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The Effects of a Four Week Single-leg Balance Training Program on Balance Error Scoring System Scores of the Trained and Untrained Leg

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THE EFFECTS OF A FOUR WEEK SINGLE-LEG BALANCE TRAINING PROGRAM ON BALANCE ERROR SCORING SYSTEM SCORES OF THE TRAINED AND UNTRAINED LEG

by

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ABSTRACT

The Effects of a Four-Week Single-Leg Balance Training Program

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The purpose of this study was to examine the effects of a 4-week single-leg stance balance training program on balance error scoring system scores of the trained and untrained leg and to determine any differences between genders for balance performance and cross education. Participants (N = 35) between the ages of 18 – 31 from Utah State University were tested three times over a 4-week period and those in the training group trained for a total of 22 minutes over that same time. Results showed balance improved for the trained leg and the untrained leg as well ($p = 0.23$). Males and females also performed similarly ($p = 0.95$). These findings show balance can improve in both the trained leg and the untrained leg after only 22 minutes of training in 4 weeks and that men and women are nearly identical in balance performance and cross education improvements.

(74 pages)

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Roger J. Davies

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CHAPTER I

INTRODUCTION

For more than a century researchers have studied the effects of unilateral motor activity on the performance of the contralateral homologous limb, in other words, the affects of training 1 limb and how that training effects the same limb on the opposite side of the body. This phenomenon has been known as cross education (CE) (also known as cross exercise, cross training, cross transfer, and bilateral transfer) (Davis, 1898; Shaver, 1975; Shima et al., 2002; Stromberg, 1988; Weir, Housh, Housh, & Weir, 1995). A review of CE studies has shown CE to be effective in nearly 75 % of these studies. With these positive effects on the untrained limb, CE may be a useful tool for rehabilitation specialists to aid in patient recovery. The ability to improve functionality of a limb without having to move it through normal range of motion would be most beneficial to patients who are unable to exercise an extremity due to injury, surgery, or other trauma. CE may even aid in decreasing recovery time.

During a review of CE studies it was common to find studies that contradict one another, with many finding CE occurs and others finding no CE results. These conflicting findings have been verified by the same researchers. One reason for the contradictions seems to be clear, no one has been able to determine the precise mechanism(s) of CE.

Although the exact mechanism(s) of CE are not known most authors subscribe to one of two theories, supraspinal or spinal. Those in the supraspinal group believe that CE occurs in the motor area of the central nervous system. The motor area is a part of the cerebral cortex from which motor impulses to muscles or glands originate (Van De

Graaff & Fox, 1999). The hypothesis is that there is a diffusion of impulses to the contralateral motor cortex during unilateral training (Zhou, 2000).

The spinal mechanism group believes that learning takes place in the afferent and efferent nerve pathways which are distal to the spine and part of the peripheral nervous system. With the use of electrical stimulation techniques researchers are able to activate efferent axons that innervate muscle fibers, causing muscle fibers to contract in a more synchronized manner, as well as afferent axons that relay sensory information from the muscle, skin, and other soft tissue (Zhou, 2000). Researchers believe that as afferent nerves from both sides of the body converge at the spinal cord excitatory contacts from the involved side of the body are conducted to the motorneurones of the uninvolved side (Corna, Galante, Grasso, Nardone, & Schieppati, 1995; Robinson, McIlwain, & Hayes, 1979), thus eliciting bilateral motor activity with unilateral excitation.

As of late, the majority of CE studies have been conducted using strength training programs whereas the early CE research examined skills such as finger tapping, toe tapping, and other manual dexterity skills were tested (Davis, 1898; Hellebrandt, 1951; Scripture, Smith, & Brown, 1894). Skill has been defined as something that requires training to do well (Skill, 2003).

The current study revisited skill testing by examining the influence of CE on balance training. Balance was classified as a skill because following balance training balance usually improves (Kovacs, Birmingham, Forwell, & Litchfield, 2004). For purposes of this study balance was operationally defined as, the combination of sensory and motor processes involved in the maintenance of standing postural control. Balance has been known to be maintained by three sensory processes working together; the visual, vestibular, and somatosensory (sensory stimuli from the skin) (Diener & Dichgans 1988; Horak, Nashner, & Diener 1990; Shumway-Cook & Horak 1986).

Problem Statement

Only two previous studies have examined unilateral balance training effects on the contralateral limb (Gauffin, Tropp, & Odenrick, 1988; Rozzi, Lephart, Sterner, & Kuligowski, 1999). While these two previous studies found positive CE effects on participants the body of research in this area has been limited and both studies were conducted using relatively small sample sizes. As was mentioned earlier, there has been conflicting findings concerning the effectiveness of CE. With only two studies examining CE and balance training logic suggests more research is needed to support those results. Furthermore, the examination of gender differences in regards to CE are relatively unknown.

Purpose of Study

The purpose of this study was to examine the effects of a 4-week single-leg stance training program on the Balance Error Scoring System (BESS) scores of the trained and untrained legs to determine if balance can be learned without direct training and to examine what, if any, differences exist between males and females in CE and balance training.

Hypothesis

After 4 weeks of unilateral balance training, using a single-leg stance on a foam pad, participants will decrease error scores for the trained leg. After 4 weeks of unilateral balance training, using a single-leg stance on a foam pad, participants will decrease error scores for the untrained leg. Furthermore it is hypothesized there will be no significant differences in balance error scoring system performance and CE effects between males and females.

Limitations

The skill of balance may be one limitation to this study. During training sessions, participants were asked to hold the untrained leg up off the ground with the hip and knee at ninety degrees. This was to be done while balancing on the training leg. Although the untrained leg will not be trained specifically on the testing task, balance learning may occur in the untrained leg from repeatedly attempting to maintain a stationary untrained leg. The factor of task specificity is discussed in the literature review.

Another limitation was the amount of time participants were not supervised by researchers. With the study lasting four weeks it was impossible to control for any extra balance training. In order to help control this limitation, participants were asked to, avoid any balance practice other than what was done during formal training with researchers.

One must be careful when interpreting results. The ability to generalize these findings may be difficult. The age, physical abilities, and lack of injury may all be limiting factors when trying to generalize to real world applications.

A final limitation was participants were told their scores after completion of the first and second tests. This was done in order to encourage participants to try their best to decrease the number of errors they score at each test. Because participants will know their scores they may strive to improve their own score out of competition within themselves, or compare their scores with others and thus compete against each other within and across groups. The larger limitation because of this is internal validity challenges. Balance improvements may be due to training or participants challenging themselves to become better or participants may strive to improve more than their peers.

Delimitations

A delimitation of this study was the age of participants and exclusions based on relevant medical history. The population was college age (18-31) limiting our ability to generalize to other age groups. The second delimitation was the exclusion of participants with a history of back, hip, leg, or ankle injuries and those with a diagnosed vestibular disorder. These exclusions seem almost in conflict with the overall purpose of some CE research which is, to provide rehabilitation alternatives for the injured. Two previous studies on CE and balance training have already examined participants with functionally unstable ankles (Gauffin et al., 1988; Rozzi et al., 1999).

Definitions

Agonist

A muscle acting as a prime mover to produce a motion (Houglum, 2001).

Antagonist

A muscle that acts in opposition to another muscle (Van De Graaff & Fox, 1999).

Bilateral

Pertaining to, affecting, or relating to two sides (Venes, 1997).

Central nervous system

Part of the nervous system consisting of the brain and the spinal cord (Van De Graaff & Fox, 1999).

Concentric motion

Dynamic activity in which the muscle shortens (Houglum, 2001).

Contralateral

Originating in or affecting the opposite side of the body (Venes, 1997).

Eccentric motion

A dynamic activity in which the muscle lengthens (Houglum, 2001).

Electromyostimulation (EMS)

The use of electricity to stimulate motor neurons to activate muscle fibers (Zhou, 2000).

Homologous

Similar in fundamental structure and in origin but not necessarily in function (Venes, 1997).

Ipsilateral

On the same side; affecting the same side of the body (Venes, 1997).

Isometric

Characterizing an activity produced when muscle tension is created without a change in the muscle's length. An isometric activity is a static activity (Houglum, 2001).

Isotonic

Characterizing an activity during which a muscle's length changes (Houglum, 2001).

Peripheral nervous system

The nerves and ganglia that lie outside the brain and spinal cord (Van De Graaff & Fox, 1999).

CHAPTER II

REVIEW OF LITERATURE

Cross education (CE) has been studied for more than 100 years. From the first study in CE research conducted in 1894 (Scripture et al.) to the more recent studies, CE research has moved from examining both strength and skill to focusing mainly on strength training (Enoka, 1988; Zhou, 2000). Skills, for what ever reason, have been examined on a very limited basis (Cannon & Caferelli, 1987; Franz, 1933; Hellebrandt, 1951; Starch, 1910) and until recently, the effects of balance training on CE had not been studied at all (Gauffin et al., 1988; Rozzi et al., 1999). The topics discussed in this review are the mechanisms that affect balance, recent unilateral balance training studies and the factors and mechanisms that affect CE, including CE studies that examine strength development. The reason for a review of CE and strength arises because relatively few studies exist that examine CE and its influence on balance or other skill development.

Mechanisms Affecting Balance

Balance control in humans is believed to be maintained through three main systems: (1) visual, (2) vestibular, and (3) somatosensory (sensory stimuli from the skin, joint, tendon, and muscle) systems (Diener & Dichgans 1988; Horak et al., 1990; Shumway-Cook & Horak, 1986). According to Diener and Dichgans (1988), only two of the three sensory systems need to be functioning properly to prevent falling after a sudden change to a person’s environment. Of the three systems, input from the somatosensory system is the preferred system for balance control in healthy adults (Shumway-Cook & Horak, 1986).

According to Diener and Dichgans (1988) there are no less than two different modes of postural stabilization. The first acts through reflex-type responses. These reflexes are sets of preprogrammed responses, stored in the motor cortex, based on the present environmental context and the present objective. This mode does not rely on feedback from any of the three systems and therefore may not be modifiable. This mode is able to serve only in response to fast corrections and disturbances in balance.

The second mode is continuous in nature. Diener and Dichgans (1988) reported that the continuous mode relies heavily on feedback from all three systems and is constantly trying to compensate for continuous corrections and disturbances in balance. The present study should test both modes of balance. From anecdotal evidence those participating in balance tests attempt to regain balance in two ways. First, when they begin to lose stability they consciously make minor adjustments (leaning) to regain balance, or second, once they begin to lose stability they make many fast, substantial movements (hopping, stepping, and/or arm movements) in order to regain balance.

Review of Balance Studies

This review of recent balance training studies includes both positive and negative findings following balance training programs (including two that discuss CE), as well as studies that justified the use of the BESS as an accurate and effective tool to assess balance in humans.

Several authors have published findings that suggested balance training improves balance (Gauffin et al., 1988; Kovacs et al., 2004; Rozzi et al., 1999; Valovich, Perrin, & Gansneder, 2003) but results from other studies show no such improvements after balance training (Cox, Lephart, & Irrgang, 1993; Guskiewicz, Ross, & Marshall, 2001; Riemann & Guskiewicz, 2000). Of these studies only a few specifically focused on unilateral balance training programs (Cox et al., 1993; Gauffin et al., 1988; Kovacs et al., 2004; Rozzi et al., 1999) and of these only two evaluated the contralateral effects of unilateral balance training (Gauffin et al., 1988; Rozzi et al., 1999).

In a 4-week study, Kovacs et al. (2004) measured the effects of neuromuscular training versus basic off-ice training on postural control in figure skaters. Figure skaters in the basic group performed basic stretching and strengthening exercises consisting of a gluteus stretch, hip flexor stretch, abdominal crunch, and a wall sit exercise. The neuromuscular training consisted of six different exercises that progressed from basic (single-leg stance on floor) to sport-specific (landing on a mini-trampoline & spinning). Postural stabilization was measured on a force platform and results showed that the neuromuscular trained group demonstrated significantly greater improvements (p = 0.004) in postural stability than the basic off-ice training group. Kovacs study also showed of the five tests, those that were more difficult, those scores improved more for the training group than did the tests that were less difficult. Suggesting as a task increases in difficulty so does the ability to improve in that task.

Two studies have been conducted on using the BESS in which repeated administrations of the BESS produced a learning effect. Susco, Valovich McLeod, Gansneder, and Shultz, (2004) used 100 recreationally active college students and

Valovich, et al. (2003) examined thirty-two high school athletes (details of these studies will be given later). The BESS consists of three different stances (double leg, single-leg, & tandem) performed on two different surfaces (hard & foam). Participants perform each stance once on each surface with their eyes closed and their hands resting on their iliac crests. Each of the six trials were performed for 20 seconds and an error was recorded if the participant broke from the starting position. A lower score represented better balance. Valovich's study consisted of recording baseline scores on day one. Then on days 3, 5, 7, and 30 they repeated the six stance regimen again. Results of Valovich's investigation showed that BESS scores on days five and seven were significantly lower than baseline scores ($p < 0.001$). The greatest decreases in scores were produced in the single-leg stance on foam. Valovich suggested that participants' performance increased the most in tasks that are novel or unique. Results from Susco's study revealed significant ($p < .001$) decreases (Pretest = 19, Posttest II = 15) in BESS scores of the control group. Control participants performed three administrations of the BESS within 40 minutes.

Although these studies used single-leg stances during training, the single-leg stance was not the exclusive mode of training furthermore, researchers did not evaluate each leg separately before and after training. Without a baseline score for the trained limb (TL) and the untrained limb (UTL) to compare to posttest scores of each leg CE cannot be assumed or implied from these types of training programs. However, two studies did examine participants balance scores of both the TL and the UTL before and after single-leg training.

In 1999, Rozzi and others studied balance training for persons with functionally unstable ankles. Pre- and posttraining balance scores were recorded for each leg using a

Biodex Stability System. Training consisted of unilateral static and dynamic balance exercises three times per week for 4 weeks. Participants with a functionally unstable ankle performed training on that ankle whereas participants without ankle instability were randomly assigned to train either leg. During static training participants were told to focus on a visual feedback screen. On the screen were a bulls-eye and a cursor, which represented the platform. Participants were asked to keep the cursor in the center of the bulls-eye as long as possible which was accomplished by maintaining a stable platform. Dynamic training consisted of participants moving the platform through a specified range of movements using the visual feedback screen. These movements consisted of anterior and posterior tilts, as well as medial and lateral tilts. These movements were followed by clockwise and counterclockwise circles. Once the four weeks of training was completed testing was again conducted on the TL and the UTL. Posttest scores for all participants showed significant improvements ($p < 0.05$) in balance for both the TL and the UTL.

Another study found similar results when examining functionally unstable ankles. Gauffin, et al. (1988) studied the effects of unilateral balance training on unstable ankles. They measured balance using a force plate and cameras, which recorded postural sway. Training was performed unilaterally for the unstable ankle and included standing on an ankle disk for 10 minutes five times per week for 8 weeks. Their results showed significant decreases in postural sway ($p < 0.001$) on both the TL and UTL. Conclusions from both of these studies suggested learning was the result of CE which occurred in the motor area of the brain. This also suggested testing on these participants was focused on the second mode of balance because of the ability to adapt to feedback given through multiple trials.

The previous studies produced results that showed improvements in unilateral balance and even CE improvements following balance training. While these results may seem impressive they do not tell the whole story of balance training, in fact there are nearly as many studies that did not find significant improvements in balance after balance training (Cox et al., 1993; Guskiewicz et al., 2001; Riemann & Guskiewicz, 2000).

Earlier it was reported that after repeated administrations of the BESS there were significant decreases in the errors recorded and thus, an increase in balance or, balance learning occurred (Susco et al., 2004; Valovich et al., 2003). These findings are contrary to what two previous studies found performing the same tests for nearly the same number of days. Guskiewicz et al. (2001) as well as Riemann and Guskiewicz (2000) both conducted studies on postural stability following a concussion. Both studies used matched control groups (1 healthy to 1 concussed). Each group performed the BESS as well as a battery of other tests on days 1, 3, and 5 following their concussion. The concussed group showed significant improvements of BESS scores ($p < 0.05$) over the three trials but the control group showed no changes in their BESS scores over the same three trials ($p > 0.05$). The authors suggested the reason for the improvement in BESS scores for the concussed group was due to recovery from concussion. The healthy groups BESS scores did not change over the same time period. These findings suggest that three trials of the BESS in five days is not sufficient enough practice to induce learning the skill of balance well enough to improve BESS scores.

Two studies reported no change in BESS scores after repeated trials in one week ($P > 0.05$) (Guskiewicz et al., 2001; Riemann & Guskiewicz, 2000) and two other studies showed significant improvement in BESS scores ($p < 0.001$) (Valovich et al., 2003;

Susco et al., 2004) after repeated trials in one week. With conflicting results like these it is difficult to discern whether or not balance improves after repeated trials of the BESS. What could have been the difference? The answer may be simple. Perhaps the two earlier studies were not long enough (5 days instead of 7 days). Or, participants did not perform enough repetitions of the BESS (3 trials instead 4 trials). Either of these variables could be the reason that other studies like Susco (2004) and Valovich (2003) were able to induce significant learning in their studies. Whatever the reason more studies need to be conducted to determine the rate at which balance is learned or if balance is learned at all.

The traditional method of measuring balance has been the use of expensive and sophisticated forceplate systems like the NeuroCom Smart Balance Master System (Guskiewicz et al., 2001). The cost alone of this type of measurement apparatus may prevent many rehabilitation specialists and researchers from using any type of balance systems for athlete testing, client rehabilitation, or clinical research. However, alternatives to expensive balance training systems have been developed. Research suggests, that relatively inexpensive, closed-cell foam blocks and a standard stopwatch can produce significant results parallel to more costly balance measurement systems (Guskiewicz et al., 2001; Riemann & Guskiewicz, 2000; Susco et al., 2004). Guskiewicz, et al. (2001) stated, “Based on our findings, the BESS is a practical, valid, and cost-effective method of objectively assessing postural stability in athletes suffering from concussion” (p. 268).

As has been discussed earlier, concussions have been shown to affect balance. The BESS has been a useful tool in assessing balance following a concussion. Fatigue has just recently been suggested as another factor that affects balance (Susco et al., 2004;

Wilkins, Valovich McLeod, Perrin, & Gansneder, 2004; Wright, 2003). All three authors chose to use the BESS as their balance assessment tool. In these studies participants balance performance was assessed using the BESS before and after they performed an exertion protocol. Results of all three studies showed that fatigue can significantly affect balance error scores ($p < 0.05$). One study showed that BESS scores did not return to normal until 20 minutes after completion of the fatigue protocol (Susco et al., 2004).

The most recent study concerning the BESS was performed in 2008 by Iverson, Kaarto, and Koehle. Their study was conducted to help establish normative data scores for the BESS throughout the life span. They conducted BESS examinations on 589 community dwelling adults between ages 20 and 69 years of age. Iverson reported there was a medium correlation between age and BESS ($r = 0.36$, $p < 0.001$). There was no relation between BESS and height ($r = - 0.03$, $p = 0.54$) and a very small correlation between BESS and weight ($r = 0.16$, $p < 0.001$) and body mass index ($r = 0.23$, $p < 0.001$). In both men and women those with higher body mass index scores performed significantly more poorly than those with lower body mass index scores. The examination of gender revealed there were no obvious affects on BESS performance ($p < 0.67$) except there was a non-significant trend toward women in the age group of 60 – 64 to perform more poorly than men in that age group.

An overview of the balance training programs showed that most researchers produced significant learning after four to eight weeks of training (Gauffin et al., 1988; Kovacs et al., 2004; Rozzi et al., 1999). Volovich et al. (2003) appear to have been an exception when they found significant learning after only five and seven days of training. With two prior studies showing positive results when examining CE and balance it is clear more research needs to be completed to both validate their findings and possibly shed more light on what the possible mechanisms of CE may be.

Cross Education

Training of one portion of the body, trains, at the same time, the symmetrical part and also neighboring parts. This was how Edward W. Scripture, the director of the psychological laboratory, defined the term CE in a paper he published in 1894 titled Studies On The Education of Muscle Control and Power.

Since then authors have also taken upon themselves the liberty of redefining CE to more closely describe their particular area of emphasis. Digby G. Sale (1987) in a review of the consequences of exercise and training on motor unit activation defined CE as, training of one limb causes increases in strength in the contralateral untrained limb without hypertrophy. This definition however, only focuses on the strength aspect of CE and does not include the affects of CE on all types of training. In a fairly recent review of muscle strength and development, Roger Enoka (1988) defined CE as the contralateral effect of chronic motor activity in one limb. Enoka's definition can be used to describe nearly, if not, all of the previous research as well as research conducted since its publication. This was also how CE was defined in this study.

Improving contralateral performance by engaging in an ipsilateral training program could be a useful tool for many rehabilitation specialists. Ipsilateral training would be especially beneficial if the contralateral limb was limited in activity, range of motion, and/or bearing weight. In comparing CE studies performed over the past one hundred years a number of authors have reported some type of positive CE results from unilateral training (Bray, 1928; Brown, McCartney, & Sale, 1990; Cannon & Cafarelli, 1987; Carolan & Cafarelli, 1992; Coleman, 1969; Davis, 1898; Evetovich et al., 2001; Farthing & Chilibeck, 2003; Gauffin et al., 1988; Hellebrandt, 1951; Hortobágyi, Lambert, & Hill, 1997; Housh & Housh, 1993; Housh, Housh, Weir, & Weir, 1996; Ikai & Fukunaga, 1970; Kannus, et.al. 1992; Komi, Viitasaio, Rauramaa, & Vihko, 1978; Krotkiewski, Aniansson, Grimby, Bjorntorp, & Sjostrom, 1979; Lewis, Nygaard, Sanchez, Egeblad, & Saltin, 1984; Rose, Radzyminski, & Beatty, 1957; Rozzi, et al., 1999; Scripture et al., 1894; Sheilds, Leo, Messaros, & Somers, 1999; Shima et al., 2002; Walters, Stewart, & LeClaire, 1960; Weir et al., 1995; Weir, Housh, Housh, & Weir, 1997; Weir, Housh, & Weir, 1994; Yasuda & Miyamura, 1983; Yue & Cole, 1992). Far fewer studies, however, have found no significant CE effects after participants performed a unilateral training program (Ebersole, et al., 2002; Gardner, 1962; Garfinkel & Cafarelli, 1992; Housh, Housh, Johnson, & Chu, 1992; Jones & Rutherford, 1987; Narici, Roi, Landoni, Minetti, & Cerretelli, 1989; Panin, Lindenauer, Weiss, & Ebel, 1961; Rutherford & Jones, 1986; Weir, Housh, Weir, & Johnson, 1995; Young, Stokes, Round, & Edwards, 1983).

Factors Affecting Cross Education

In CE research the improvement of strength and the increase of skill have been attributed to three main factors. These factors include: (1) specificity of training; (2) unintentional training of the UTL; and (3) duration of training. Mechanisms responsible for CE include supraspinal and spinal mechanisms.

The first factor discussed relating to CE is specificity of training. Specificity refers to the functional and structural adaptations of the organs and systems that are subjected to the exercise stress (Zhou, 2000). According to Zhou (p.180), typically, the greatest training results had normally been found when the testing routine matches the training exercise. However, Zhou pointed out, CE seems to contradict the concept of specificity. The activities of the contralateral muscles, although not trained, have been reported to change significantly following the training of the opposite limb. Specificity and its affects on CE and have also been studied in relation to the type of training performed by the exercised limb (i.e., eccentric, concentric, isometric, etc.) or at what joint angle or speed the training was performed. Results of these studies vary with some reporting that CE occurs throughout nearly all angles and/or speeds (Davis, 1898; Housh & Housh, 1993; Weir et al., 1997) while most others report that results of the UTL are specific to the joint angle and/or speed of the limb during training movements (Brown et al., 1990; Farthing & Chilibeck, 2003; Gardner, 1962; Hortobágyi et al., 1997; Hortobágyi, Scott, Lambert, Hamilton, & Tracy, 1999; Housh et al., 1996; Jones & Rutherford, 1987; Rutherford & Jones, 1986; Sheilds et al., 1999; Weir et al., 1994; Weir et al., 1995, 1977).

One of the earliest studies conducted on CE suggested that CE was not specific to muscles trained. In 1898, Walter W. Davis conducted a study on CE to determine if CE was specific to the homologous muscles of the UTL or, if the specific training would be diffused to other limbs of the body. Davis trained participants in unilateral finger tapping. He reported that although the results for every participant were not consistent there were still fundamental results showing CE from the trained hand to the other hand and both feet (Davis, 1898). Other, much more recent, studies have agreed with Davis's findings (Housh & Housh, 1993; Weir et al., 1997).

In 1997, investigators (Weir et al.) examined the effects of a unilateral concentric only leg extension weight training program on joint angle specificity, cross-training, and the bilateral deficit. Participants were tested pre- and posttraining using maximal isometric strength at three joint angles in both limbs as well as a one-repetition maximum (1-RM) concentric strength of the TL, UTL, and bilaterally. Training lasted eight weeks consisting of three times per week of 3-5 sets of six repetitions. Results of the study showed that participants TL and UTL increased in isometric strength through all three joint angles ($p < 0.05$) as well as in concentric 1-RM of the TL, UTL, and bilaterally ($p < 0.05$).

Although these studies reported that training specificity may not be a critical element for positive CE results, many other studies, as stated above, do not agree. In a study of unilateral eccentric weight training on joint angle specificity, cross-training and bilateral deficit investigators found CE was joint angle specific (Weir et al., 1995). After 8 weeks of unilateral eccentric only training of the quadriceps investigators reported that significant ($p < 0.05$) isometric strength increases only occurred in two out of three angles tested. These increases were recorded in both the TL and the UTL. Another study comparing the differences in muscle strength following voluntary or stimulated muscle contractions found CE was specific to the UTL and not the hands (Hortobágyi et al., 1999), as was suggested by Davis (1898). Hortobágyi and colleagues (1999) performed pre- and posttraining tests for handgrip strength and quadriceps strength. Four groups were formed, three groups performing different types of contractions (voluntary, electromyostimulation, and remote-electromyostimulation) and one control group which did not exercise. Upon completion of a six week strength training program investigators reported that handgrip strength showed low, non-significant, levels of strength increase. Conversely, both the TL and UTL quadriceps increased in strength ($p < 0.05$) for all training groups following the strength program.

The second factor in CE deals with unintentional training of the UTL during training of the TL. This unintentional training of the UTL has been reported to occur in three different forms, co-contractions, postural stabilization, and increased coordination. Co-contraction refers to the activity of the contralateral homologous muscle during training of the ipsilateral muscle group. Postural stabilization refers to the activation of muscles, in the contralateral limb, to maintain body position during training. Finally, increased coordination in this setting is the learning effect of the agonist and antagonist muscles in order to optimize performance of the agonist.

Hellebrandt, in 1951, was one of the first who suggested the idea of co-contraction when she stated, "It is common experience that whenever unilateral exercise of large muscle groups is performed against heavy resistance, widespread postural readjustments always occur. These call forth the synergistic co-contraction of many muscle groups involving the trunk and remote extremities as well as those of the opposite limb" (p. 136). Her statement was backed by further research (Carr, Harrison, & Stephens, 1994; Devine, LeVeau, & Yack, 1981; Hortobágyi et al., 1999; Gregg, Mastellone, & Gersten, 1957; Jones & Rutherford, 1987; Panin et al., 1961). Jones and Rutherford (1987) visually observed the leg of the UTL gripping the table during training of the TL. Gregg et al. (1957) observed that when exercise stress increased in the TL, EMG amplitudes of the UTL also increased. Two studies separated by nearly forty years have also shown co-contractions during unilateral training (Hortobágyi et al., 1999; Panin et al., 1961). These two authors compared the EMG amplitudes of the UTL during training of the TL. They both reported the amplitudes as “very low,” somewhere between 15-20% of that registered in the TL during voluntary contractions. Knowing the EMG amplitude of the UTL was markedly lower than that of the TL during training, Hortobágyi and others then examined the strength gains in the UTL after 6 weeks of eccentric training. The gains in muscle strength of the UTL were greater than 100%. Hortobágyi proposed that EMG amplitudes of only 15-20% would not be enough to generate the over 100% increase in muscle strength.

Though these authors have reported activity in the UTL during training, at least two authors have reported no such activity as evidenced by EMG recordings (Carolan & Cafarelli, 1992; Lewis, Nygaard et al., 1984). Lewis and others in 1984 recorded muscle activity, via EMG, in the TL and UTL while participants performed unilateral training of knee extensors. Throughout the nine week training program participants trained two times each day, five days each week. During training sessions participants performed two bouts of sixty maximal isometric contractions of the quadriceps. While performing these bouts EMG electrodes were placed over the vastus lateralis muscle of the quadriceps. Results of the study showed that after nine weeks of training strength of the TL and UTL increased 21% and 5% ($p < 0.05$), respectively. Lewis and colleagues specifically reported that EMG recordings of the UTL showed no activity during training sessions.

Similarly, Carolan and Cafarelli (1992) unilaterally trained knee extensors three times per week for eight weeks. During training they recorded EMG signals of both agonists and antagonists of the TL and UTL during knee flexion. They also controlled for possible training of the UTL by displaying the EMG signals of the UTL on an oscilloscope in front of the participant during each training session. Results of their study showed that unilateral maximal isometric training produced an increase of 16% ($p < 0.05$) in maximal voluntary contractions (MVC) of the UTL and a decrease of 13% ($p < 0.05$) in hamstring activity during the same MVC. As for EMG activity in the contralateral limb during unilateral training Carolan and Cafarelli reported they saw almost no activation of the UT leg during the eight weeks of training. The decrease in the force of the antagonists (hamstrings) leads into the next topic of increased coordination between the agonists and antagonists.

Increased coordination between agonist and antagonist has also been suggested as a reason for CE. Carolan and Cafarelli in 1992 examined this factor by recording EMG readings of the contralateral limb during unilateral training. As was stated earlier, after the first two weeks quadriceps strength of the UTL increased 16 % ($p < 0.05$) with no EMG increases, while EMG readings of the UTL hamstrings decreased 13 % ($p < 0.05$). With less activation of the antagonist (hamstrings) the agonists (quadriceps) are able to do more work without increasing EMG activity. A final note to this study was that hamstring activity decreased in the first week of the study whereas strength gains continued to increase throughout the remainder of the 8-week study. Because of the lack of consistency between force increases in the quadriceps and force reductions in the hamstrings the full explanation of the continued increase in strength of the UTL quadriceps is still unknown.

The areas of postural stabilization and coordination could play a major role in the present study. As participants perform the single-leg stance on the TL they will have to hold the foot of the UTL approximately 6 inches off the ground. By holding the UTL off of the ground participants will unintentionally be training the UTL. This unintentional training of the UTL should not specifically aid the UTL in balance training but, according to some researchers in the previous section on specificity of training (Davis, 1898; Housh & Housh, 1993; Weir et al., 1997), performing nonspecific postural stabilization training of the UTL may influence the CE outcomes. While not all previous research agrees, it is unclear if this amount of nonspecific and unintentional training will affect balance scores for the UTL.

The third and final factor that affects CE is duration and intensity. Duration of training was defined two ways in this study: (1) duration of individual training bouts (measured in seconds and minutes); and (2) the total duration of the training program (measured in days and weeks). Intensity has been measured previously using a one hundred point scale with zero being no effort and one hundred being a complete maximal effort (Sheilds et al., 1999; Walters et al., 1960). Strength and/or balance training studies can be as short as 2 weeks or as long as 20 weeks with participants performing three to six bouts per week and three to six sets per exercise (Cannon & Cafarelli, 1987; Evetovich et al., 2001; Sale, 1988; Zhou, 2000). There does not seem to be any consistency in the literature concerning duration of training and increases in CE. One study did observe a gradual increase in CE by assessing at regular intervals (Hortobágyi et al., 1999). There may not be any consistency in the literature about duration of training but according to review of muscle strength and development by Roger Enoka (1988) he suggested that as the intensity of the training program increases the CE affect also increases. Most studies have participants train at an intensity greater than sixty percent of their maximal voluntary contraction force (Zhou, 2000).

Two studies, one concerning duration and the other pertaining to intensity, have shown positive CE findings although they do not fit within the typical parameters of CE studies. The study concerning duration of training was conducted in 1960 by Walters and others. They conducted an investigation involving isometric and isotonic training of the forearm flexors. Their training lasted for 2 weeks, with eight total days of training, and only three, 15-s bouts of exercise per day. Although they did not find significant CE results for each mode of training they did report significant increases in strength in the UTL for participants who trained with maximal isometric training (22%, $p < .05$). While not significant, the other two modes of training, two-thirds max isometric and two-thirds isotonic, showed strength increases in the UTL of 28% and 17% respectively.

The second study was conducted in 1999 by Sheilds, Leo, Messaros, and Somers. The purpose of their study was to determine the influence of submaximal rhythmic handgrip training on rhythmic handgrip work (RHW), isometric handgrip endurance time (IHE), and maximal voluntary isometric contraction for the handgrip force (MVIC). Rhythmic handgrip work, IHE, and MVIC were determined bilaterally before and after training. Two groups performed 6 weeks of rhythmic right handgrip training, one at thirty percent of MVIC and a second group trained at a near-zero load. CE results of the study showed RHW increased significantly for the 30% group (43%, $p \leq 0.05$) and the low-level training group increased but not significantly (36%). Rhythmic handgrip training appeared to be highly specific, for there were no CE results for either IHE or MVIC. The control group showed no significant improvements in RHW, IHE, or MVIC for either hand. Although the low-level training group did not reach significance the percent increase was relatively similar to the percent increase of the 30% group. This seems to be the key finding in this study, CE may not be intensity-dependent.

Possible Mechanisms of Cross Education

Supraspinal mechanisms are the first of two reported possible mechanism used to explain CE. This idea was built upon the anatomy of the nervous system. During unilateral training the portion of the motor cortex that activates the TL was said to diffuse motor impulses across a common neural pathway and thus create a learning effect on the UTL (Zhou, 2000). Yue and Cole (1992) investigated the supraspinal mechanism by examining increases in strength after training with maximal voluntary muscle contractions and imagined muscle contractions. Testing included pre- and posttraining testing of the maximal isometric abduction force of the fifth digit and maximal force of the left great toe extensors. Training lasted only four weeks and was limited to the abductor muscles of the fifth digit of one hand. One group trained using maximal isometric contractions while the other group only imagined producing the same contractions. Researchers reported finding strength gains in the UTL of 14% ($p < 0.02$) and 10% ($p < 0.005$), respectively (Yue & Cole, 1992).

This was not the only study in which the authors suggest the central nervous system (CNS) may play a role in CE. Other authors have also suggested that supraspinal mechanisms may have aided in CE during unilateral strength training (Carolan & Cafarelli, 1992; Farthing & Chilibeck, 2003; Hellebrandt, 1951; Kannus et al., 1992;

Kristeva, Cheyne, & Deecke, 1991; Shima et al., 2002; Stinear, Walker, & Byblow, 2001). While these authors have all reported that supraspinal mechanisms are responsible for increased strength gains before hypertrophy there are, as always, those who do not agree. Those who are not convinced that supraspinal mechanisms are the major mechanism for strength gains before hypertrophy are the advocates of the spinal mechanism group.

Spinal mechanisms are the second and final mechanism reported to be a cause of CE. This mechanism is concerned with the learning that takes place in the afferent and efferent nerve pathways, nervous tissue distal to the spine (Zhou, 2000). With the use of transcutaneous electromyostimulation (EMS) researchers can artificially stimulate motor neurons that would normally be stimulated by the motor cortex (Zhou). Therefore, any learning from this type of training would be learned, not from the motor cortex or CNS but, somewhere within the afferent and efferent nerves of the peripheral nervous system (PNS). In other words, by using EMS stimulation only, researchers would eliminate all the supraspinal mechanisms that affect CE and the results would be the CE effects of spinal mechanisms.

EMS investigations have already begun. Researchers have discovered that the use of EMS to activate muscle fibers allows fibers to contract in a more synchronized pattern. With repeated training in this manner innervated muscles should learn to contract voluntarily in a more synchronized manner and therefore should produce greater force following training (Zhou, 2000).

Two studies have been conducted using this technique, one by Hortobágyi et al. (1999) training the quadriceps femoris, and another by Cannon and Caferelli (1987) training the adductor pollicis muscle of each hand. Because the exact mechanisms of CE are still unknown there is a likelihood that two similar studies will show differing results. Many of the details concerning Hortobágyi et al. have been discussed earlier. The information relevant to spinal mechanisms is EMS training. By using EMS to train the muscles it was Hortobágyi's claim that only spinal mechanisms were in use. In their study the EMS trained group was superior in the TL and the UTL. The EMS groups' strength of the TL while performing stimulated eccentric contractions increased in strength 54 - 177% of pretest scores. The increase in strength of the UTL ranged from 37 - 104% when performing stimulated eccentric contractions in the EMS group. The voluntary strength increase of the UTL in the EMS group was only 37%. In the summary, Hortobágyi stated, "training with EMS-evoked contractions at the same intensity as that used in voluntary training is capable of achieving the same or greater cross education" (p. 217).

Unfortunately, the findings reported by Hortobágyi et al. (1999) were not significant nor did they agree with a previous study conducted in 1987 by Cannon and Caferelli. Their study examined central adaptation to resistance overload. To do this, researchers had participants unilaterally train the adductor muscles of the thumb. Participants trained three times per week for five weeks using one of two types of contractions voluntary or EMS. Following the training changes in strength were reported. Increases in the TL were 15% ($p < 0.05$) for both the voluntary and EMS groups. However, for the UTL, the voluntary group showed a 9.5% ($p < 0.05$) increase in strength but the EMS group showed no significant increases in strength. Cannon's CE findings contradict Hortobágyi's findings and Cannon's conclusions suggest opposing ideas as well. Cannon and Cafferelli suggested when the cross-over effect is observed it is either because the pretraining MVC's were not truly maximal or because learning has occurred proximal to the final common pathway.

The seemingly always contradictory world of CE has been examined much more intensively as of late. But there seems to be an obvious concentration in the area of strength development. While strength development has been an important factor in everyday life and in rehabilitation settings, it is not the only one. Understanding how skills, like balance, are developed should be just as important. The present study may help fill the void that has been created in the CE research regarding skill development.

CHAPTER III

METHODS

Participants

Forty-four potential participants were recruited from Utah State University undergraduate students taking health, physical education, and recreation courses as well as undergraduate age (18 - 30 years) persons from student housing. Participants had no previous balance training in the past year and had no previous spine, hip, leg, or ankle injury in the last year that has limited daily activities. None of the participants reported a previous medical diagnosis of a vestibular disorder.

Of these, one was ineligible due to pregnancy, six were unable to make the time commitment and two were dropped from the study due to inability to attend testing sessions. Thirty-five participants were subsequently enrolled in the study with the mean age of all participants being 24 years ± 2.7 (20 - 31 range), the average mass was 77.75 kg ± 15.31 (50 kg – 117 kg range), the mean height was 1.71m ± 0.10m (1.54 m – 1.92 m range). No one in the study reported participating in any type of balance training program in the past year. There were also no reports of a spine, hip, leg, or ankle injury in the past year that limited their daily activities. Participants did not report any medical diagnosis of a vestibular disorder. One participant did report being legally blind. Nearly all participants, 32 of 35, reported their right leg to be their dominate leg.

Of the 35 participants, 18 were randomly assigned to the treatment group and 17 were assigned to the control group. The demographic characteristics of the two groups were calculated using independent *t* tests and are reported in Table 1. Mass scores were statistically different between the two groups with the control group reporting a higher mass. This may have been due to more males being randomly assigned to the control group. As was cited earlier, Iverson et al. (2008) research on the BESS has shown there was only a small correlation between BESS scores and weight ($r = 0.16$, $p < 0.001$) with participants who had a higher body mass index (BMI) score scoring more poorly than those with a lower BMI score.

Faithfulness to the training program was excellent. All participants in the training group completed all their required training sessions with only three participants changing one training session time by a few hours. All 35 participants completed their respective training and testing schedules and their data were analyzed according to the protocol.

Table 1

Physical Characteristics of Each Group

	M ± *SD*	*M* ± *SD*	$p < .05$
Physical Characteristics Measures	TG (*n* = 18) (f = 11) (m = 7)	CG (*n* = 17) (f = 7) (m = 10)	
Age (years)	24.00 ± 2.87	23.82 ± 2.60	0.85
Mass (kg)	72.65 ± 13.4	83.14 ± 15.72	0.04
Height (m)	1.69 ± 0.10	1.74 ± 0.10	0.23

Note. TG = Training Group; CG = Control Group; f = Females; m = Males. $p < 0.05$ = groups are significantly different.

Procedures

This study was a prospective, randomized controlled trial. The study was unblinded as both the investigators as well as the participants were aware of the interventions and outcomes from each test. Testing and training sessions were performed in the Wellness Center at the USU Health, Physical Education, and Recreation (HPER) Building. Testing sessions and training sessions were scored and supervised by individuals with previous experience administering the BESS. Participants were given two copies of the informed consent form (Appendix A) approved by the Utah State University Institutional Review Board and instructed to read and ask any questions relevant to the consent form or the study, then sign both copies. Participants were then randomly assigned to one of two groups training (n = 18) or control (n = 17). After a participant was assigned to a group their demographic information was obtained by an Athletic Trainer and recorded (Appendix B). Each participant was given a numeric identification (ID) number (00-34). Using a table of random numbers (Thomas & Nelson, 2001) researchers assigned participants to either the training or control groups.

Once groups were assigned and consent forms completed pre-training testing was performed. Participants were individually instructed by researchers on the proper testing position (single-leg stance on foam, one of the six stances used in the BESS): standing on one leg, raising the opposite knee (foot about 6 inches off the floor), hands on iliac crests, head up, and eyes closed. Researchers then demonstrated for participants the proper testing stance and possible errors. Errors were scored by the testers if the participant (1) opened their eyes, (2) stepped, stumbled, or fell out of the test position, (3) removed their hands from their hips, or (4) remained out of the test position for longer than 5 seconds (Domingo, 2004; Finnoff & Mildenberger, 2005). Timing began when participants were in the testing position and their eyes closed. Once they were placed in the testing position they were encouraged to remain as motionless as possible until they hear the command, “stop.” They were also told to make any necessary adjustments if they lost their balance and to return to the testing position as quickly as possible.

After all demonstrations and instructions were given participants then performed two (1 right, 1 left), 20 second single-leg stances on a $46 \times 43 \times 13cm^3$ pad of medium-density foam. Random assignment was used to determine which leg was tested first. The order in which the legs were tested was recorded and repeated for future testing. Error scores for both the right and left legs were entered on a score sheet (Appendix C) next to the participant’s numeric ID.

After completing the baseline testing participants were told their scores. This was done to encourage participants to better their scores from previous tests. When each participant completed the pre-training test they were informed of their training schedule and asked by investigators to avoid any balance practice other than what they do during formal training with researchers.

Schedules for the two groups were as follows: The control group was instructed to return in 2 weeks at the same time on Friday and in 4 weeks at the same time on Friday for identical testing. Participants who were in the training group completed a training session after they completed their initial testing. The training group was instructed to return to the USU Wellness Center on Mondays, Wednesdays, and Fridays for a total of 11 training sessions. Training sessions consisted of six, 20-second bouts of a single-leg stance, of the dominant leg, on the $46 \times 43 \times 13cm^3$ foam pad with 20 second rest periods between bouts. Total training time on the foam was 3 minutes each session for a total of 33 minutes of training during the experiment. The sessions were scheduled with participants at the same time each day and lasted about 12 minutes each. Phone calls and in class reminders were used to improve compliance to testing and training times.

Data Analysis

To evaluate whether training had an effect on balance scores researchers used a repeated-measures analysis of variance. Dependent variables were balance scores and independent variables were group, leg, and gender. The time of test was defined as the within-subjects factor with 3 levels (pre, post1, and post2). There were three between-subjects factors, each with 2 levels. They were group (control and training), leg (dominant and non-dominant), and gender (male and female). Further examination was performed using Scheffe’s post hoc analysis. An alpha level of 0.05 was used to denote statistical significance throughout the analysis. Statistical analysis was performed using Statistica software (version 7.1, 2006; StatSoft, Tulsa, Oklahoma).

CHAPTER IV

RESULTS

Analysis of the balance error scores revealed two statistically significant results and two results that were not statistically significant but important to this study. The two results that were not statistically significant were the test by leg and test by gender calculations. The test by leg calculation was not significantly different (see Table 2) and suggests as one leg improved so did the other regardless of the amount of training. These findings were true when the training group was analyzed separately as well (Figure 1).

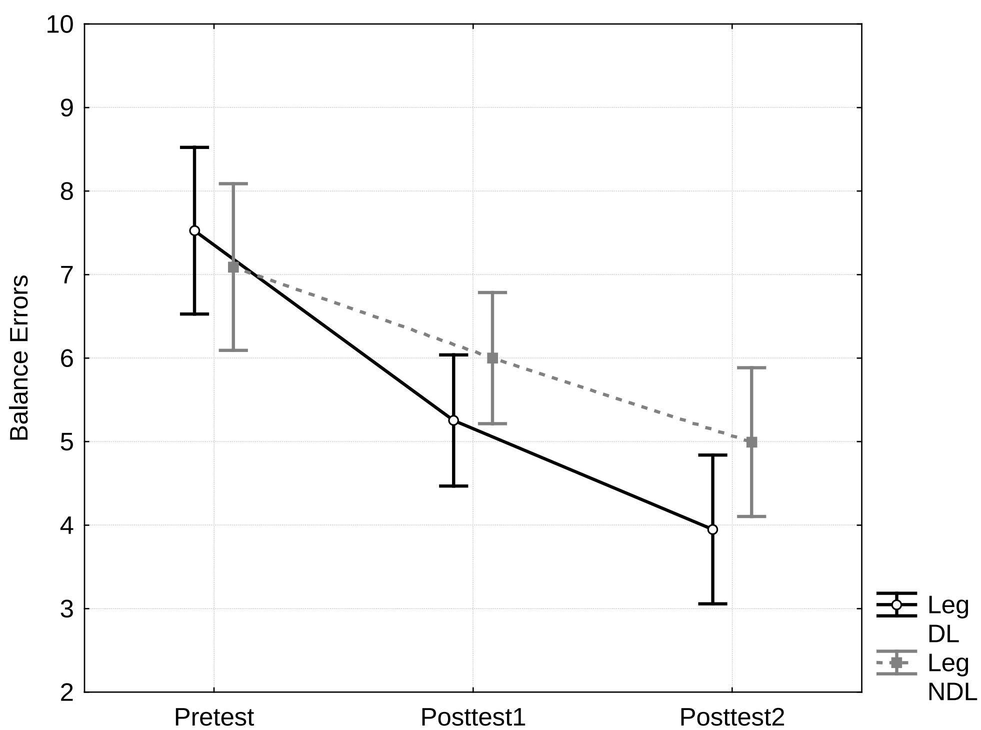

Figure 1. Error scores across tests for each leg of the training group. F (2, 64) = 2.34, p = 0.10, $\eta_p^2 = 0.07$. Vertical bars denote 0.95 confidence intervals.

Table 2

Repeated Measures Analysis of Variance with Effect Sizes

Effect	SS	*df*	MS	*F*	*p*	η_p^2
Intercept	7087.407	1	7087.407	1438.253	0.000000	0.958674
Gender	0.024	1	0.024	0.005	0.944512	0.000079
Group	3.403	1	3.403	0.691	0.409171	0.011015
Leg	7.866	1	7.866	1.596	0.211166	0.025100
Gender x Group	7.567	1	7.567	1.536	0.219938	0.024170
Gender x Leg	0.005	1	0.005	0.001	0.975811	0.000015
Group x Leg	0.164	1	0.164	0.033	0.855657	0.000538
Gender x Group x Leg	0.832	1	0.832	0.169	0.682493	0.002717
Error	305.523	62	4.928			
TEST	119.767	2	59.883	24.573	0.000000	0.283839
TEST x Gender	4.148	2	2.074	0.851	0.429427	0.013541
TEST x Group	31.581	2	15.791	6.480	0.002106	0.094621
TEST x Leg	7.291	2	3.646	1.496	0.228052	0.023560
TEST x Gender x Group	1.133	2	0.566	0.232	0.792965	0.003735
TEST x Gender x Leg	0.777	2	0.388	0.159	0.852886	0.002563
TEST x Group x Leg	5.358	2	2.679	1.099	0.336333	0.017422
TEST x Gender x Group x Leg	2.183	2	1.092	0.448	0.639991	0.007173
Error	302.186	124	2.437			

The test by gender also showed no significant differences (Figure 2) suggesting males and females performed similarly in balance tests independent of group or test. Looking at the main effect for gender the results showed males and females scores were quite similar (see Table 2).

Significant findings were the test by group interaction (Figure 3) as well as a significant main effect for test (Table 2). The test by group interaction explained the significant test effect meaning, in order to obtain a significantly different test score it depended on what group participants were in.

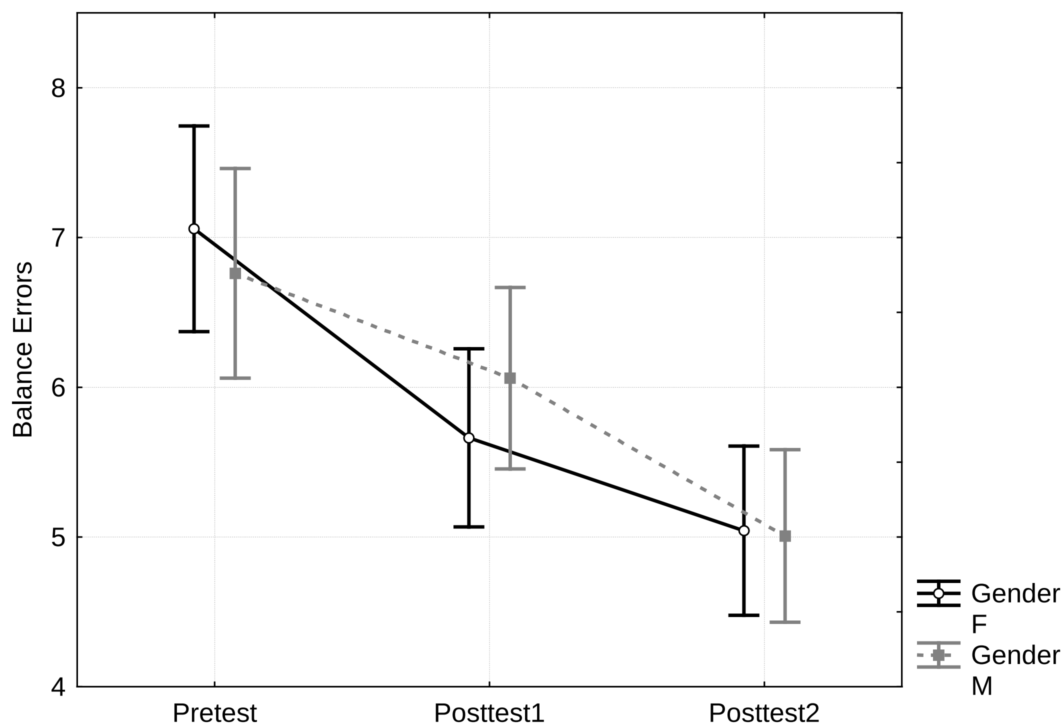

Figure 2. Balance error scores for gender with groups combined and across tests. *F* (2, 124) = 0.85, *p* = 0.43, $\eta_p^2 = 0.01$). Vertical bars denote 0.95 confidence intervals.

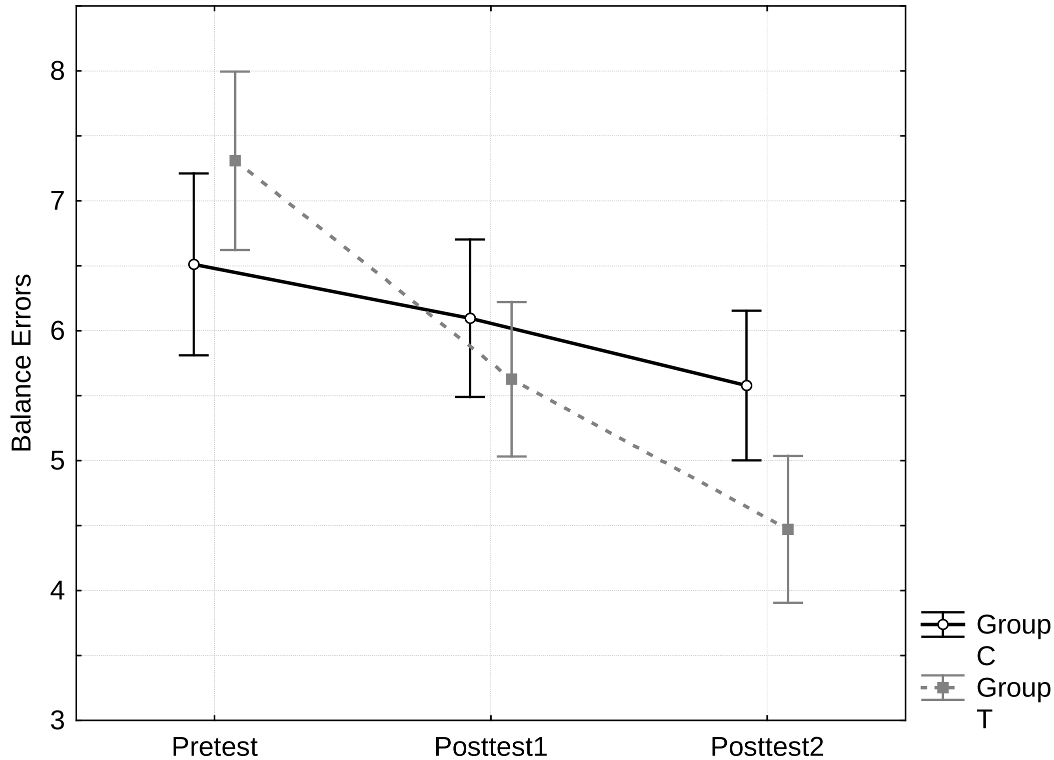

Figure 3. Balance error scores for groups across tests. *F* (2, 124) = 6.48, *p* = 0.002, η_p^2 = 0.10. Vertical bars denote 0.95 confidence intervals.

Further analysis of the test by group interaction showed no significant changes between test scores for the control group and significant changes in two of the three comparisons in the training group (Table 3). Further evidence of this test by group interaction is displayed in the posthoc analysis (Table 4). The Scheffe's table clearly shows the training group mean scores improved significantly over time whereas the control group scores improved just not significantly.

Table 3

Scheffe's Post Hoc Group Mean Score Changes with Legs Combined

Group	P – P1	*p*	*d*	P – P2	*p*	*d*	P1 – P2	*p*	*D*
Control	-0.32	0.98	0.17	-0.88	0.37	0.52	-0.56	0.82	0.33
Training	-1.72	.01*	0.97	-2.83	.01**	1.48	-1.11	0.11	0.65

Note. P = pretest. P1 = posttest1 or the 2-week test. P2 = posttest2 or the 4-week test. *d* = Cohen's *d*. Pooled MS Error = 3.27. **p* = 0.001045. ***p* = 0.0000001.

Table 4

Scheffe's Post Hoc Probability Scores of the Test by Group Interaction

Mean Scores Per Test			{1} 6.5000	{2} 6.1765	{3} 5.6176	{4} 7.3611	{5} 5.6389	{6} 4.5278
Cell#	Group	TEST	Mean 1 Comp.	Mean 2 Comp.	Mean 3 Comp.	Mean 4 Comp.	Mean 5 Comp.	Mean 6 Comp.
1	C	PRE		0.980889	0.371373	0.555638	0.555638	0.001375
2	C	POST1	0.980889		0.822929	0.191837	0.906828	0.015196
3	C	POST2	0.371373	0.822929		0.007907	1.000000	0.278673
4	T	PRE	0.555638	0.191837	0.007907		0.001045	0.000000
5	T	POST1	0.555638	0.906828	1.000000	0.001045		0.112941
6	T	POST2	0.001375	0.015196	0.278673	0.000000	0.112941	

Note. C = control group. T = training group. PRE = pretest. POST1 = test at week 2. POST2 = test at week 4. 1 = mean score of the control group pretest. 2 = mean score of the control group posttest1. 3 = mean score of the control group posttest2. 4 = training group pretest. 5 = training group posttest1. 6 = training group posttest2. Pooled mean squared error = 3.2673. *df* = 164.73.

CHAPTER V

DISCUSSION

The purpose of this study was to examine the effects of a four week single-leg stance training program on the Balance Error Scoring System scores of the trained and untrained legs to determine if balance can be learned without direct training and to examine what, if any, differences exist between males and females in CE and balance training.

The results of this study support the hypothesis that four weeks of unilateral balance training, using a single-leg stance on a foam pad, will not only decrease the error scores for the trained leg but decrease the error scores of the untrained leg as well. These results support the findings of Gauffin et al. (1988) and Rozzi et al. (1999) which found unilateral balance training not only improved balance on the TL but the UTL as well.

Regarding males and females, it was hypothesized that there would be no significant differences in BESS performance and CE effect between males and females. Results showed males and females performed nearly identical ($p = 0.95$) when compared across tests. Not only did genders score baseline scores evenly but as the training continued males and females improved at nearly the same rates. These findings agree with the recent findings of Iverson et al. (2008) who examined BESS performance and reported no significant differences between genders.

Specificity of training, was one of the factors believed to contribute to CE and was used in both the present study and in Rozzi, et al. (1999). Between the two studies the type of apparatus, measurements, and length of training were different but within each study participants trained and tested using the same apparatus and measurements and the length of training bouts were the same length as test bouts.

Another factor found to influence CE was the duration of training. Each of the three balance training studies found significant improvements in balance but used different durations of training (number of weeks, and time of each training session). While participants in the current study trained for only 33 total minutes and obtained significant results ($p = 0.0000001$) the participants in the other two unilateral balance training studies (Gauffin et al., 1988; Rozzi et al., 1999) also obtained significant results but with much longer training regimens, 400 minutes ($p < 0.001$) and 72 minutes ($p < 0.05$), respectively. These results on training duration also agree with previous BESS research (Susco et al., 2004; Valovich et al., 2003) which showed improvements in balance scores after just three administrations of the test. Results from the present study also aligned with the strength training study of Walters et al. (1960). After only 6 minutes maximal isometric training participants improved strength in the UTL 22 percent ($p < 0.05$). These findings and the findings of the present study oppose those of Guskiewicz et al. (2001) as well as Riemann and Guskiewicz (2000). Both of these BESS studies showed no significant improvements ($p > 0.05$) in balance after repeated trails.

The present study showed significant improvements for the training group overall as compared to the control group however the training group did not improve consistently. Improvements in the training group were between pretest to posttest1 and from pretest to posttest2, there was no significant improvement from posttest1 to posttest2. By examining Figure 1 the dominant leg or TL did not improve consistently whereas the non-dominant leg or the UTL appeared to have improved more linearly over the month long training. These findings are not consistent with Hortobágyi et al. (1999) who found CE gradually increased over time. Differences between the present study and the Hortobágyi et al. study were they tested strength instead of balance, the length of their study was 6 weeks rather than 4 weeks, and they tested participants weekly instead of biweekly as in the present study. With more testing points the present study would have had a clearer picture of the rate of CE.

Intensity of training was another factor said to contribute to CE. Walters et al. (1960) and Zhou's (2000) review of CE reported the more intense the training more CE occurred. Researchers of the two previous balance studies on reporting CE (Gauffin et al., 1988; Rozzi et al., 1999) did not specifically control for intensity. In the BESS study conducted by Valovich and others in 2003 data showed participants recorded more balance errors in the single-leg stance on foam than for any other stance. Researchers in the present study assumed participants would train at the highest intensity possible because of four factors. The first factor was the chosen stance the single leg stance on foam recorded the most errors for those in the BESS studies (Valovich et al.). The other three factors were instructions given to the participants. Those instructions were "remain as motionless as possible," "make any necessary adjustments if you lose your balance," and to "return to the testing position as quickly as possible." If the assumptions of maximal effort were not actual efforts by participants then this study would agree more with Sheilds et al. (1999) who found significant CE effects for participants who trained at only thirty percent of their maximal isometric test.

Limitations

Though the present study has shown significant CE effects of training and agrees with other research care must be taken when comparing different studies due to their different methodologies and analysis. As in all research this study also had a number of limiting factors. Noteworthy are the following: (1) training of the UTL during training; (2) balance training of participants outside of testing and training times; and (3) the ability to generalize the results.

As noted in the literature review a third factor believed to influence CE was unintentional training of the UTL during training. Researchers conducting this study were aware of the possible unintentional training effects on the UTL. Previous research has controlled for unintentional training through visual observations of the UTL moving during training of the TL (Jones & Rutherford, 1987) as well as EMG recordings of electrical activity in the UTL during training of the TL (Hortobágyi et al., 1999; Panin et al., 1961). Two main rationales were used to eliminate EMG recordings: (1) previous research suggests the EMG activity recorded for the UTL would be low (15-20% of maximal activity) (Panin et al.) and would not be enough to produce the end results (Hortobágyi et al.); and (2) during a single-leg balance activity it was expected that the uninvolved leg would be used by the participant to maintain balance. As was expected the UTL was observed moving during training and testing of all participants. Therefore it is important to note that some of the training in the UTL may have come from co-contractions.

The second limitation also had to do with training. With a study lasting four weeks researchers were unable to directly control for balance training by participants outside of the training sessions. Therefore researchers attempted to control for this by asking participants to avoid any balance practice other than what they do during formal training with researchers.

The ability to generalize the findings, with a small sample size (18 in training group) and narrow age range (18 – 31), researchers caution results may not generalize to all populations especially those over 50. Iverson et al. (2008) also reported age has a small to medium correlation with BESS scores being consistent across age until 50 years when they worsen. Lastly, researchers set out to determine if balance training would ffect the UTL because clinicians may be able to use this type of treatment in rehabilitation settings. Since all of the participants in the present study reported no previous spine, hip, leg, or ankle injury in the last year that have limited daily activities generalizing improvements in balance to the UTL of injured patients would be inappropriate.

Finally, the fact that the study was unblinded because participants were told their scores after each test questions the internal validity of the experiment. Did the improvements in the training group come from the training or from the participants desire to improve? This may also explain the improvements of the control group without practice. The unblinded aspect of the study is an important aspect for further research and clinical application as well.

Implications and Further Research

While conducting the present research and after reviewing the findings many ideas for further research were formed. A follow up on the limitation of being able to generalize the findings to the injured population would be beneficial to the rehabilitation community. Participants who have had a previous spine, hip, leg, or ankle injury in the past year would be another population to examine. With balance errors of the training group improving two – three points clinicians may benefit from knowing patient's perception of balance improvements following training. Do patients feel more confident, self sufficient, and are they able to return to daily activities earlier. Another area that needs more research is retention. Balance and strength retention have been studied but looking specifically at balance learned through CE. Although CE appeared to have worked in the current study results for the UTL still lagged behind the TL in balance improvements. Perhaps visualization techniques or longer more difficult training sessions are possible areas of investigation for those investigating supraspinal or spinal effects of CE. Finally, the last implication of research would be to repeat this procedure to determine if the results are reproducible.

Conclusions

The purpose of this study was to examine the effects of a four week single-leg stance training program on the Balance Error Scoring System scores of the trained and untrained legs and to determine if balance can be learned without direct training and to examine what, if any, differences existed between males and females in CE and balance training. The results provided evidence that a four week single-leg stance balance training program consisting of only 22 minutes of total training does improve BESS performance of the TL and UTL and that males and females perform virtually the same on the BESS for the TL and UTL.

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APPENDICES

APPENDIX A

Informed Consent

The Effects of a Four Week Single-leg Balance Training Program on Balance Error Scoring System Scores of the Trained and Untrained Legs

Introduction

Dr. John Kras, Principal investigator, and Roger Davies, student researcher, from the Health, Physical Education, and Recreation (HPER) Department, are conducting a research study to determine the effects of a four week single-leg stance balance training program on the trained leg and the untrained leg in Utah State University students.

It is an ethical principal that the human subjects of a research protocol be informed of the purpose and benefits of the project; the research methods to be used; the potential risks or hazards of participation and the right to ask for further information at any time during the research procedures.

Your choice to participate is voluntary, and you are free to withdraw from the research project at any time without consequence.

Your signature at the end of this consent form will indicate that the principal investigator, or his agent, has answered all your questions and that you voluntarily consent to participate in this investigation.

Procedures

If you agree to be part of this study, you will be asked three questions concerning your medical history that will assess you current medical health with regards to participation in this study. Your height and weight will be measured and you will be asked to report your age and gender. All responses and measurement information will be kept confidential.

On the three testing days all participants will provide one performance of a single-leg stance on a two inch foam pad for both the right and left legs. These performances will be conducted at the HPER wellness center, room 152, and will take approximately three minutes per participant.

If you are selected to be part of the treatment group you will need to return to the HPER wellness center on Monday,

Wednesday, and Friday each week from June 13, 2005 to July 8, 2005 to perform a balance training program. Each training session will last approximately six minutes and will consist of six, twenty second bouts of single-leg stance on a two inch pad with twenty seconds rest between each bout.

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Discomforts and Risks
Your risk of injury by participating in this study is considered to be minimal. You may experience soreness or fatigue in leg muscles after training sessions, but sensible rest between training sessions will help with fatigue.

Exclusions
If you answer 'yes' to any of the following questions please notify the principal investigator or his agent. All of your responses to any conditions will be treated confidential.

- Have you ever been diagnosed, by a doctor, with a vestibular disorder?
- Are you currently suffering from an injury to the spine, hips, legs, or ankles that restrict your daily activity?
- Have you had a spine, hip, leg, or ankle injury in the past 1 year for which you have seen a doctor?
- Have you had any previous balance training in the past 1 year?

Benefits to Participants
There may or may not be any direct benefit to you from these procedures. However, results from this study may help rehabilitation specialists in designing training programs for patients who are able to exercise one limb but not the other due to surgery, injury, or other ailments and thus speeding the patients' recovery time.

There will be extra credit offered for those in Dr. Heath's and Dr. Fronske's classes. For those in these classes who do not wish to participate in the study there will be alternate opportunities to obtain extra credit.

Reimbursement for Medical Treatment
It is not the policy of Utah State University, its agents or its employees to compensate for or provide free medical care for human subjects in the event that any injury results from participation in a human research project.

In the unlikely event that you become ill or injured as a direct result of participating in this study, you understand that any medical care you receive will not be free of charge.

If you feel you have sustained an injury as a result of your participation in this research project, please contact the Institutional Review Board Office at (435)797-1821.

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Confidentiality
According to state and federal regulations it is mandatory that any information provided by you in relation to this study will be kept confidential. Your identity will be coded and will not be released with any published results. Only the John Kras, the principal investigator, and Roger Davies will have access to the data. All data will be kept indefinitely in a locked drawer in a locked office.

Other Information
Your participation in this study is strictly voluntary. You may refuse to participate or withdraw at anytime without consequence or loss of benefits. If you have any further questions about your participation in this study or your rights as a participant, or if any problems arise, please contact Dr. John Kras at (435)797-3881 or Roger Davies at (435)797-6777.

IRB Approval Statement
The Institutional Review Board (IRB) for the protection of human participants at USU has reviewed and approved this research study.

Copy of Consent
You have been given two copies of this Informed Consent. Please sign both and retain one for your records.

Investigator Statement
"I certify that the research study has been explained to the individual, by me or my research staff, and that the individual understands the nature and purpose, the possible risks and benefits associated with taking part in this research study. Any questions that have been raised have been answered."

Informed Consent
The Effects of a Four Week Single-leg Balance Training Program on Balance Error Scoring System Scores of the Trained and Untrained Legs

_______________________________ ______________
Principal Investigator Date
Dr. John M. Kras
(435)797-3881

_______________________________ ______________
Student Researcher Date
Roger Davies
(435)797-6777

I (participant) have read and understand this Consent Form and I am willing to participate in the study.

____
Participant (Print)

_______________________________ ______________
Participant (Signature) Date

APPENDIX B

Demographic Information of Participants

Code#	***Name***	***T/C***	***Dominant Leg***	***Age***	***Gender***	***Height***	***Weight***	***BMI***

APPENDIX C

Score Sheet

Code #	***Name***	***T/C***	***BTL***	***BUL***	***FU1TL***	***FU1UL***	***FU2TL***	***FU2UL***