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The Effects of Limb Dominance on Cross-Education in a Four Week Resistance Training Program

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Eastern Illinois University
This research is a product of the graduate program in Kinesiology and Sports Studies at Eastern Illinois University. Find out more about the program.

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THE EFFECTS OF LIMB DOMINANCE ON CROSS-EDUCATION IN A FOUR-WEEK RESISTANCE TRAINING PROGRAM

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ABSTRACT

Cross-education is known as the phenomenon of strength transfer from the trained side of the body to the untrained side of the body by unilateral resistance training. Research has shown that limb dominance has an effect on the amount of strength that is gained on the untrained side. Studies have found that there is a greater cross over effect in strength from the dominant side of the body to the non-dominant side of the body than vice versa. The present study examined this effect by taking 12 college females and splitting them into three groups: dominant training, non-dominant training, and control group. The hypothesis was that the dominant training group would have a greater increase in peak grip strength in the untrained, non-dominant arm than the arm of the untrained, dominant group of the non-dominant training group. The dominant training group only trained their dominant arm with a hand dynamometer, while the non-dominant training group only trained their non-dominant arm with the same hand dynamometer. Both groups went through a 4-week, 13 sessions of grip strength training on the handy dynamometer. They performed 3 sets of 6 maximal squeezes with a 2-minute rest in between sets. Pre-and post-tests were taken of maximum grip strength squeeze. There was no significance difference in peak grip strength between the untrained arms of both groups. Also, there was no significance difference in peak grip strength between the trained arms of both groups however there was a trend in data in the untrained arm of the dominant training group showing a slight increase in strength from baseline measurements. These findings do not directly support the hypothesis however, if the number of subjects’ value was greater, the trend in data in the dominant training group might have found significant effect from limb dominance.
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CHAPTER I
Introduction

Statement of Problem

According to the Center for Disease Control and Prevention, in 2014 about 800,000 Americans suffer from a stroke each year. Of these victims, on average nine out of ten suffered from some type of paralysis with two out of three being over the age of 65. The CDC also estimated in 2012 that roughly 1.9 million Americans will live with a missing limb due to trauma, infection, disease, diabetes, heart disease, or cancer. Most of these patients will go through some sort of physical therapy or rehabilitation to regain some, if not all, of their daily function. Therefore, there is a need to conduct research studies that help better understand the mechanisms underlying effective rehabilitation for these patients so they can recover to their fullest capacity so they can live a long, healthy life.

For over a century, researchers have investigated the phenomena of cross-education which refers to unilateral resistance training (training only one side of the body) and gaining strength in the contralateral homologous limb (Pearce et al., 2013). Studies have shown an average of 7.6% increase in strength in the opposite untrained arm that corresponding to approximately 52% of the strength gained in the trained limb (Carrol et al., 2006). Many studies have examined the underlying causes of cross-education. A review article from 2007 by Lee and Carroll analyzed the two-main hypotheses for this increase in strength of the opposite untrained limb. Hypothesis I states that resistance training reorganizes the peripheral nervous system, changing the motor pathways that lead to the contralateral homologous muscle. Changes in the PNS have been show through electromyography (EMG) readings in studies that compared pre- and post EMG measurement from cross-education training. A study by Dragert and Zeher (2012)
measured EMG activity in the flexor muscles after 6-weeks of unilateral training in stroke patients. Their results showed a significant increase in neural activation in the flexor muscles of the untrained ankle. Hypothesis II is related to changes in motor learning within the central nervous system (Lee & Carroll, 2007). Research studies have shown that with resistance training different areas of the brain become activated in the hemisphere of the untrained limb. For example, if the left arm is the untrained arm, it is the right hemisphere that will experience and increase in cerebral-cortical regions (Farthing et al., 2011; Furlan et al., 2016; Hatsopoulos et al., 2011). This hypothesis has been supported by results from functional magnetic resonance imaging (fMRI). One study examined areas of the brain using a fMRI after a five-week training program of the right hand. The results indicated that more areas in the motor cortex were activated in the hemisphere of the untrained hand as well as areas in the hemisphere of the trained hand (Farthing et al., 2011).

Despite the underlying mechanisms, research has shown that different variables can affect cross-education. One of those variables is limb dominance (Farthing, 2009). In studies where the dominant limb was trained, a significantly greater cross-education effect was found to the non-dominant limb compared what was found in the dominant limb when the non-dominant was trained (Munn et al., 2003). Farthing, Chillibeck, and Binsted (2005) tested only right-handed individuals which were split up into a right-hand training group, left hand training group, and a control group. Participants did unilateral isometric ulnar deviation training for six-week with the assigned hand. The right-hand training group saw an average of 39.2 percent increase in strength in their left. However, the left-hand training group only had an average increase of 9.3 percent in their right, untrained hand. These findings support the theory that there is a greater cross-education transfer from dominant to non-dominant limb than from non-dominant to
dominant. In a similar study, Magnus, Barss, Lanovas, and Farthing (2010) also found greater cross education transfer when training the dominant hand.

There are a couple reasons why it is important for further examination on the effects of limb dominance in cross-education. First, several studies that have investigated cross-education in the upper limbs did not controlled for the limb dominance variable (Farthing, 2009). Farthing (2009) identified eleven cross-education studies that targeted the upper limbs. Out of these eleven studies that were conducted between 1987 and 2008, seven of the studies did not report which limb was the dominant limb among the participants. Without controlling for limb dominance, it is difficult to assess the entirety of the cross-over effect of strength from one side of the body to the other.

Second, understanding the implications limb dominance has on cross-education will carry over into the physical rehabilitation settings. According to Ootes, Lamebrs, and Rink (2012) who conducted an epidemiology report of upper extremity injuries that were presented in emergency departments in the United States, an estimated 3,468,996 upper extremity injuries were reported in 2009. The most common injury was a fracture and the most common places of these accidents were in one’s own home and areas of recreation and sports. Understanding the limb dominance factor, may speed recovery after an immobilization injury. A person cannot always control which arm they will injure, however, by better understanding of limb dominance, therapists may be able to better determine prognosis and recovery time of an injury.

Purpose

The purpose of this study was to analyze the effects of limb dominance on cross-education in twelve college age females.

Hypothesis
It was hypothesized that there would be a greater cross-education effect in the group that only trained their dominant arm as opposed to a lesser effect in the group that only trained their non-dominant arm. It was also hypothesized that both groups would experience an increase in strength in the non-trained arm.

**Limitations**

Potential limitations of this study are having a small sample size (N=12) and recruiting subjects from a single university.

**Delimitations**

This study included only female college age students, therefore, the conclusions derived from this study are not applicable to males of any age or females of other ages. Participants were required to not partake in any upper body resistance training outside of what was required of them for this study. The purpose of this requirement was to control for outside variables that could affect the untrained arm in each group of participants.

**Assumptions**

There was an assumption that all the participants were highly motivated, and gave their maximum effort during the grip strength training protocols and during their baseline measurements.

**Definition of Terms**

*Cross-Education:* The phenomenon whereby training one side of the body increases the strength of muscles on the other side of the body (Carroll, Herbert, Munn, Lee, & Gandevia, 2006).
Neural Plasticity: The brain's capacity to adapt and change (Bezzola, Merillat, & Jancke, 2012).

Mirror Neuron System (MNS): A neuroanatomical basis located in the lateral wall of the right hemisphere of the brain, that connects sensory neurons responding to visual properties of an observed action to motor neurons. The MNS matches the observed action with an internal motor representation of that action (Zult, Howatson, Kadar, Farthing, & Hortobagyi, 2014).

Phantom Limb Pain: Projected pains described by the amputee as being perceived in the area of the lost limb (Barbin, Seetha, Casillas, Paysant, & Perennou, 2016).
CHAPTER II

Literature Review

For over a century, researchers have investigated the phenomenon known as cross-education. The first study, although not very scientific, was conducted in 1894 by a researcher who squeezed a bulb connected to a manometer with only one hand over a series of 13 days. It was reported that the researcher’s untrained forearm increased in strength by 43% (Carroll, et al., 2006). The increase in strength in the contralateral homologous untrained limb is known as cross-education, or in some texts, cross-activation (Carroll et al., 2006). The purpose of this literature review is to: A.) analyze the different hypothesizes of the underlying mechanisms behind cross-education; B.) examine the different factors that can affect the magnitude of the cross-education effect; C.) to explore the different health fields that could potentially utilize cross-education theory; D.) examine the affect limb dominance has on cross-education.

Underlying Mechanisms

Over the years, research has produced two major hypotheses pertaining to the neurological mechanisms that cause the cross-education effect in unilateral resistance training. Hypothesis I states that the peripheral nervous system (PNS) undergoes neurological changes during unilateral resistance training, which then transfers the strength by altering cortical motor pathways to the untrained arm via the PNS (Lee & Carroll, 2007). Hypothesis II states that the neurological changes occur within the central nervous system (CNS) and the brain undergoes specific neurological changes (Carrol, Herbert, Munn, Lee, & Gandevia, 2006; Ruddy, Leemans, Woolley, Wenderoth, & Carson, 2017). There are two theories within the CNS hypothesis as to what the specific changes are. The next two sections will explain in detail these underlying mechanisms.
Hypothesis I: peripheral nervous system mechanisms.

Researchers and scientists have tried to analyze what exactly causes the increase in strength in an untrained limb. It is understood that to increase one’s strength, a force must be applied to the muscle fibers, creating microtrauma, and then is repaired, making the muscle stronger (Correa, Cunha, Marques, Oliveira, & Pinto, 2016; Pearson & Hussain, 2015). However, if an untrained arm becomes stronger without any force applied, this insinuates that there is something else at work. There are two different theories that try to explain this phenomenon. Hypothesis I explains cross-education derives from alterations in the motor pathways from performance changes in the peripheral nervous to system to the homologous contralateral muscle (Lee & Carroll, 2007). For example, if a person trains their right bicep only, this also activates PNS motor pathways to the left bicep thus increasing the strength of the untrained left bicep. Dragert & Zehr (2012) indicated evidence of this transfer using an EMG machine during pre-and post-tests after a six-week training program in nineteen stroke patients. Based on the EMG results, their findings indicated an increase in muscle activation in the untrained leg by thirty-one percent from baseline measurements. Their findings also indicated a decrease in reciprocal inhibition through EMG readings in the tibialis anterior muscle of the more affected, untrained leg. Researchers speculated that repeated bouts of high intensity dorsiflexion in one leg could lead to an increased contralateral depression of sensitivity of the Ia inhibitory interneurons and larger increase of alpha-motoneuron excitability (Dragert & Zehr 2012, Hundza & Zehr, 2009). Interneurons such as Ia are responsible for yielding reciprocal inhibition between the motor neuron and the antagonist muscle. They control the antagonist muscle to relax while the agonist muscle is contracting (Binder, Hirokawa, & Windhost, 2009) so their inhibition through cross education would increase muscle activation of the contralateral,
untrained limb. Cunningham et al. (2002) conducted research to support the peripheral neuromuscular transfer of strength in the upper limbs. Their study found twenty-four percent less interrupted movement paths and increases in peak velocity in the untrained upper arm. With less interrupted movement pathways, the movement of picking up the cup and setting it down was more precise without excess and unnecessary movement. This study was unique in that while the participant lifted the cup with training arm during the pre-and post-tests, the participant was instructed to lift the untrained arm simultaneously to mirror the action of the untrained arm. This added an extra component during training which could help augment the cross-education effect to the untrained limb. That extra component was having the arm that was not picking up the cup, mimic the action of picking up the cup during the movement without the load of the cup. Tabak and Plummer-D’Amoto (2010) used the phrase “cross transfer effect in bilateral movement” to label this phenomenon from Cunningham et al. (2002). Perhaps this extra movement of the opposite limb increases peripheral nervous system activity, which would increase activation of motor units in the limb that is not being trained.

**Hypothesis II- cortical mechanisms.**

Hypothesis II theorizes that the cross-education effect stems from the central nervous system, more specifically, in the motor cortex of the brain (Lee and Carroll, 2007). Studies have tried to examine this phenomenon by using a fMRI machine to analyze brain activating during cross-education training (Palmer, H.S. et al., 2013; Pearce et al., 2012). One theory is that there may be an increase in myelination from cross-education training. It is known that electrical activity travels faster down a myelinated axon and the more layers that of myelin sheaths, the faster the conduction rate is (Yoon et al., 2016). Palmer, H. S. et al. (2013) observed changes in the grey matter and white matter in the untrained hemisphere of participants after a 16 sessions
of plantarflexion dominant, single leg training in healthy, active individuals. Therefore, since there was an increase in white matter, it can be hypothesized that cross-education may increase the myelination of white matter with in the brain. Other research has looked at cortical mechanisms and have found that perhaps there is a transfer between the trained hemisphere, through the corpus callosum, to the untrained hemisphere of axonal excitability (Carroll et al., 2006). This concept can be applied to the Interhemispheric Competition Model Theory for stroke victims which states, “that an increased excitability and neural activation within motor areas of the contralesional hemisphere may generate a pronounced inhibitory drive towards motor areas of the ipsilesional hemisphere…” (Ludemann-Podubecka, Bosl, & Nowak, 2015). Therefore, when a stroke occurs in one of the hemispheres of the brain, the limb that is connected to that hemisphere (which would be on the opposite side of that hemisphere) is maladaptively affected. To combat the lesion that is formed from a stroke, studies have shown that using TMS (transcranial magnetic stimulation) on the affected, lesioned side of the brain can increase this neural activity in the brain. Many studies have examined TMS activity on the premotor cortex (M1) in stroke patients and have found that there is some positive feedback in regaining motor function in the affected hand after a stroke (Guo et al., 2016; Ludemann-Podubecka et al., 2015; Kakuda, et al., 2012). For example, Ludemann-Podubeck et al. (2016) placed the coil of the low-frequency (1Hz) rTMS over the M1 in the hemisphere that was affected by the stroke. Results from their study indicated an increase in motor function in the hand that corresponds to the hemisphere that was stimulated by rTMS.

**Influencing Factors**
Researchers have investigated different factors that may have an influence on cross-education and could possibly increase the cross-education effect when training. This review will examine the two factors best supported by research: limb dominance and eccentric training.

**Limb dominance.**

Early studies of cross-education have not always controlled for handedness or limb dominance but more recent literature has shown limb dominance plays a role in cross-education. While some studies did not examine the affect that handedness had on the strength transfer effect (Fimland et al., 2009; Nelson et al., 2012) a few others did. One of the first studies to analyze the impact of handedness and limb dominance was conducted by Farthing, Chilibeck, and Binsted (2005). In their experiment, a total of thirty-nine females who were all right-handed, underwent a six-week training protocol of unilateral isometric ulnar deviation 4 times a week. Subjects were split into three groups; a control group who did not complete any physical training, a group who only trained their left arm and a group that only trained their right arm. They found a statistical significance in the right-hand training group. The right-hand training group, which trained their dominant right hand, had a significant increase in strength, 39.2 percent ±7.8 percent in the left, untrained, nondominant hand. Whereas the left-hand training group did not show significant strength improvements, 9.3 percent ±4.9 percent in their right, untrained, dominant hand. Therefore, these results indicate that there is a much greater cross-education effect from dominant limb to nondominant limb than vice versa. Farthing (2009) explains the asymmetrical transfer that takes place during unilateral practice, exercise, or skill learning by theorizing that the skill is transferred in only one direction. This means that learning a skill is easier for one side of the body, typically on the dominant side. The transfer that Farthing (2009) is referring to is the neuronal transfer from one side to the corresponding hemisphere in the brain. For example, if
someone is right handed, it easier and faster to learn a new movement task with the right hand/arm because the skill is transferred faster to the left hemisphere. Whereas that same person may struggle more to learn a skill with their left (nondominant) hand/arm because the skill transfer is slower from the left side of the body to the right hemisphere of the brain. It is suggested by Wang and Sainburg (2006) unidirectional skill transfer occurs due to the proficiency of a limb (dominant limb). Their findings support that initial movement direction accuracy transferred only from nondominant to dominant arm and the final position accuracy transferred from dominant to nondominant arm. Therefore, both hemispheres in the brain that correspond to nondominant and dominant limbs play an important role in task performance.

Not only does limb dominance play a role in the transfer of cross-education, but the type of training as been shown to have an effect as well. Limb dominance has not always been shown to have an impact on this transfer of strength. Cross-education can be bidirectional when there isn’t a learning curve to an exercise, and when the exercise is not done slow and controlled (Coombs, Frazer, Harvath, Pearce, Howatosn, & Kigell, 2016).

**Eccentric training.**

Eccentric training has been shown to have a greater impact on strength gains in bilateral training when compared to concentric training. (Mjolsnes, Arnason, Osthagen, Raastad, & Bahr 2004; Roig, O’Brien, Kirk, Murrany, McKinnon, Shadgan, & Wendy, 2008). This same concept has been applied to unilateral resistance for cross-education effects. Hortobagyi, Lambert, and Hill (1997) found a seventy-seven percent increase in eccentric strength compared to a thirty percent increase in concentric strength after thirty-six sessions of training with specific exercises. The study above utilized twenty-one sedentary male volunteers and put seven in the eccentric training only group and eight in the concentric training only group. The rest were placed in the
control group and did not perform any exercise. After twelve weeks of thirty-six sessions of four to six sets at eight to twelve repetitions on the isokinetic machine, subjects’ peak concentric and eccentric maximal isometric force were retested. Eccentric training can perform using an isokinetic machine and dynamic constant external resistance training (i.e. a barbell or isotonic machines) (Coratella, Milanese, & Schena, 2015). It has been shown both eccentric-only isokinetic training and eccentric dynamic constant external resistance training using a leg extension machine can elicit the same amount of cross-education effect by increasing 1RM knee extension by 4.3 percent and eccentric peak torque by 21.1 percent in the opposite, untrained limb (Coratella et al., 2015). In addition to different modes of eccentric training, the speed at which eccentric training is done at has been shown to produce a greater effect of cross-education (Farthing & Chilibeck, 2003; Lepley & Palmieri-Smith, 2014; Zhou, 2000). Farthing and Chilibeck (2003) research indicated that there was a greater increase in torque velocity of the untrained arm in the fast training group that trained one limb at a velocity of 180 degrees per second as opposed to the slow training group that trained one limb at a velocity of thirty degrees per second. Farthing and Chilibeck (2003) and other studies have suggested that the faster the speed of the eccentric training, the greater the neural transfer is to the untrained arm. The data from the above research suggests that when using cross-education training in the rehabilitation clinics, using higher velocity and eccentric contraction exercises will benefit the patient with better increase in strength in the more unmovable limb.

Practical Application

Application of cross-education is benefiting the sports medicine and rehabilitation fields. Some common applications that utilize cross-education are mirror therapy and providing relief
from phantom limb pain. The following sections will take a closer examination as to how cross-
education plays a role in these applications.

**Mirror therapy.**

Mirror Therapy works by having the patient place their injured limb behind a mirror. The
mirror is faced so the patient can look into the mirror so that it looks as if they are looking at
their injured limb. However, it is a reflection of the non-injured limb. The patient will proceed by
doing an exercise with the non-injured limb, while looking into the mirror of the reflection of
this movement (Tilak et al., 2016; Hunter, Katz, & Davis, 2003; Ji & Kim, 2015). In recent
research, it has been suggested that the same areas of the brain (sensorimotor cortex and primary
motor cortex) that are activated in the untrained hemisphere during cross-education training are
also activated during mirror therapy (MT) (Howatson, Zult, Farthing, Zijdewind, & Hortobagyi,
2013; Zult, Goodall, Thomas, Solnik, Hortobagyi, & Howatson, 2016). Palmer, Haberg,
Fimland, Solstad, Iversen, Hoff, Helgerud, and Eikenes (2013) found through the use of fMRI, a
visual increase in white and grey matter in the motor cortex after sixteen sessions of thirty-six
voluntary repetitions of plantar flexion in their dominant leg. Michielsen, Sellas, Van Der Geest,
Eckhardt, Yavuzer, Stam, Smits, Ribbers, and Bussmann (2011) found similar areas in the motor
cortex that were increased in activation in the hemisphere corresponding with the untrained side
that were also increased in Palmer et al. (2013). Michielsen et al. (2011) utilized stroke patients
who were instructed to use Brunnstrom phases of motor recovery in the hand as well as
functional exercises such as moving objects.

The sensorimotor cortex and primary motor cortex of the brain have been found to
contain mirror neurons (Hatsopoulos & Suminski, 2011). The first study to examine this area of
the brain and to locate these mirror neurons used monkeys as subjects (Rizzolatti, Fadiga,
Gallese, & Foggasi, 1995). Mirror neuron activity was monitored and analyzed with a head implant and a voltage discriminator. Mirror neurons were shown to activate every time the monkey observed the experimenter move a cup in front of them. However, not all the observed movement activated the mirror neurons. Roughly 60% of the mirror neuron activation occurred when the monkey watched the cup being grasped. Since the study conducted by Rizzolatti et al. (1995) more research has carried out similar findings of the mirror-neuron system (MNS) in humans using various methods (Decety, Grezes, Costes, Perani, Jeannerod, Procyk, Grassi, & Fazio, 1997; Buccino, Binkofski, Fink, Gadiga, Fogassi, Gallese, Seitz, Zilles, Rizzolatti, & Freund, 2001; Gazzola, Aziz-Zadeh, & Keysers, 2006). Gazzola, Rizzolatti, Wicker, and Keysers (2007) conducted an experiment that examined the same areas of the brain in humans. However, their study examined if the observation of a robotic arm had a different impact on the MNS in the brain as opposed to observing a human arm. Subjects observed different actions, simple and complex, by the robotic limb and the human limb. The findings through fMRI support MNS was activated in the subjects when they observed actions performed by either human or robotic arms.

Mirror Therapy has been used to treat patients who have experienced phantom limb pain, phantom limb sensation, and stroke patients (Ramachandran & Altschuler, 2009; Ramachandran & Rogers-Ramachandran, 1992). Phantom limb pain can be described as pain, burning, gnawing, stabbing, pressure, or aching in the area of the missing limb; whereas phantom limb sensation can be described as feeling the sensation that the amputated limb is still there (McCormick, Chang-Chien, Marshall, Huang, & Harden, 2014). Mirror therapy is a simple yet affective way to help alleviate pain, increase strength, and regain partial motor function by adapting neuroplasticity in the brain (Zult, Howatson, Kadar, Farthing, & Hortobagyi, 2014; Timms & Carus, 2015). Although several studies have examined the role of the mirror-neuron system in
mirror therapy the exact cortical mechanisms underlying mirror therapy are still not completely understood. Zult et al. (2014) explains that the mirror-neuron system (MNS) is located within the occipital, temporal, and parietal visual areas, and in two frontoparietal motor areas in the brain. The MNS operates by connecting the sensory neurons that are responsible for responding to a visual property of an observed action to the motor neurons (Ramachandran & Altschuler, 2009; Zult et. al., 2014). In other words, the MNS is used for imitating a movement. Over the past decade, research has tried to connect mirror therapy to cross-education training, proposing that mirror therapy can augment the cross-education effect.

**Stroke patients.** Hemiparesis is a common physical, cognitive, and neurological symptom that many stroke survivors spend the rest of their lives trying to overcome (National Center for Chronic Disease Prevention and Health Promotion, Division for Heart Disease and Stroke Prevention, 2017). Medical practitioners and professionals in the physical rehabilitation field have turned to physical methods to help stroke patients regain movement and increase strength in side of the body that suffers from hemiparesis. Research has already shown that strength can be increased through resistance training in stroke survivors who have not been paralyzed (Zehr, 2011; Taylor, Dodd, & Damiano, 2005). This finding opened the possibility that cross-education training could perhaps increase strength or enhance movement in the affected side of a hemiparesis stroke patient. Dragert and Zher (2012) studied this possibility in nineteen subjects who had had a stroke after 6 months and had one-sided, dorsiflexor weakness. Subjects underwent six weeks (eighteen sessions) of isometric training of the non-affected leg. The results showed an increase in maximal isometric voluntary contraction in the untrained (most affected leg) by 31.37% from baseline measurement. EMG activity increased as well in the non-trained leg after the six-week training period. These results support another study that also saw an
increase in strength (seventy-three percent) in the more affected limb by hemiparesis after a stroke (Urbin, Harris-Love, Carter, & Lang, 2015). The middle cerebral artery, largest cerebral artery in the brain, is the artery where most strokes occur (Slater, 2017). The outer surfaces of the motor cortex, close to the middle cerebral artery, have shown neurological connection to the upper limbs of the body (Petersen, Butler, Taylor, & Gandevia, 2010). Therefore, it is speculated that due to the location of the middle cerebral artery, strokes more often elicit upper limb paresis or full paralysis. Several studies have examined cross-education training in stroke patients and in subjects training the upper limbs. For example, cross-education training in the upper limb has increased strength by 28.7 percent in the untrained, fractured arm of older women with distal radial fractures, (Magnus et al., 2013). For this study, researchers utilized thirty-nine older women (average age 63.0±10.0 years) who were recovering from a distal radius fracture. Eighteen of the women were put into a control group that underwent standard clinical rehabilitation and the other twenty-one women in the experimental group did resistance training in addition to the standard clinical rehabilitation. The resistance training program progressed from two sets to five sets of eight maximal voluntary effort handgrip contractions. Research has started to take a direct approach by using transcranial magnetic stimulation (TMS) over the motor cortex in the brain to elicit a cross-education effect. This could be due to the strong effect TMS has shown in an increase strength after just a few sessions. Broersma, Koops, Vroomen, Hoeven, Aleman, Leenders, and Beilen (2015) conducted a study that improved hand grip strength in patients with functional neurological flaccid paresis of one hand. Patients in the experimental group (N=12) underwent rTMS treatment of fifteen Hz rTMS over the contralateral motor cortex for thirty minutes once daily over two periods of five consecutive days. The control group (N=9) was given a placebo. The group who received rTMS treatment had a median
improvement of grip strength by twenty-five percent with a range of -1 to 663 percent, whereas the control group had a median grip strength improvement of ten percent with a range of -77 to 81 percent. Ludemann-Podubecka, Bosl, and Nowak (2016) and Kakuda et al. (2012) found that TMS in the hemisphere corresponding to the affected paretic hand by 7.2 percent and in the later study, motor function improved by a mean of four points on the FMA test. FMA is a performance-based quantitative measure for the assessment of various impairments in post-stroke patients (Broersma et al., 2015).

Mirror therapy has been researched in stroke patients to aid in the recovery of strength and functionality. Ji and Kim (2015) support the use of the mirror therapy in addition to conventional rehabilitation that used neurodevelopment facilitation techniques. Their study divided thirty-one post-stroke patients into a control group that underwent a sham therapy and conventional therapy and an experimental group that underwent mirror therapy and conventional therapy. Both therapy procedures lasted for forty-five minutes for five days per week for four weeks. The results indicated a greater increase in gait function in the experimental group that used mirror therapy. The experimental group had a 10.6 (confidence interval of 17.5-3.7) percent increase in single leg stance, 8 (CI of 14.0-2.7) percent increase in step length, and a 17 (CI of 28.3-6.2) percent increase in single leg stance, 8 (CI of 14.0-2.7) percent increase in step length, and a 17 (CI of 28.3-6.2) percent increase in single leg stance, 8 (CI of 14.0-2.7) percent increase in step length, and a 17 (CI of 28.3-6.2) percent increase in single leg stance, 8 (CI of 14.0-2.7) percent increase in step length, and a 17 (CI of 28.3-6.2) percent Mirror therapy has been used in patients with hemiparesis that has affected the upper limbs, which still had an effect six months post MT (Samualkamaleshkumar, Reethajanetsureka, Pauljebaraj, Benshamir, Padankatti, & David, 2014).

**Phantom limb pain.** As of 2005, there was an estimated 1.6 million people living in the United States without a limb and by 2050, that number is projected to double to 3.6 million (Varma, Stineman, & Dillingham, 2014). One side effect of an amputation is phantom limb pain. It has been described as a burning, throbbing, or tingling sensation and occurs in 60-80% of
amputees (Tilak et al., 2015). Flor (2002) indicates that not all amputees experience phantom limb pain, however, it is suggested that if a person already has pain in the area near where the amputation is, they are more likely to experience phantom limb pain. It has been suggested that certain areas of the brain, principally the primary somatosensory and motor cortex, are reorganized in the areas that control the amputated side of the body and that these areas are invaded by the opposite side of the brain which control the extremities that are not amputated (Subedi & Grossbert, 2011). The support for this idea of different areas of the brain invading and controlling other areas are supported through research of the Homunculus Model of the brain which can be seen in Figure 1. (Penfield & Rasmussen, 1950; Parpia, 2011).

![Figure 1. The Homunculus (Topographic) Model developed by Penfield and Rasmussen, 1950.](image)

Hunter, Katz, and Davis (2003) conducted a study using upper limb amputee patients who had current signs and symptoms of phantom limb pain. During the study, the experimenter
would add a light stimulation (a touch on the cheek) while the patient looked into a mirror of the in tacked arm. When the light touch was added to the face, the patient had a general increased awareness of their phantom limb. There was no pain, but a sense of the limb still being attached to the body. It is speculated that the reasoning behind this phenomenon is through the Homunculus Model due to the areas of the brain that control the face and upper arms are next to each other (Figure 1). This model illustrates possible connections between proprioceptive and visual inputs that are caused by organization in the brain (Timms & Carus, 2015). Studies utilizing fMRI have shown visual differences in composition within primary somatosensory and motor cortex (Flohr & Elbert, 1995; Simoes et al., 2012). Mirror Therapy has been used to treat phantom limb pain for over two decades (Datta & Dhar, 2015; Carus & Timms, 2015; Barbin, Seetha, Casillas, Paysant, & Perennou, 2016; Tilak et al., 2016; Hunter, Katz, & Davis, 2003). Mirror therapy has been used to help alleviate the pain and sensations that come with phantom limb pain (Datta & Dahr 2015). However, majority of studies have not completely isolated the use of mirror therapy. Most studies combine mirror therapy with visual therapy, touch sensations, and/or pharmacological agents. Hunter, Katz, and Davis (2003) used mirror therapy with tactile input and the subjects noticed a significant decrease in phantom limb pain and phantom limb sensation. This technique helped alleviate the pain, however, the subjects still reported phantom sensation as if the muscles had relaxed in their phantom limb. They also noted interesting findings that coincide with the Humunculous model. Six or half of their subjects experienced general awareness of their phantom limb when the subject received a light touch on the face or arm. This phenomenon is supported by Parpia (2011) who’s analysis of the somatosensory Homunculus in which the area of the brain that controls the face sensory is next to the area of the brain that controls the upper limb senses.
Kim and Kim (2012) utilized mirror therapy with different narcotics to ease the phantom limb pain. Several different narcotics were prescribed to the patient first, as well as giving the subjects spinal stimulation. When none of the treatments were improving the pain, mirror therapy was added into the treatment protocol. Mirror therapy lasted fifteen minutes a session, four times a week. After a week of this additional mirror therapy, the patients pain level dropped from 10/10 (medication only) to a 7/10 and, a month later, the pain was rated at a 4/10 for the patient. These are similar results to what Datta and Dahr (2015) experienced with their case studies. Each of their case studies had patients start out on narcotic medications and then implemented mirror therapy, and saw a decrease in pain level within one week of the added therapy.

**Conclusion**

The margins surrounding the mechanisms behind cross-education are wide and leave vast room for research to be conducted to better understand this phenomenon.

After reviewing the explanation of the theories for the causes of cross-education, it is important to understand the different implications that can affect the cross-education effect. As in bilateral strength training, different factors and training modes can enhance the strength gains in unilateral strength training. Throughout the literature, limb dominance has shown to have a significant effect on cross-education. There is a greater neural transfer from the dominant limb to non-dominant then the reverse. This has been indicated by analysis of motor learning and the existing neural pathways within the brain.

The purpose of the present study was to examine if limb dominance has an effect on cross-education. From the evidence and data described in the above sections, there is still a large area of the cortical regions of the brain that need to be understood regarding the limb dominance
effect on cross-education. Future research is needed with the utilization of proper neuroimaging and brain mapping to aid in the understanding of how the cross-education transfer operates and it can be potentially controlled to facilitate in more efficient physical rehabilitation settings.
The purpose of this study was to evaluate the effect of limb dominance on cross-education in college females after a four-week handgrip resistance training program. Specifically, this study sought to determine if the cross-education transfer effect is significantly greater from the dominant limb to the non-dominant limb compared to the effect from the non-dominant to the dominant hand.

**Subjects**

College age females were recruited to participate in this study. All participants were enrolled as full-time students at Eastern Illinois University. Participants were recruited by personal contact and via email by the lead investigator. No incentives were given for participation. Inclusion criteria were females currently enrolled as a student at the university who were non-hypertensive and did not have any musculoskeletal injuries to the upper extremities. Additional criterion was the participants could not partake in any upper body resistance training during the four-week training period outside of what was prescribed to them for the sake of the study. Participants were allowed to continue any current aerobic training such as running, walking, biking, stair-stepper, or the elliptical. There were no exclusionary criteria regarding participants’ race, economic status, place of origin, sexual orientation, level of education, or nutritional habits.

Thirteen females with an average age of 21.92 (± 2.02) years volunteered to participate in the study. Prior to testing, the requirements for participating were explained and each participant completed a comprehensive informed consent that included the list of exclusion criteria. All
eligible participants were assigned randomly to one of three groups: a control group (n=4), a dominant group (n=4), and a non-dominant group (n=4). The control group did not participate in any training for the four-week period, except pre-test and post-test measurements. The dominant group only trained the dominant arm for the four-week training period, and the non-dominant group only trained the non-dominant arm during the four-week training period. After completing the consent form, all twelve participants were verbally asked which hand they used for writing which was identified as the dominant hand and recorded on each participants’ signed consent form. Out of the twelve total participants, eleven were right handed and one participant was left handed. Data for each participant was identified and analyzed by a code number in order to keep their information confidential. The code was assigned in the order that the researcher received their consent form. For example, the first participant who turned in their form was assigned with the code F1 (female 1).

Grip Strength Measurements

Grip strength was assessed during the first and sixth week of the study on all twelve participants according to the American College of Sports Medicine (ACSM) grip strength protocol (Johnson, 2014). A Takei 5001 Grip A Grip Strength Dynamometer was used in the study, which was similar to the studies by Amaral, Mancini, & Novo, 2012; Poyatos, Saches, Gonzalez-Moro, & Orenes, 2016; Dodds, et al., 2014. The lab contained three of the Takei 5001 Grip A Grip Strength Dynamometer, all with the same model number, 68812. All three were used in the study throughout the training program. Per ACSM recommendations the dynamometer handle was set at the level of the participants’ second knuckle. Participants stood with the arm being assessed bent ninety degrees at the elbow. Participants were then instructed to take in a deep breath and as the exhale, squeeze the dynamometer as hard as possible while
keeping elbow bent at ninety degrees. The ACSM does not specify how long to squeeze the dynamometer. The participants in this study were instructed to squeeze as hard as they could until they felt fatigue. The dynamometer was set back to zero after each trial. [how much time was there between trials?] This protocol was repeated three times on each arm in an alternating fashion between right and left arms and until three measurements were taken with each arm. The greatest of the three scores from each arm recorded as the peak grip strength value. While the ACSM protocol is designed to determine average grip strength that was not the objective of the study which was to measure the peak grip strength recorded for each arm.

**Training protocol**

Between pre- and post-testing, the dominant group and non-dominant group trained only their respective arms three times a week for four weeks. All participants in the dominant group and non-dominant group completed all twelve sessions. Both groups used a hand dynamometer to train their arms using a protocol similar to previous studies (Poyatoes, Sanchez, Gonzalaz-Moro, & Orenes, 2016; Amaral, Mancini, & Novo, 2012; Dodds, Syddall, Cooper, Benzeval, Deary, Dennison, et al., 2014). The dominant group and non-dominant group performed three sets of six maximal squeezes on the hand dynamometer with a three-minute rest period in between sets. This protocol is very similar to Magnus et al. (2013) who used hand dynamometers with women over the age of fifty years old who had distal radius fractures and were measuring the cross-education effect on their recovery. The training weeks took place from the second to the fifth week of the six week study.
CHAPTER IV
RESULTS

The purpose of this study was to determine if dominance in handedness influenced the cross-education effect after a four-week hand dynamometer training program in women.

Out of the thirteen total participants, twelve completed the study. Participant F7 dropped from the study since she was unable to make the first two training sessions during the first training week. The eight participants in the two experimental groups completed all training sessions; which was thirteen sessions total. All participants completed a baseline peak grip strength assessment on both arms using hand dynamometers.

Table 1. lists all of the participants’ pre- and post-test grip strength scores of the dominant and non-dominant arms. Participants are grouped by the training group they were in or control group.

<table>
<thead>
<tr>
<th>Participant</th>
<th>Pre-Test Dominant Arm</th>
<th>Post-Test Dominant Arm</th>
<th>Pre-Test Non-Dominant Arm</th>
<th>Post-Test Non-Dominant Arm</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1</td>
<td>35.5 Kg</td>
<td>39.5 Kg</td>
<td>36 Kg</td>
<td>37.5 Kg</td>
</tr>
<tr>
<td>F2</td>
<td>24 Kg</td>
<td>25.5 Kg</td>
<td>20 Kg</td>
<td>19.5 Kg</td>
</tr>
<tr>
<td>F3</td>
<td>31.5 Kg</td>
<td>20 Kg</td>
<td>31.5 Kg</td>
<td>29.5 Kg</td>
</tr>
<tr>
<td>F4</td>
<td>33.5 Kg</td>
<td>34.5 Kg</td>
<td>27 Kg</td>
<td>30 Kg</td>
</tr>
<tr>
<td>F5</td>
<td>32 Kg</td>
<td>30 Kg</td>
<td>23 Kg</td>
<td>25.5 Kg</td>
</tr>
<tr>
<td>F6</td>
<td>29.5 Kg</td>
<td>32.5 Kg</td>
<td>26.5 Kg</td>
<td>28 Kg</td>
</tr>
<tr>
<td>F7</td>
<td>27.5 Kg</td>
<td>Dropped Out</td>
<td>31.5 Kg</td>
<td>Dropped Out</td>
</tr>
<tr>
<td>F8</td>
<td>36.5 Kg</td>
<td>36 Kg</td>
<td>32.5 Kg</td>
<td>32.5 Kg</td>
</tr>
<tr>
<td>F9</td>
<td>29.5 Kg</td>
<td>29.5 Kg</td>
<td>25 Kg</td>
<td>26.5 Kg</td>
</tr>
<tr>
<td>F10</td>
<td>35 Kg</td>
<td>35.5 Kg</td>
<td>29 Kg</td>
<td>34.5 Kg</td>
</tr>
<tr>
<td>F11</td>
<td>31.5 Kg</td>
<td>29.5 Kg</td>
<td>30.5 Kg</td>
<td>36 Kg</td>
</tr>
<tr>
<td>F12</td>
<td>20 Kg</td>
<td>21 Kg</td>
<td>17.5 Kg</td>
<td>21 Kg</td>
</tr>
<tr>
<td>F13</td>
<td>22 Kg</td>
<td>24.5 Kg</td>
<td>21 Kg</td>
<td>26.5 Kg</td>
</tr>
</tbody>
</table>
Table 2. contains pre- and post-test mean peak grip strength values of both arms for all three groups. There was an increase in strength in all groups in both arms except in the non-dominant training which did not see an increase in strength in the dominant arm.

<table>
<thead>
<tr>
<th></th>
<th>Dominant Training Group</th>
<th>Non Dominant Training Group</th>
<th>Control Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre Dominant Arm</td>
<td>31.00±6.3 Kg</td>
<td>31.00±5.2Kg</td>
<td>27.63±5.2Kg</td>
</tr>
<tr>
<td>Post Dominant Arm</td>
<td>34.00±5.4 Kg</td>
<td>30.25±4.3Kg</td>
<td>28.25±5.0Kg</td>
</tr>
<tr>
<td>Pre NonDominant Arm</td>
<td>29.50±6.7 Kg</td>
<td>26.50±6.0Kg</td>
<td>25.13±5.8Kg</td>
</tr>
<tr>
<td>Post NonDominant Arm</td>
<td>31.63±5.7 Kg</td>
<td>28.38±7.4Kg</td>
<td>25.50±5.1Kg</td>
</tr>
</tbody>
</table>

Table 3. provides the baseline results of the dominant group, non-dominant group, and control group before the training intervention. An ANOVA analysis with a significant of 0.05 was used to analyze significant differences in baseline measurements between groups and within groups between different arms.

<table>
<thead>
<tr>
<th></th>
<th>Dominant Training</th>
<th>Non-Dominant Training</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dominant Arm</td>
<td>31.00 ±6.3 Kg</td>
<td>29.25 ±6.7 Kg</td>
<td>31.00 ±5.2 Kg</td>
</tr>
<tr>
<td>Non-Dominant Arm</td>
<td>31.00 ±6.7 Kg</td>
<td>31.00 ±5.2 Kg</td>
<td>26.50 ±6.0 Kg</td>
</tr>
<tr>
<td>Control</td>
<td>27.63±5.2 Kg</td>
<td>25.13 ±5.8 Kg</td>
<td>25.13 ±5.8 Kg</td>
</tr>
</tbody>
</table>

Notes. There was no significance found between baseline measurements between the three groups, p value = 0.05

After completion of the four-week training program, post training measurements were recorded. The results are shown in Table 4. There was no significantly greater increases in
strength in either of the three groups after the training program. No significant differences were found within the groups between the different arms.

Table 4.

Post-Test Measurements of Mean (± Standard Deviation) Peak Grip Strength in Both Arms in All Three Groups

<table>
<thead>
<tr>
<th>Dominant Training</th>
<th>Non-Dominant Training</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dominant Arm</td>
<td>Non-Dominant Arm</td>
<td></td>
</tr>
<tr>
<td>34.00 ±5.5 Kg</td>
<td>31.63 ±5.7 Kg</td>
<td></td>
</tr>
<tr>
<td>29.50 ±4.3 Kg</td>
<td>36.00 ±7.1 Kg</td>
<td>28.50 ±5.0 Kg</td>
</tr>
<tr>
<td>25.50 ±5.1 Kg</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes. There was no significance found between post-test measurements between the three groups, p value =0.05

Table 5. shows the change from the dominant training group in both arms from the pre-test to the post-test measurements. These data indicates that the dominant training group had an greater increase in strength in both the dominant (trained) arm and in the non-dominant (untrained) arm however the greater increase was not significant.

Table 5.

A Comparison of Mean (± Standard Deviation) Peak Grip Strength Between the Dominant and Non-Dominant Arms of Dominant Arm Training Group

<table>
<thead>
<tr>
<th>Dominant Arm</th>
<th>Non-Dominant Arm</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.00±1.80</td>
<td>2.38±1.00</td>
</tr>
</tbody>
</table>

Note. P value = 0.05. There was no significance found in the change from pre and post-tests in either arm.
Table 6. illustrates the change in the non-dominant training group in both arms. The results show that there was no significant increase or decrease in the dominant arm or the non-dominant arm after the training program.

<table>
<thead>
<tr>
<th></th>
<th>Dominant Arm</th>
<th>Non-Dominant Arm</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Comparison of Mean (± Standard Deviation) Peak Grip Strength Between the Dominant and Non-Dominant Arms of the Non-Dominant Training Group</td>
<td>-0.75±1.70</td>
<td>1.88±2.80</td>
</tr>
</tbody>
</table>

Note. P value = 0.05. There was no significance found in the change of the pre-and post-test measurements between the different arms.

The change in strength of the control group in both arms after completing the four-week training program are found in Table 7. The control group did not have any significant changes in either arm after the training program.

<table>
<thead>
<tr>
<th></th>
<th>Dominant Arm</th>
<th>Non-Dominant Arm</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Comparison of Mean (± Standard Deviation) Peak Grip Strength Between the Dominant and Non-Dominant Arms of the Control Group</td>
<td>0.63±1.90</td>
<td>0.38±1.70</td>
</tr>
</tbody>
</table>

Note. P value = 0.05. There was no significance found in the change of the pre-and post-test measurements between the different arms.

In summary, there was no significant differences in mean peak grip strength from baseline measurements to post-test measurements in the dominant group, non-dominant group, or control group. The dominant group did not have a significant increase in mean grip strength in
the non-dominant (untrained) arm. Likewise, the non-dominant group did not have a significant increase in mean grip strength in the dominant (untrained) arm.
CHAPTER V

DISCUSSION

The hypothesis of this study was the dominant training group would experience a greater cross-education effect manifested in a significantly greater increase in peak grip strength than the non-dominant group after a 4-week grip strength training program. However, the results did not show a statistically significance difference between the two groups, a difference between pre- and post-test measurements within each group, nor a difference between pre- vs post-test between the groups. However, there was a trend for an increase in strength in the non-dominant arm of the dominant training group. This trend was more prevalent in the dominant training group than in the non-dominant training group. One possible reason for the lack of significant differences is the low number of participants. Farthing, Chilibeck, and Binsted (2005) undertook a similar study, using thirty-nine participants, that compared the cross-education between a dominant arm training group and a non-dominant arm training group. Their study found a significant thirty-nine percent increase in strength in the untrained arm of the dominant group. Their results are similar to other studies that found anywhere from seven to fifty-two percent change in the untrained non-dominant limb. However, these studies had subject numbers ranging from twelve to fifty-one (Magnus, Arnold, Johnston, Haas, Basran, Krentz, & Farthing, 2013; Ehsani, Nodehi-Moghadam, Ghandali, & Ahmadizade, 2014; Adamson, Macquaide, Helgerud, Hoff, & Kemi, 2008; Munn, Herbert, Hancock, & Gandevia, 2005; Magnus, et al., 2013).

Considering that distal radial and ulnar fractures are the most common upper extremity injury in the United States among all ages in women other studies have indicated the importance
that cross-education can play in physical rehabilitation (Karl, Olsen, & Rossenwasser, 2009).

Ehsani et al. (2014) compared the cross-education effects between young and older populations. The young group consisted of twelve females between the ages of twenty-four and thirty-two and the older group consisted of twelve females between the ages of sixty-four and seventy-nine. The older female group had an increase in strength of the untrained, non-dominant arm by thirty-nine percent after a two-week training program of isometric, progressive, resistive exercises of elbow flexion in the dominant arm. Therefore, it was inferred that cross-education effects from resistance training can have similar effects on the elderly population.

In accordance with the idea that cross-education has the same implications in the elderly population, Magnus et al. (2013) found similar results. Their study used fifty-one women with the average of sixty-three who had suffered from distal radius fractures. By adding strength training to the non-fractured arm in the experimental group, as opposed to normal physical rehabilitation with no strength training in the control group, the experimental group was able to increase strength in the fractured arm by 38.4%. The control group only had a 4.4% increase in strength in the fractured arm with the routine rehabilitation program. These results reflect similar findings from a previous study conducted by Magnus, Barss, Lanovaz, and Farthing, (2010). This study used healthy men and women without any orthopedic impairments, but still underwent a four-week training program while immobilizing their non-dominant arm. The results from this study indicated a significant increase in strength in the immobilized group that strength trained by 5.5 percent in the untrained, immobilized arm. This same group also experienced an increase in muscle thickness in the biceps brachii and triceps brachii by roughly three percent in the immobilized arm. However, the immobilized group that did not strength train, saw a decrease in muscle thickness in the immobilized arm by six percent. It can be
speculated that in the physical rehabilitation setting, applying cross-education training to the normal rehabilitation programs, patients in the clinical settings can keep their strength in the injured limb, and lessen the likelihood of atrophy after immobilization. More research is needed to be done using various techniques to understand the neural components that play a role in the cross-education effect so more efficient approaches can be utilized in the rehabilitation fields.

In summary, cross-education is the increase in strength in an untrained limb from resistance training of the opposite, homologous limb. Limb dominance has shown to play a role in degree of strength transfer from the trained side to the untrained side. Continuing research in cross-education needs to control for limb dominance since it has shown to have a significant impact on results. Recent fMRI research has discovered areas in the premotor cortex that activated during cross-education. Future research should incorporate brain and neuroimaging techniques during cross-education training for better understanding of the motor areas and how their neural pathways operate across hemispheres.
REFERENCES


