J. E. & Robertson, R. (1986). Co-activation of sprinter and distance runner muscles in isokinetic exercise. *Medicine and Science in Sports and Exercise*, 18(4), 431-435.

Shima, N., Ishida, K., Katayama, K., Morotome, Y., Sato, Y. & Miyamura, M. (2002). Cross education of muscular strength during unilateral resistance training and detraining. European Journal of Applied Physiology, 86(4), 287-294.

Zhou, S. (2000). Chronic neural adaptations to unilateral exercise: Mechanisms of cross education. *Exercise and Sport Sciences Reviews*, 28(4), 177-184.

Zult, T., Goodall, S., Thomas, K., Solnik, S., Hortobágyi, T., & Howatson, G. (2016). Mirror training augments the cross-education of strength and affects inhibitory paths. *Medicine and Science in Sports and Exercise*, 48(6), 1001-1013.

APPENDIX A: SUBJECT INFORMED CONSENT

CONSENT TO PARTICIPATE IN RESEARCH

EFFECTS OF UNILATERAL RESISTANCE TRAINING OF THE BICEPS BRACHII WITH AND WITHOUT A MIRROR ON MAXIMAL ISOMETRIC VOLUNTARY CONTRACTION AND MUSCLE ACTIVATION

You are invited to participate in a master's thesis study conducted by the graduate student Brendon David Truax, and his faculty sponsor is Dr. Alfred Finch, from the Kinesiology, Recreational, and Sports Department at Indiana State University. Your participation in this study is entirely voluntary. Please read the information below and ask questions about anything you do not understand, before deciding whether to participate. You have been asked to participate in this study because you have met its inclusion criteria that includes: having done little to no resistance or strength training in the past three months, have answered no to all questions on the PAR-Q+, have a biceps skinfold thickness below 18 mm, and are able to commit to a four week training program.

- **PURPOSE OF THE STUDY**

The purpose of this study is to determine if mirror training will augment the cross-education effect between the trained and untrained arms following four weeks of unilateral resistance training of the right biceps by assessing changes in strength and muscle activation.

- **PROCEDURES**

SUBJECT SELECTION AND PREPARATION

If you volunteer to participate in this study, you will be asked to do the following things:

1. You will meet with the researcher in the Exercise Physiology Lab located in room A-127 in the Arena building on the campus of Indiana State University During this meeting, the researcher will inquire your resistance training background and any contraindications to exercise using a PAR-Q+ form. Following completion of the PAR-Q+, you will have a non-invasive skinfold test administered to determine the thickness of your skin over the upper arm where sensors will be placed to record muscle activation. Skin acts as insulation and excessive thickness may hinder the reading of electrical signals produced during muscle contractions (muscle activation). If you have not resistance trained in the past three months, have no contraindications to exercise, and your skinfold thickness is suitable for the study, you will then be asked to fill out this Informed Consent document approved by the Indiana State University Institutional Review Board. The investigator will go through this document with you, answer any questions, and make sure it is fully understood and signed.
2. Next, you will have your body mass, height, and age recorded. You will be assigned a random number, which will dissociate your name from the data. You will then be randomly allocated into a group will that resistance train using a mirror reflection or one without. Afterwards, you will schedule three training sessions with the researcher for the following week each minimally spaced by 48 hours. Your first training session will

involve baseline testing of your biceps strength and muscle activation, as well as triceps muscle activation during a maximal, isometric curl.

WEEKLY ASSESSMENT TESTING FOR MUSCLE STRENGTH AND ACTIVATION

3. Assessments for maximal, isometric strength of the biceps and muscle activation of the biceps and triceps will take place at the beginning of each week during the four-week training program. A post assessment will also be recorded at the beginning of the week following the program
4. Before assessment, you will be set-up for surface electromyography (sEMG) which will measure muscle activation. The researcher will affix non-invasive sensors onto the surface of the skin to record muscle activation while the biceps and triceps contract. Sensor sites include the bellies of the biceps and tricep on both arms, and just above the right knee cap. For the biceps and triceps sensor placement, the researcher will measure the halfway distance of your upper arm. Each site will be cleaned using an isopropyl alcoholic swab to remove any dead skin, oil, and other possible contaminants that may hinder electrical signals. If excessive body hair is present on any of the sites, you may be asked to shave only where the sensors will be placed. The researcher will provide you with a metal razor if necessary.
5. A hypo-allergenic adhesive will be attached to the conducting surface of each sensor so that it may affix onto the skin site. A baseline recording of the biceps and triceps muscle activity will be recorded afterwards.
6. Afterwards, you will undergo a warm-up of the biceps. For week one testing, you will warm-up by doing arm curls using moderate to light resistance bands for three sets of ten

repetitions. One minute of rest will be given between each warm-up set. For week two, week three, week four, and post assessments, the warm-up will consist of lifting dumbbells weighing approximately 50% of your maximal strength instead of resistance bands. Two minutes of rest will be given between the warm-up and maximal, isometric strength testing.

7. Your left or right arm will be randomly selected to test first. You will stand with the posterior upper arm, back and glutes against the wall where a load cell will be positioned below you. The load cell will measure the force of the biceps during the maximal, isometric curl. Attached to the load cell, is a handle that will adjust to the height of your arm flexed at 90°. You will grip the handle and maintain this flexed position for each maximal attempt. There will be three attempts per arm with one minute of rest between each attempt.
8. You will be informed of the testing motion and cued on when to maximally curl against the load cell. The load cell will not move, but instead record the force you are applying against it. After three attempts, the other arm will be measured. Maximal, isometric strength of the biceps and activation of the biceps and triceps will be recorded.
9. In addition to week one, assessments will also occur at the beginning of week two, week three, week four and the week following the four-week training program.

TRAINING SESSION OF THE RIGHT BICEPS BRACHII

10. Whether you are in the mirror training group or the non-mirror training group, you will schedule three training sessions per week. For each session, you will meet with the researcher at the Exercise Physiology Lab, before going down to the Strength and

Conditioning Lab for exercising. No resistance or strength training may be done outside this training program.

11. Only the right biceps will be training during each session. You will undergo a warm-up at 50% of your maximal biceps curl as determined from your previous assessment for three sets of 10 repetitions with one minute of rest between each set. Afterwards, you will perform three working sets of 6-10 repetitions with a weight equivalent to 65-75% your maximal biceps curl strength. When the 6-10 repetition range is exceeded by two repetitions for two consecutive sessions, lifting weight will be increased.
12. After the training session, you may cool down by walking at a normal pace around the Strength and Conditioning lab. Training sessions may take 20 to 30 minutes. Training sessions that include assessments may take last 45 minutes to one hour.

- **POTENTIAL RISKS AND DISCOMFORTS**

The potential risks offered in this study are considered minimal. You will be asked to perform multiple maximal, isometric biceps curls during assessments while having your muscle activation recorded with hypo-allergenic electrodes affixed to your arm. You will also undergo a moderate volume training program of the right biceps three times per week for four weeks.

- You may experience:
    - <u>Mild discomfort from exertion during training and testing</u>: if exertion becomes to uncomfortable, you may have your lifting weight reduced
    - <u>Increased blood pressure</u>: if you become dizzy or short of breath, you will be seated and shown breathing techniques to reduce blood pressure.

- Increased risk of musculoskeletal injuries: warm-ups and cool downs will be issued, and weight increases will be gradual to reduce the risk of musculoskeletal injuries.
- Increased risk of external injuries: the researcher will supervise you throughout your training session to minimalize any risk of dropped weights or pinch zones.

The researcher will be present to reduce any of these risks. If you ever feel any discomfort outside of the work performed by the biceps brachii during the curl, any dizziness, or shortness of breath, inform the investigator and he will stop the test and have you perform breathing exercises. If you are injured during the study, treatment will be available, including first aid, emergency treatment and follow-up care as needed. Payment for such treatment must be provided by you or your health insurance.

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

Participation in this study will expand the body of knowledge involving mirror training and its effects on cross-education. Individuals suffering from immobilized limbs from an injury or stroke may be better rehabilitated and have their recovery enhanced with this research. The participant in this study may also benefit from exercise involved in this study by understanding the strengthening effects that resistance training has on the body.

- **CONFIDENTIALITY**

The records of this study will be confidential. No information that may make it possible to identify you as a participant will be released. Research records will be kept in a locked file in the Exercise Physiology laboratory for three years. Only the researcher will have access to this file.

- **PARTICIPATION AND WITHDRAWAL**

Your decision to participate in this study is completely voluntary. Acceptance to participate in this study does not imply obligation. You are free to leave the study at any point during the study or within three months from the end of the study if you wish. Your relationship with Indiana State University, the Department of Kinesiology, Recreation and Sport, the School of Health and Human Services, or the researchers involved in this study will not be affected in any way, current or future. You do not need to have an excuse to withdraw from the study and there will be no penalty for withdrawal.

- **IDENTIFICATION OF INVESTIGATORS**

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

Principal Investigator

Brendon David Truax

Arena C54

Indiana State University

Terre Haute, IN 47809

btruax3@sycamores.indstate.edu

Phone: (812) 890-3762

Faculty Advisor

Dr. Alfred E. Finch

HHS 237

Indiana State University

Terre Haute, IN 47809

afinch.indstate.edu

Phone: (812) 237-3927

- **RIGHTS OF RESEARCH SUBJECTS**

If you have any questions about your rights as a research participant, you may contact the Indiana State University Institutional Review Board (IRB) by mail at Indiana State University, Office of Sponsored Programs, Terre Haute, IN 47809, by phone at (812) 237-3088, or e-mail the IRB at irb@indstate.edu. You will be given the opportunity to discuss any questions about your rights as a research participant 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 ISU. The IRB has reviewed and approved this study.

I understand the procedures described above. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form.

____

Printed Name of Participant

______________________________ ____________________

Signature of Participant Date

APPENDIX B: SUBJECT SCREENING QUESTIONNAIRE

2018 PAR-Q+

The Physical Activity Readiness Questionnaire for Everyone

The health benefits of regular physical activity are clear; more people should engage in physical activity every day of the week. Participating in physical activity is very safe for MOST people. This questionnaire will tell you whether it is necessary for you to seek further advice from your doctor OR a qualified exercise professional before becoming more physically active.

GENERAL HEALTH QUESTIONS

Please read the 7 questions below carefully and answer each one honestly: check YES or NO.	YES	NO
1) Has your doctor ever said that you have a heart condition ☐ OR high blood pressure ☐?	☐	☐
2) Do you feel pain in your chest at rest, during your daily activities of living, **OR** when you do physical activity?	☐	☐
3) Do you lose balance because of dizziness **OR** have you lost consciousness in the last 12 months? Please answer **NO** if your dizziness was associated with over-breathing (including during vigorous exercise).	☐	☐
4) Have you ever been diagnosed with another chronic medical condition (other than heart disease or high blood pressure)? **PLEASE LIST CONDITION(S) HERE:** ____________	☐	☐
5) Are you currently taking prescribed medications for a chronic medical condition? **PLEASE LIST CONDITION(S) AND MEDICATIONS HERE:** ____________	☐	☐
6) Do you currently have (or have had within the past 12 months) a bone, joint, or soft tissue (muscle, ligament, or tendon) problem that could be made worse by becoming more physically active? Please answer **NO** if you had a problem in the past, but it ***does not limit your current ability*** to be physically active. **PLEASE LIST CONDITION(S) HERE:** ____________	☐	☐
7) Has your doctor ever said that you should only do medically supervised physical activity?	☐	☐

If you answered NO to all of the questions above, you are cleared for physical activity.
Please sign the PARTICIPANT DECLARATION. You do not need to complete Pages 2 and 3.

- Start becoming much more physically active – start slowly and build up gradually.
- Follow International Physical Activity Guidelines for your age (www.who.int/dietphysicalactivity/en/).
- You may take part in a health and fitness appraisal.
- If you are over the age of 45 yr and NOT accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional before engaging in this intensity of exercise.
- If you have any further questions, contact a qualified exercise professional.

PARTICIPANT DECLARATION

If you are less than the legal age required for consent or require the assent of a care provider, your parent, guardian or care provider must also sign this form.

I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that the community/fitness centre may retain a copy of this form for records. In these instances, it will maintain the confidentiality of the same, complying with applicable law.

NAME ____________ DATE ____________

SIGNATURE ____________ WITNESS ____________

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER ____________

If you answered YES to one or more of the questions above, COMPLETE PAGES 2 AND 3.

Delay becoming more active if:

- You have a temporary illness such as a cold or fever; it is best to wait until you feel better.
- You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the ePARmed-X+ at **www.eparmedx.com** before becoming more physically active.
- Your health changes - answer the questions on Pages 2 and 3 of this document and/or talk to your doctor or a qualified exercise professional before continuing with any physical activity program.

2018 PAR-Q+

FOLLOW-UP QUESTIONS ABOUT YOUR MEDICAL CONDITION(S)

1. Do you have Arthritis, Osteoporosis, or Back Problems?

If the above condition(s) is/are present, answer questions 1a-1c — If **NO** ☐ go to question 2

1a. Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments) — **YES** ☐ **NO** ☐

1b. Do you have joint problems causing pain, a recent fracture or fracture caused by osteoporosis or cancer, displaced vertebra (e.g., spondylolisthesis), and/or spondylolysis/pars defect (a crack in the bony ring on the back of the spinal column)? — **YES** ☐ **NO** ☐

1c. Have you had steroid injections or taken steroid tablets regularly for more than 3 months? — **YES** ☐ **NO** ☐

2. Do you currently have Cancer of any kind?

If the above condition(s) is/are present, answer questions 2a-2b — If **NO** ☐ go to question 3

2a. Does your cancer diagnosis include any of the following types: lung/bronchogenic, multiple myeloma (cancer of plasma cells), head, and/or neck? — **YES** ☐ **NO** ☐

2b. Are you currently receiving cancer therapy (such as chemotheraphy or radiotherapy)? — **YES** ☐ **NO** ☐

3. Do you have a Heart or Cardiovascular Condition? *This includes Coronary Artery Disease, Heart Failure, Diagnosed Abnormality of Heart Rhythm*

If the above condition(s) is/are present, answer questions 3a-3d — If **NO** ☐ go to question 4

3a. Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments) — **YES** ☐ **NO** ☐

3b. Do you have an irregular heart beat that requires medical management? (e.g., atrial fibrillation, premature ventricular contraction) — **YES** ☐ **NO** ☐

3c. Do you have chronic heart failure? — **YES** ☐ **NO** ☐

3d. Do you have diagnosed coronary artery (cardiovascular) disease and have not participated in regular physical activity in the last 2 months? — **YES** ☐ **NO** ☐

4. Do you have High Blood Pressure?

If the above condition(s) is/are present, answer questions 4a-4b — If **NO** ☐ go to question 5

4a. Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments) — **YES** ☐ **NO** ☐

4b. Do you have a resting blood pressure equal to or greater than 160/90 mmHg with or without medication? (Answer **YES** if you do not know your resting blood pressure) — **YES** ☐ **NO** ☐

5. Do you have any Metabolic Conditions? *This includes Type 1 Diabetes, Type 2 Diabetes, Pre-Diabetes*

If the above condition(s) is/are present, answer questions 5a-5e — If **NO** ☐ go to question 6

5a. Do you often have difficulty controlling your blood sugar levels with foods, medications, or other physician-prescribed therapies? — **YES** ☐ **NO** ☐

5b. Do you often suffer from signs and symptoms of low blood sugar (hypoglycemia) following exercise and/or during activities of daily living? Signs of hypoglycemia may include shakiness, nervousness, unusual irritability, abnormal sweating, dizziness or light-headedness, mental confusion, difficulty speaking, weakness, or sleepiness. — **YES** ☐ **NO** ☐

5c. Do you have any signs or symptoms of diabetes complications such as heart or vascular disease and/or complications affecting your eyes, kidneys, **OR** the sensation in your toes and feet? — **YES** ☐ **NO** ☐

5d. Do you have other metabolic conditions (such as current pregnancy-related diabetes, chronic kidney disease, or liver problems)? — **YES** ☐ **NO** ☐

5e. Are you planning to engage in what for you is unusually high (or vigorous) intensity exercise in the near future? — **YES** ☐ **NO**

2018 PAR-Q+

4. **Do you have any Mental Health Problems or Learning Difficulties?** *This includes Alzheimer's, Dementia, Depression, Anxiety Disorder, Eating Disorder, Psychotic Disorder, Intellectual Disability, Down Syndrome*

If the above condition(s) is/are present, answer questions 6a-6b — If **NO** ☐ go to question 7

6a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
6b.	Do you have Down Syndrome **AND** back problems affecting nerves or muscles?	YES ☐ NO ☐

5. **Do you have a Respiratory Disease?** *This includes Chronic Obstructive Pulmonary Disease, Asthma, Pulmonary High Blood Pressure*

If the above condition(s) is/are present, answer questions 7a-7d — If **NO** ☐ go to question 8

7a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
7b.	Has your doctor ever said your blood oxygen level is low at rest or during exercise and/or that you require supplemental oxygen therapy?	YES ☐ NO ☐
7c.	If asthmatic, do you currently have symptoms of chest tightness, wheezing, laboured breathing, consistent cough (more than 2 days/week), or have you used your rescue medication more than twice in the last week?	YES ☐ NO ☐
7d.	Has your doctor ever said you have high blood pressure in the blood vessels of your lungs?	YES ☐ NO ☐

6. **Do you have a Spinal Cord Injury?** *This includes Tetraplegia and Paraplegia*

If the above condition(s) is/are present, answer questions 8a-8c — If **NO** ☐ go to question 9

8a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
8b.	Do you commonly exhibit low resting blood pressure significant enough to cause dizziness, light-headedness, and/or fainting?	YES ☐ NO ☐
8c.	Has your physician indicated that you exhibit sudden bouts of high blood pressure (known as Autonomic Dysreflexia)?	YES ☐ NO ☐

7. **Have you had a Stroke?** *This includes Transient Ischemic Attack (TIA) or Cerebrovascular Event*

If the above condition(s) is/are present, answer questions 9a-9c — If **NO** ☐ go to question 10

9a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
9b.	Do you have any impairment in walking or mobility?	YES ☐ NO ☐
9c.	Have you experienced a stroke or impairment in nerves or muscles in the past 6 months?	YES ☐ NO ☐

8. **Do you have any other medical condition not listed above or do you have two or more medical conditions?**

If you have other medical conditions, answer questions 10a-10c — If **NO** ☐ read the Page 4 recommendations

10a.	Have you experienced a blackout, fainted, or lost consciousness as a result of a head injury within the last 12 months **OR** have you had a diagnosed concussion within the last 12 months?	YES ☐ NO ☐
10b.	Do you have a medical condition that is not listed (such as epilepsy, neurological conditions, kidney problems)?	YES ☐ NO ☐
10c.	Do you currently live with two or more medical conditions?	YES ☐ NO ☐

PLEASE LIST YOUR MEDICAL CONDITION(S) AND ANY RELATED MEDICATIONS HERE: ______________________