BALANCE: RELATIONSHIP TO FUNCTIONAL MOVEMENT AND TRAINING TO MINIMIZE ASYMMETRY

by

Layci J Harrison

A Dissertation Submitted in Partial Fulfillment
of the Requirements for the Degree of
Doctor of Philosophy

Middle Tennessee State University
August 2018

Dissertation Committee:

Dr. Jennifer L. Caputo, Chair

Dr. John M. Coons

Dr. Dana K. Fuller

Dr. Lindsey K. Lepley

Dr. Sandra L. Stevens

This work is dedicated to my parents and my sister.

You have never doubted me and always encouraged me to continue chasing my dreams. Thank you for your love and support throughout my academic career. I am fortunate to have a family that is always there for me even when there are hundreds of miles between us. I hope I will continue to make you proud.

I love you,

Layci

ACKNOWLEDGEMENTS

I would like to acknowledge my mentors from Lock Haven University, Cumberland University, and Middle Tennessee State University. Thank you for your advice which has guided both my academic and professional career. Without the support of mentors from these multiple phases of my career I would have never achieved this goal.

I would also like to acknowledge my family. Both my parents as well as my mother-in-law, father-in-law, and extended family have shown me unconditional support and love throughout this process. Specifically, I would like to acknowledge my husband, Daniel. He has continued to encourage me even when I made it difficult. Thank you, Daniel, for reminding me to celebrate every small accomplishment. Your positive attitude has helped me through this journey.

Lastly, I would like to acknowledge my friends. Thank you for your understanding and the continuation of kind words while I was working toward my goals. To those friends who have turned into family, specifically those who are working toward the same goal, thank you for struggling and laughing with me. You have made this process truly enjoyable.

ABSTRACT

Functional movement assessments are used to predict injury in multiple populations, but the components that most contribute to functional movement are unknown. Identifying the influence of static balance via the Balance Error Scoring System (BESS) and dynamic balance via the Y-Balance Test (YBT), can provide valuable information to clinicians. This information can be used to help individuals improve functional movement screening (FMS) scores which, in turn, can reduce injury risk. After injury, some individuals experience anterior balance asymmetry, which further increases injury risk. However, early balance training on a limb during rehabilitation is often contraindicated. The cross-over effect, which occurs when training benefits are observed in an untrained limb following training of the contralateral limb, may be helpful in minimizing the development of balance asymmetries following injury. In study one of the dissertation, the contributions of static and dynamic balance on functional movement were evaluated and the contributions of BESS and YBT scores to FMS scores were determined. The effects of unilateral balance training on bilateral anterior reach in those with a bilateral asymmetry in anterior reach was tested in the second study.

In the first study, participants from the general population ($N = 71$) completed the FMS, the YBT, and the BESS. Together ($p < .001$, $R^2 = .54$) and individually, both YBT ($p < .001$, $R^2 = .498$) and BESS ($p < .001$, $R^2 = .321$) were significant predictors of FMS scores. When controlling for age ($p < .001$, R^2 *Change* = .364) and history of lower body surgery ($p < .001$, R^2 *Change* = .532), the YBT and the BESS were still significant predictors of the FMS. Risk of injury according to YBT risk and FMS risk were not

associated, $\chi^2(1, N = 77) = 1.20,$ p = .273, *Cramer's V* = .125. There was a significant association between BESS risk and FMS risk, $\chi^2(1, N = 77) = 9.27,$ p = .01, *Cramer's V* = .347.

In the second study, a subgroup from the first study (N = 16) with an anterior reach asymmetry completed 5 weeks of balance training on the leg with the better balance according to the YBT. After 5 weeks of balance training, there was not a significant interaction between group and time for the trained leg (*G-G p* = .594, n^2_p = .035) indicating the training was not effective at improving anterior reach of the trained leg. There was also not a significant interaction between group and time for the untrained leg (*G-G p* = .403, n^2_p = .028), showing no cross-over of balance ability to the untrained leg.

Overall, static and dynamic balance both contribute to functional movement. This information can be used when developing training and rehabilitation protocols to reduce injury risk as measured by FMS. However, the training outlined in this study did not significantly improve anterior reach of the trained or untrained leg in individuals with an anterior reach asymmetry. As a result, more research in needed to identify a training protocol to improve anterior reach and, therefore, reduce injury risk in this population.

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER III Page

CHAPTER IV

LIST OF FIGURES

CHAPTER IV Page

LIST OF APPENDICES

CHAPTER III Page

CHAPTER IV

CHAPTER I

DISSERTATION INTRODUCTION

Functional movement assessments have been used to predict injury in multiple populations, but the components that make up functional movement or training to improve functional movement scores are unknown; therefore, there is a need to explore the benefits of balance training on functional movement. Given the importance of balance ability, clinicians incorporate balance training in rehabilitation after injury. After injury, unilateral balance training may be contraindicated, making it difficult to improve balance ability. Cross-over effect training, a technique using unilateral limb training for bilateral limb benefits, may be a way to improve balance and reduce bilateral balance asymmetries which have been shown to increase injury risk.

Balance ability, both static and dynamic, is important for daily activities and skill development (Haywood & Getchell, 2009). Static balance and dynamic balance are used simultaneously in activities such as walking and sport performance (Haywood & Getchell, 2009). Although there are many ways to assess balance, clinicians and researchers prefer methods that are cost effective and require minimal training. Such assessments include the Balance Error Scoring System (BESS) and the Y-Balance Test (YBT). These assessments have similarities including sensitivity to detect ankle instability (Docherty, Valovich McLeod, & Shultz, 2006; Olmsted, Carcia, Hertel, & Shultz, 2002), the ability to assess changes in balance after an intervention, and both are easy for clinicians to administer and participants to complete. After joint injury, balance and strength deficits are common (Evans, Hertel, & Sebastianelli, 2004). Incorporating balance training into rehabilitation can reduce risk of re-injury (Mattacola & Dwyer, 2002) and may also improve functional movement.

The BESS is frequently used to assess balance changes due to concussions, ankle instability, and muscular fatigue (Bell, Guskiewicz, Calk, & Padua, 2011). The BESS is used to assess static balance under 6 conditions. The test consists of three, 20-second stances including double leg stance, single leg stance on the nondominant leg, and tandem stance with the dominant leg in front. All three stances take place on a firm surface and on a foam surface.

In contrast, the YBT measures dynamic movements which are more applicable to everyday activities. Frequently used in preparticipation exams, the YBT has been shown to predict injury risk in young, active populations (Miller et al., 2017; Plisky, Rauh, Kaminski, & Underwood, 2006). Specifically, an anterior asymmetry greater than 4cm can increase injury risk up to 2.5 times (Plisky et al., 2006). Balance is measured as relative reach distance in anterior, posterior medial, and posterior lateral directions (Gribble, Hertel, & Plisky, 2012). Postural control can be analyzed by individual direction or as a composite average of the three directions.

Balance training is commonly used to correct bilateral asymmetries associated with joint injuries (Bonetti, Schneider, Barbosa, Ilha, & Faccioni-Heuser, 2015; Lephart, Pincivero, Giraldo, & Fu, 1997; Sarabon, 2012) and after stroke (Gok, Geler-Kulcu, & Alptekin, 2008). If the goal is injury prevention or rehabilitation, balance training should take place three times a week for at least 4 -6 weeks, (Sarabon, 2012). The balance program should progress from mostly static, simple movements to dynamic, difficult movements (Mattacola & Dwyer, 2002). Clinicians can use unstable surfaces such as foam pads and wobble boards or create unstable environments using perturbations (Sarabon, 2012).

Movement patterns are studied to predict occupational or sport performance. The Functional Movement Screening (FMS) is used as a preparticipation assessment in which deficits are corrected to avoid injury (Cook, Burton, Hoogenboom, & Voight, 2014; Cook, Burton, Kiesel, Rose, & Bryant, 2010.). The 7-movement assessment includes a deep squat, hurdle step, inline lunge, trunk stability pushup, rotary stability, shoulder mobility, and straight-leg raise. These specific movements are used to assess a combination of flexibility, strength, and neuromuscular control (Cook et al., 2010). Scoring is based on a scale of zero to three for each movement where a score of zero means there was pain with the attempted movement. A score of one indicates the participant had no pain, but was unable to complete the movement. A score of two means the participant could complete the movement with compensatory movements and a score of three means the participant completed the movement with no pain and no compensatory movements (Cook et al., 2010). Most of the movements require scoring of both the left and right sides of the body, but only the lowest score is used when calculating the total score (Cook et al., 2010).

Both the FMS and YBT have been used together to identify those with a history of injury (Chimera, Smith, & Warren 2015) but, to the author’s knowledge, no one has identified the specific elements that contribute to successful functional movement or how to improve functional movement scores. If the FMS will continue to be used to predict injury, it is crucial to explore ways to improve functional movement. Core strength does not have a significant effect on functional movement patterns (Okada, Huxel, & Nesser, 2011). Furthermore, Frost, Beach, Callaghan, and McGill (2012) concluded that even with strength training or movement coaching, some participants effectively and safely compensate for their movement deficits leading to a low FMS score; therefore, the scoring system may be flawed, and researchers may not see an increase in functional movement score after strength training. Kiesel, Plisky, and Butler (2011) suggested using an individualized plan to correct functional movement deficits. By identifying and targeting specific muscle groups associated with the deficit, they were able to decrease the number of individuals at risk of injury according to the FMS. Also, a combination of strength and balance training has been shown to increase FMS scores (Wang et al., 2016).

During times when bilateral limb training may be contraindicated, such as after injury, the cross-over effect has been shown to be an effective rehabilitation technique. The cross-over effect is the bilateral gain in strength or balance after unilateral training (Farthing, Borowsky, Chilibeck, Binsted, & Sarty, 2007; Farthing & Chilibeck, 2003). It is understood that the cross-over effect is likely due to changes in neural activation (Farthing et al., 2007), but the actual mechanism remains unknown. While the optimal training period for a cross-over in strength is 5-12 weeks (Dagert & Zehr, 2013; Lepley & Palmieri-Smith, 2014; Magnus et al., 2013; Munn, Herbert, Hancock & Gandevia, 2005), more research is needed to determine the volume of training needed for a cross-over of balance ability. Both Oliveira, Silva, Farina, and Kersting (2013) and Schlenstedt, Arnold, Mancini, Deuschl, and Weisser (2016) were able to show increases in balance ability using the cross-over. While a progressive single leg stance protocol can enhance reactions to perturbations (Oliveira et al., 2013) and increase static balance (Schlenstedt et al., 2016), there is no research on the cross-over of functional or dynamic balance ability.

Overall Purpose

Due to similarities in the use of the FMS, YBT, and BESS in preparticipation exams and as assessments of training protocol outcomes, the purpose of this research is to first, identify any bivariate relationships between FMS scores and dynamic balance (YBT), static balance (BESS), or a combination of both dynamic and static balance, respectively. The second purpose is to determine if FMS scores can be predicted based on dynamic and static balance assessment scores. The third purpose of this research is to examine the effect of unilateral balance training on bilateral anterior reach in those with a bilateral anterior reach asymmetry.

Significance of Studies

Examining the relationship between functional movement and balance will enhance the current research by highlighting potential components to include when trying to improve functional movement. The improvement of functional movement is crucial due to the relationship to noncontract injuries. Furthermore, when asymmetries in balance are noted, such as after injury, the application of the results from balance training could provide a training technique that clinicians can use when unilateral weight-bearing and balance training are contraindicated due to injury.

CHAPTER II

REVIEW OF LITERATURE

This review of the literature begins with definitions of balance and postural control followed by a description of common balance assessments to measure static and dynamic balance in healthy and injured populations. The review then transitions to a focus on functional movement and how asymmetries in both balance and movement patterns can lead to an increased risk of injury or re-injury, followed by a description of research aimed at correcting asymmetries. Lastly, the cross-over effect is defined as a method of rehabilitation to potentially maintain strength and balance of an uninjured limb while decreasing the deficit typically present in the injured limb after injury and/or immobilization.

Balance and Postural Control

Although balance is a vague term, it is generally defined as reactions of the body to avoid falls by maintaining center of body mass within limits of stability (Winter, 1995; Woollacott & Shumway-Cook, 1996). More specifically, postural control is defined by Pollock, Durward, Rower, and Paul (2000) as either predicting or reacting to maintain, recover, or achieve balance during activity. The main components contributing to the central nervous system's ability to maintain balance are the visual, somatosensory, and vestibular systems (Woollacott & Shumway-Cook, 1996). Specifically, postural control has three main components and respective subcomponents: biomechanics, motor coordination, and sensory organization (Horak, 1997). Voluntary movement, reaction to the environment, and changes in surfaces will also affect postural control (Pollock et al., 2000). The body must provide proper force from the hip, knee, and ankle joints to maintain position and successfully complete tasks with balance and postural control (Taube & Gollhofer, 2013). Decreases in postural control due to changes in any of the mentioned components can lead to falls (Alexander, 1994).

Balance and stability are required to complete many daily activities and skills (Haywood & Getchell, 2009). The human body is constantly receiving information which helps maintain balance in the body for static activities, when the body is stationary, and in dynamic activities, which require maintaining balance during movement and directional changes (Clark, Lucett, McGill, Montel, & Sutton, 2018; Haywood & Getchell, 2009). For example, walking requires an individual to leave a stable two-foot position and propel forward on one foot (Haywood & Getchell, 2009).

Balance can be divided into two categories: reactive and proactive (Woollacott & Shumway-Cook, 1996). Reactive balance is controlled by muscular responses and is initiated when the body is moved away from a stable position (Woollacott & Shumway-Cook, 1996). Usually this strategy is used when a person is standing still, and an outside force creates movement of the body. Proactive balance involves the anticipation of destabilizing movements (Woollacott & Shumway-Cook, 1996). For example, when voluntarily moving the body to complete a task such as bending forward to pick up an object, proactive balance activates muscles to counteract the center of mass shift and avoid a fall (Woollacott & Shumway-Cook, 1996).

Assessments of balance are used to either identify a deficiency or identify the cause of a deficiency (Mancini & Horak, 2010). However, most clinical balance assessments are used to identify deficiencies in balance (Horak, 1997; Mancini & Horak, 2010). Common clinical assessments utilized to measure stability and function include the Timed “Up and Go Test,” the Balance Error Scoring System, the Romberg Test, and the single leg stance test (Mancini & Horak, 2010). Also, commonly used, the Star Excursion Balance Test, is a dynamic balance assessment used to measure postural control while an individual is moving (Gribble et al., 2012). Posturography is becoming popular as a method to identify center of pressure of the force under the feet during a simulated fall (Haywood & Getchell, 2009). Movement of center of pressure, or sway, is used as a measure of stability (Alexander, 1994). Postural sway can be used as an index of fall risk, but cannot identify the cause of increased risk (Horak, 1997; Mancini & Horak, 2010). In addition, posturography requires expensive equipment such as a force plate and an enclosure to manipulate outside stimuli (Haywood & Getchell, 2009).

Assessments used to identify the cause or source of a balance deficit include the Balance Evaluation Systems Test and the Physiological Profile. These assessments have limitations though and require a significantly longer amount of time than the clinical balance assessments identified above and are specific to certain populations, as they are not sensitive enough for use with healthy populations (Mancini & Horak, 2010). Although clinical balance assessments are useful to identify balance deficits related to specific tasks or changes following a balance intervention, there is no single assessment that can evaluate all components of balance (Horak, 1997). Due to the complexity of balance, more research is needed to determine the best balance assessments and the relationship that balance shares with functional movement. Researchers need to determine tests that are user friendly for the clinician, unburdensome for the participant, and valid measures of balance. Within these criteria, the Balance Error Scoring System and the Y-Balance Test are the common clinical assessments of static and dynamic balance, respectively.

Balance Error Scoring System. The Balance Error Scoring System, also known as BESS, is a clinical test used to evaluate static balance under 6 conditions (Bell et al., 2011). The BESS consists of three, 20 second stances that are scored based on postural deviations. The test includes a double leg stance, a single leg stance on the non-dominant leg, and a tandem stance with the dominant leg in front on a firm surface and on a foam surface (Bell et al., 2011). The BESS has been used to identify concussions, ankle instability, and fatigue (Bell et al., 2011). The BESS shows moderate to good reliability and correlates well with other balance tests (Bell et al., 2011). Some researchers have suggested eliminating the first two conditions, double leg stance on a firm surface and double leg stance on a foam surface, due to small score variances (Hunt, Ferrara, Bornstein, & Baumgartner, 2009). The low variability in scores may be due to homogeneous samples comprised of young athletes.

When using BESS as a recovery assessment or for research, it is important to limit the number of tests conducted. When participants completed the BESS 5 and 7 days after baseline measurements, respectively, followed by a post-test 30 days later, a learning curve was observed compared to the control group, who only completed a pre- and a post-test (Valovich, Perrin, & Gansneder, 2003). In addition, the BESS is sensitive to fatigue. Wilkins, McLeod, Perrin, and Gansneder (2004) found BESS scores significantly increased (postural stability decreased) if participants completed a fatigue protocol prior to the BESS compared to those who did not complete the fatigue protocol.

The 20-minute fatigue protocol consisted of jogging, sprints, pushups, and sit-ups. When using the BESS to evaluate an injury or to detect changes following strength or balance protocols, the clinician should schedule adequate time to avoid testing while the participant is fatigued.

The BESS can be used to differentiate between those with and without functional ankle instability (Docherty et al., 2006). In a study with Division I college athletes, the BESS was able to distinguish between individuals with a history of lateral ankle sprain and feelings of ankle instability or the ankle “giving way” and those without ankle symptoms (Docherty et al., 2006). Although this test is able to eliminate the visual system and test balance relying on the vestibular system and proprioception by requiring eyes to be closed, the BESS only measures static balance. Although many tests utilize the static positions included in the BESS, other tests assess balance during movement, which may be more relevant to daily function of most populations.

Star Excursion Balance test / Y-Balance Test. The Star Excursion Balance Test, now adapted to be called the Y-Balance Test (YBT), has been used as a screening tool to predict injury and detect changes in balance due to training and rehabilitation (Filipa, Byrnes, Paterno, Myer, & Hewett, 2010; Gribble et al., 2012; Smith, Chimera, & Warren, 2014). The YBT provides a measure of dynamic postural stability that is more closely related to the demands of physical activity than static balance because of the demands the test places on the ankle and hip joints (Gribble et al., 2012; Winter, 1995). Reach distance, measured in centimeters, is used as an index of dynamic postural control (Gribble et al., 2012). Continued revision of the test has decreased the assessment from eight axes (anterior, posterior, medial, lateral, anterior medial, anterior lateral, posterior medial, and posterior lateral) to three axes (anterior, posterior medial, and posterior lateral). Identification of the learning curve associated with the test and consequential adaptations have lead the YBT to be a valid and reliable measurement of dynamic postural control given that the participant completes 4 trials in each direction (Gribble et al., 2012.)

Inclusion of the YBT in preparticipation exams for athletics has been suggested with the support of multiple research studies. Smith and associates (2014) included the YBT in preparticipation exams of Division I athletes and monitored injuries throughout the seasons. Injuries were recorded by asking athletic trainers to report any incident in which an athlete reported to the athletic training room for a noncontact muscular injury and received an intervention. They found that athletes with an anterior asymmetry greater than 4 cm had an increased risk of noncontact injury (Smith et al., 2014). Similar results were found by Plisky and associates (2006) who showed individuals with an anterior reach asymmetry greater than 4 cm had significantly greater odds of experiencing a lower body muscular injury than those with less than a 4-cm anterior asymmetry. Specifically, individuals with an asymmetry in anterior reach were 2.5 times more likely to experience a lower extremity injury and females with a decreased normalized composite score (less than 94%) were 6.5 times more likely to experience a lower body injury (Plisky et al., 2006). Plisky and associates (2006) also identified that a decreased limb composite score of the right limb predicted injury in high school basketball players. Furthermore, athletes who specialized in one sport had a greater anterior reach asymmetry than those who played multiple sports likely due to alterations in movement patterns derived from the limited tasks of single sports (Miller et al., 2017). Using the YBT as a prediction tool can identify multiple factors that place an athlete at an increased risk of injury.

The YBT has been shown to be sensitive enough to detect differences in dynamic balance between healthy groups and individuals with multiple injuries. Olmsted and associates (2002) used both a between and within subjects' design to examine the sensitivity of the YBT to identify chronic ankle instability (CAI). Reach was significantly less in the limb with CAI compared to both the participants' healthy limb and the matched limb of a group without CAI (Olmsted et al., 2002). Because of the sensitivity of the YBT to detect dynamic postural stability differences due to CAI and the low cost and ease of use, this balance test is an important assessment utilized during injury rehabilitation (Olmsted et al., 2002).

Using a similar design to Olmsted and colleagues (2002), Herrington, Hatcher, Hatcher, and McNicholas (2009) found decreased postural stability using the un-adapted YBT in individuals 5 months to 2 years post anterior cruciate ligament reconstruction (ACLR). The authors speculated that a disruption of the mechanoreceptors after ACLR leads to decreased feedback, reducing proprioception, and, in turn, decreasing dynamic postural control (Herrington et al., 2009). Because there was a difference in reach between the nonsurgical leg of the ACLR group and the matched leg of the healthy group, the YBT may be used to predict injury, if a lack of dynamic postural control is leading to ACL tears (Herrington et al., 2009).

To reduce lower body injuries in high school soccer players, Filipa and associates (2010) conducted an 8-week training protocol including lower extremity strengthening and core stability. The training group improved the overall composite score on the YBT by increasing posterior lateral and posterior medial reaches, but not the anterior reach (Filipa et al., 2010). As the YBT is sensitive to changes in balance following lower body strength and core stability training, it may be used to test the effectiveness of rehabilitation and training.

Both the BESS and YBT have been used to predict injury, evaluate differences in injury history, and measure the effects of training protocols. Although not without limitations, these assessments are cost effective and easy to use. They are both used in multiple populations without extensive training needed for the clinician or the participant. Both assessments are useful as preparticipation and pre-intervention measurements and should continue to be utilized as applicable tools for clinicians and researchers in multiple settings. These assessments have frequently been used during preparticipation exams and are useful for identifying bilateral asymmetries in balance ability.

Balance Training for Injury Rehabilitation and Balance Asymmetry

Balance training is used to improve joint stability, decrease risk of injury (McKeon & Hertel, 2008) and to reestablish motor-system function after injury (Bonetti et al., 2015; Lephart et al., 1997; Sarabon, 2012). Tissue damage and swelling due to joint or ligamentous damage can damage sensory input as well we cause changes in length tension relationships and arthrokinematics (Clark et al., 2018). These changes lead to a decreased limit of stability which results in flawed movement patterns by limiting the amount of movement an individual has without losing balance (Clark et al., 2018). The simple balance assessments mentioned above can be used to assess sensory deficits after injury (Mattacola & Dwyer, 2002). During injury, specifically of the knee, mechanoreceptors are damaged which makes it difficult for an individual to sense changes in joint position (Lephart et al., 1997) and maintain postural control (Wikstrom, Naik, Lodha, & Cauraugh, 2009). These deficits protect the joint by limiting force production of the muscle during the acute phases of injury (Lephart et al., 1997), but can cause balance deficits in the uninjured leg as well (Zätterström, Fridén, Lindstrand, & Moritz, 1994). These deficits may be due to a decreased neural environment around the injured joint (Needle, Lepley, & Grooms, 2017). Balance ability should be reestablished before an individual with an injury can progress to more challenging rehabilitation (Mattacol & Dwyer, 2002).

Although there is not a firm decision on the dose response or specific exercises needed to improve balance (McKeon & Hertel, 2008; Wikstrom et al., 2009), The National Strength and Conditioning Association (NSCA) suggests balance training three times a week for at least 4 weeks and that each balance exercise should consist of at least 1 set lasting at least 20 seconds (Sarabon, 2012). McKeon and Hertel (2008) suggested balance training for a longer duration, at least 6 weeks, to prevent reinjury or as rehabilitation for lower body injuries such as acute ankle sprains. They also suggested a progression, especially with individuals with an injury, that starts with slow, simple, controlled movements. As the individual progresses, the movements should increase in speed and complexity (Sarabon, 2012). Balance progression should move from double leg to single leg, eyes open to eyes closed, a firm surface to a foam surface, and finally from stationary exercises to balance exercise which require movement (Mattacola & Dwyer, 2002). Creativity of the clinician is encouraged when creating a balance training program based on goals for return to play or return to activity. Clinicians can alter stabilization by using foam pads or wobble boards and perturbations while imitating sport-related activities (Sarabon, 2012). Exercises such as perturbations, which train reactive balance, are suggested to reestablish neuromuscular mechanisms during the rehabilitation process (Lephart et al., 1997). Balance training is frequently utilized after knee and ankle injuries to correct sensory deficits present after joint injuries (Needle et al., 2017) and these techniques can be used with multiple populations and injuries such as after ankle sprains and post anterior cruciate ligament (ACL) injury.

Ankle instability and balance training. Ankle injuries lead to balance (Evans et al., 2004) and strength deficits of the involved limb (Holme et al., 1999). To protect the ankle and foot from further or recurrent injury, balance and muscular strength must be regained during the rehabilitation process (Mattacola & Dwyer, 2002). After joint injury there is not only a deficit in balance ability of the injured limb, but the uninjured limb can also present with decreased balance ability (Evans et al., 2004). Evans and associates (2004) reported collegiate athletes who suffered ankle sprains had significant deficits in balance ability compared to preinjury measures as measured by center of pressure and excursion velocity for both the injured and uninjured legs at days 1 and 7 after injury. The injured limb was still at a deficit 21 days post injury. The uninjured leg quickly improved, but a bilateral deficit was still present 21 days post injury. These researchers concluded that the bilateral deficit in balance may be a centrally mediated deficit and not solely due to damage to mechanoreceptors (Evans et al., 2004).

In a study involving 92 recreational athletes recruited directly from a hospital after being diagnosed with an ankle sprain, postural sway and ankle strength were significantly decreased on the injured side compared to the non-injured side 6 weeks after injury (Holme et al., 1999). These participants were randomly assigned to either a training or control group. Both groups completed at home exercises consisting of range of motion, strengthening, and balance while the treatment group was assigned to additional supervised physical therapy twice a week which included additional balance and strengthening exercises. Both groups eliminated the bilateral limb deficit in both strength and balance by 4 months post injury, but the treatment group had significantly less reinjury of the ankle in the 12-month follow up (Holme et al., 1999). These results support other researchers that have concluded increased balance training may prevent recurrent ankle injury (Holme et al., 1999; Wikstrom, et al., 2009).

Wobble boards have been used to train reactive balance in those with an ankle sprain. Wester, Jespersen, Nielsen, and Neurmann (1996) assigned 48 men and women to a wobble board training group or a control group after being diagnosed with an ankle sprain. Individuals in the training group completed 12 weeks of wobble board training including double leg stances, single stances, and maintaining balance with movements every day for 15 minutes while those in the control group did basic, traditional, acute ankle sprain treatment for swelling and pain. A follow up was completed 230 days after injury. Of the 24 participants in the training group, only 6 experienced another ankle sprain whereas in the control group, 13 of the 24 participants experienced another ankle injury. In addition, the treatment group had significantly less complaints of ankle instability than the control group. The authors concluded that 12 weeks of wobble board training can significantly reduce the chances of reinjury and ankle instability (Wester et al., 1996).

The addition of dynamic balance training to conventional therapy can improve balance ability in those with ankle sprains (Chaiwanichsiri, Lorprayoon, & Noomanoch, 2005). The Star Excursion Balance Test was used to train balance after ankle sprains. Men from an Armed Forces academy preparatory school were randomly assigned to a balance training or control group after experiencing an ankle sprain. The training group completed 10-minute sessions, 3 times a week, of Star Excursion Balance training. After 4 weeks of training, the single leg stance time of the injured limb in the control group was 2.2 times longer than the injured limb of the control group suggesting improved balance of the trained limb**.** Not only is balance training used during rehabilitation of ankle injuries, but also after knee injuries.

Anterior cruciate ligament reconstruction and balance training. Balance training is utilized after knee injuries such as ACLR. Some people opt out of surgical intervention following ACL injuries and attempt to return to sport or activity post rehabilitation (Cooper, Taylor, & Feller, 2005; Zätterström et al., 1994). Work that directly illustrates the positive effect of balance training on recovery after ACL injury has been conducted by Zätterström and colleagues (1994). Here investigators recruited 26 individuals who with ACL injures who remained ACL deficient (ACLD) to complete a supervised and at home coordination and postural control training program of the ACLD limb for 6 months. A reference group of 55 healthy participants was also included in the study. Balance was measured via body sway velocity during single leg stance of both the ACLD and uninjured limb on a force plate. At mid-point in the training, the uninjured limb was not significantly different than the matching leg of the reference group for speed of sway, but the ACLD limb remained significantly different than the reference group. However, at 12 months **(**6 months after training**)**, there were no differences between groups for postural sway and these results remained constant at the 36-month follow up showing positive long-term results after balance training. These results suggest that balance training the injured leg of participants with ACL instability can improve balance of the injured limb when compared to a reference group. Furthermore, balance training for at least 3 months can also reduce balance asymmetry witnessed after ACL injury in this population.

After surgical ACLR balance training is often included in rehabilitation programs. Risberg, Holm, Myklebust, and Engebretsen (2007) assigned individuals who had ACLR to a 6-month neuromuscular or strength training group. The neuromuscular training consisted of progressive balance, stabilization, and agility training and the strengthening group was focused on strengthening the quadriceps, gluteal region, and hamstrings. Interestingly, there were no differences between groups for the functional hop test, balance, and muscle strength possibly due to similarities in the treatments, but the neuromuscular training group showed a significant increase in functional knee scores on the Cincinnati Knee Score. Hence, the inclusion of neuromuscular training in ACLR rehabilitation lead to an increase in perceived function of the knee via the Cincinnati Knee Score after neuromuscular based training indicting improvement in activities such as walking, pain, stair climbing, and general activity (Risberg et al., 2007).

The clinician must consider that balance deficits may be present in both the injured and uninjured joint. Because bilateral balance asymmetry has been linked to increased injury risk (Plisky et al., 2006), the clinician should monitor balance of both the injured and uninjured limb and use rehabilitation to reduce the deficit. Although balance training may not completely eliminate the bilateral deficit, it can reduce the chances of reinjury to the joint (Wester et al., 1996). Similar to orthopedic injuries, neurological injuries can cause balance asymmetries between limbs in which balance training may be beneficial.

Stroke and balance training. Although different from orthopedic injuries, a stroke can cause bilateral balance deficits which can affect activities of daily living. Balance training has been shown to improve gait, activities of daily living, and sitting and standing balance in individuals who have experienced a stroke (Gok et al., 2008; Wester et al., 1996). Individuals who have had a stroke frequently participate in balance training during rehabilitation. Gok and associates (2008) used a new balance training and testing system, The Kinesthetic Ability Trainer, to test and train 30 participants post-stroke who had hemiplegia, decreased neuromuscular function on one side. The Kinesthetic Ability Trainer uses visual feedback and adjustment to an air-filled bladder based on the participant’s shifts in movement. Out of 30 participants, 15 participants completed conventional stroke rehabilitation while the other 15 participated in conventional training plus Kinesthetic Ability Training for 4 weeks. The researchers measured static and dynamic balance via the balance index on the Kinesthetic Ability Trainer and the Fugle-Meyer Stroke Assessment Instrument balance score. The group using the Kinesthetic Ability Trainer showed significantly better balance in the measured tests than the group that completed only conventional stroke rehabilitation. However, functional independence measurements were similar between the groups. The balance differences between groups were no longer apparent 3 months after the end of training. Although the additional balance training via the Kinesthetic Ability Trainer improved both static and dynamic balance ability better than conventional stroke rehabilitation, the training would have to be constant to maintain results in this population (Gok et al., 2008).

In those who have experienced hemiplegia as the result of a stroke, the best way to train balance has not been established, most likely due to there being an affected and a non-affected side. When traditional group balance training was compared to an individualized trampoline training protocol, 10, 30-minute trampoline sessions resulted in superior balance outcomes (Miklitsch, Krewer, Freivogel, & Steube, 2013). Both training protocols resulted in better post rehabilitation scores for functional tests including the 6-minute walk test and timed "Up and Go," but there were significant trends towards the trampoline training being the better rehabilitation technique. The researchers concluded trampoline training provided significantly better outcomes in postural control and trends towards improvements in functional mobility and activities of daily living (Miklitsch et al., 2013). These results could be due to both the dynamic balance training provided by the trampoline and the individualized training verses the group training class.

More research is needed on the topic; specifically, how balance can be affected by training the non-affected side to improve balance ability and functional movement of the effected side using techniques such as the cross-over effect for balance and strength training. Similar to balance ability, asymmetries in functional movement patterns can lead to an increased risk of injury.

Functional Management Systems

Many researchers study injury prevention to improve sport and occupational performance using assessments to rate physical activity or performance. However, few assessments are available to examine movement patterns and identify specific muscular weaknesses. To fill this void, functional management systems were developed to identify functional deficits which should be addressed prior to exercise training (Cook et al., 2014; Cook et al., 2010). Efficient, pain free movement should come before strength, endurance, coordination, training and acquisition of sport related skill (Cook et al., 2010). In fact, Ransdell and Murray (2016) indicated the foundation of athleticism is proper movement patterns due to the need to complete multiplanar movements explosively without compensation of posture or other muscle groups. Muscle imbalance can cause altered arthrokinematics causing poor movement efficiency which can lead to injury (Clark et al., 2018). Muscle compensation is cyclic as it creates muscle trauma which in turn creates further compensation of movements; therefore, addressing and correcting imbalances is crucial to prevent further injury (Clark et al., 2018).

Movement patterns are used to screen an individual because the brain operates in patterns versus individual movements (Cook et al., 2010). Movements, such as the overhead squat or inline lunge, are multidimensional in that they can assess flexibility, core strength, balance, and neuromuscular control by utilizing multiple movements that happen in unison (Clark et al., 2018). These patterns are how individuals complete functional activities efficiently and effectively and can be assessed quickly and simply using the Functional Movement Screening (FMS; Cook et al., 2014; Cook et al., 2010). Identifying deficits or bilateral asymmetries included in the FMS can help focus strengthening programs and rehabilitation aimed at return to sport or activity (Cook et al., 2014).

The FMS includes movements that are activity specific and the foundation for more complex skills (Cook et al., 2010). The evaluated movements are as follows: deep squat, hurdle step, inline lunge, shoulder mobility, active straight-leg raise, trunk stability push up, and rotary stability (Cook et al., 2010). The deep squat, hurdle step, inline lunge, trunk stability pushup, and rotary stability focus on core stability, flexibility, and coordination while the shoulder mobility and active straight-leg raise focus on flexibility (Cook et al., 2010). The seven movements are scored with a range of zero to three for each movement. Most of the movements require scoring of both the left and right sides of the body, only the lowest score is used when calculating the total score, a note should be made documenting the asymmetry (Cook et al., 2014; Cook et al., 2010).

A score of zero for a movement indicates the participant experienced pain during the movement and that specific assessment is ended. If the participant does not experience pain, but is unable to complete the movement, he/she receives a score of one for that movement. If the participant can complete the movement, but shows any compensatory movements, a score of two is assigned. If the participant is able to complete the movement with no pain or compensatory movements, a score of three is given. The highest total score across the seven movements is 21 (Cook et al., 2014; Cook et al., 2010). The FMS was developed for pain free individuals. If pain is present, the Selective Functional Movement Assessment (SFMA) should be used (Cook et al., 2010). This SFMA differs from the FMS because is it a movement-based diagnostic system in which the clinician can identify dysfunctional but nonpainful movement that can be used as rehabilitation to improve balance and muscle balance without pain (Cook et al., 2010). Functional management systems, such as the FMS, are simple and inexpensive and are therefore beneficial to exercise science professionals and clinicians (Letafatkar, Hadadnezhad, Shojaedin, & Mhamadi, 2014).

Reliability of the Functional Movement Screening. The FMS is a reliable screening tool (Onate et al., 2012; Shultz, Anderson, Matheson, Marcello, & Besier, 2013; Teyhen et al., 2012). Onate and colleagues (2012) looked not only at the reliability of the overall score of the FMS, but also at the individual movements. The FMS had good interrater and intra-rater reliability as a whole, but poor interrater and intra-rater reliability for the hurdle step movement (Onate et al., 2012). Onate and associates (2012) speculated that this hurdle step is difficult to rate from different angles and they had one rater in the front of the participant and one rater on the side. To address this concern, they suggested assessing this movement only from the front of the participant. This study is unique in that one rater was FMS certified and the other rater had only read the FMS manual, showing that in depth training on scoring of the FMS is not needed to produce reliable results (Onate et al., 2012).

Military members who participated in a reliability study also produced adequate interrater and intra-rater reliability as a total score, but low reliability for the inline lunge and rotary stability (Teyhen et al., 2012). Similar to Onate and colleagues, (2012), Teyhen and associates used novice raters and results implicated that an FMS certification may not be necessary. Although a limitation to this study was the lack of variance in scores due to the participants being young service members, the researchers were able to conclude that interrater variance were within 1 point and it could take up to a 3-point change to show a significant change over time in the FMS score (Teyhen et al., 2012). Parenteau-G and associates (2014) also studied a specialized sample of young, elite hockey players. These researchers suggested further research is needed to assess the reliability of the FMS when studying participants with varying fitness levels. The FMS showed good intra-rater and interrater reliability for total score and for five of the seven movements. In agreeance with Teyhen et al. (2012), Parenteau-G et al. (2014) also found low reliability with rotary stability. Over 60% of the hockey players scored below a 14 out of 21 indicating they may be at an increased rate of injury (Cosio-Lima et al., 2016). Interestingly, half of the hockey players had experienced non-contact injuries while playing hockey prior to this assessment indicting that the FMS is sensitive to injury history (Parenteau-G et al., 2014).

Using the Functional Movement Screening to predict injury. The FMS has been studied for use in predicting injury with hopes that clinicians can correct deficits in movement patterns or predict performance in various occupations. Although there has not yet been success in using the FMS to predict occupational performance, specifically with police offers (Bock, Stierli, Hinton, & Orr, 2016), some researchers have shown its use in predicting injury (Chalmers et al., 2017; Cosio-Lima 2016; Letafatkar et al., 2014). Letafatkar and associates (2014) used a convenience sample of healthy athletes who participated in soccer, handball or basketball at a competitive or recreational level and tracked injuries for each competition season. The athletes who scored less than a 17 out of 21 on the FMS were 4.7 times more likely to experience a lower body injury than those who scored a 17 or above (Letafatkar et al., 2014).

Similarly, Cosio-Lima et al. (2016) included the YBT and the FMS in preparticipation screenings for Coast Guard training. The YBT was implemented in both the lower body and upper body. Cosio-Lima and associates (2016) concluded the injury prediction cut off is below 14 of 21 points in the FMS by showing that 80% of those below this mark suffered a lower body injury. They did not find an association between upper body YBT and injury, but they did find an association between the lower body YBT and injury. Similarly, Chalmers and colleagues (2017) agreed with Cosio-Lima and associates (2016) in finding a score of below 14 out of 21 predicted injury in junior Australian football players. In addition, the presence of one or more asymmetry also increased injury risk (Chalmers et al., 2017).

Other attempts have been made to identify the sensitivity of the FMS and the YBT to identify past injuries and how the FMS and YBT relate to sex. Chimera et al. (2015) examined Division 1 college athletes and found that those with a history of hip, hand, elbow, and shoulder injuries had a lower FMS total score than those who had not experienced injury. Those with a history of hip injuries performed worse on rotary stability, deep squat, and hurdle step (Chimera et al., 2015). The YBT total score and asymmetry assessment were unable to differentiate between those with and without a history of lower body injuries (Chimera et al., 2015). Although overall FMS score did not differ between men and women, a few movements had some difference between sexes. Women performed worse than men in rotary stability and better in motions that required flexibility such as the straight leg raise and shoulder mobility (Chimera et al., 2015). The researchers did not look for a relationship between the YBT and the FMS.

Both the FMS and YBT have been successfully used to predict injury. While a total score of less than 14 out of 21 on the FMS can predict injury, balance asymmetries also play an important role in predicting injury from both the YBT and FMS; therefore, understanding how to correct movement and balance asymmetries is crucial. Currently, the majority of the conclusions are drawn from samples of young, healthy participants. Further research is needed with different age groups and fitness levels to determine the true capability of predicting injury with the FMS and the YBT and the components that contribute to proper movement patterns.

Components of functional movement. In order for movement deficits to be corrected, researchers must identify factors related to successful performance of movement patterns. Okada et al. (2011) studied the relationship between functional movement, core stability, and performance. They used the FMS to screen functional movement, McGill’s Trunk Muscle Endurance Tests to measure core stability, and the backward overhead medicine ball throw, T-run agility, and single leg squat to measure performance. The study of young recreational athletes revealed significant correlations between core stability and performance, but no correlations between core stability and the FMS (Okada et al., 2011). Interestingly, when looking at the specific movement components in the FMS, both positive and negative correlations were found with performance. The hurtle step and push up movement of the FMS were positively correlated with the backwards throw test while the rotary stability of the FMS was negative correlated with the backwards throw test (Okada et al., 2011). The T-run was positively correlated with shoulder mobility of the FMS and negatively correlated with the hurtle step of the FMS while the single leg squat was negatively related to shoulder mobility (Okada et al., 2011). They concluded poor core stability cannot be detected by or is not important to the movements included in the FMS. As such, improving core stability may not be a way to correct movement pattern deficits that have been shown to lead to injury.

By trying to find the components related to the functional movements in the FMS, Frost and associates (2012) pointed out, what they believe, is the flaw in the FMS scoring system. Fire fighters were randomly assigned to a 12-week intervention group focused strictly on fitness improvements, proper technique, and injury prevention, or to the control group. There was no significant difference in FMS changes after the 12-week intervention (Frost et al., 2012). These researchers used a unique approach by not coaching the participants through the FMS. They explained to them how to do each movement and allowed them to do the movements how they felt comfortable. It is possible that individuals compensate safely and effectively and by coaching, the clinician is leading the participant to do a movement in a way different than he/she would normally (Frost et al., 2012). Another possibility is that strength and knowledge of proper movement techniques may not be contributing factors to the functional movements in the FMS.

Other interventions, focused on balance and reducing fall risk, have been assessed using the FMS. Wang and associates (2016) examined functional movement in older adults after 6 months of traditional Tai Chi, 6 months of simplified Tai Chi, or being in a control group. They found that FMS scores increased for both training groups and not for the control group, indicating that FMS may be altered by a combination of strength and balance training (Wang et al., 2016).

A better approach may be to specialize interventions to the participants' specific deficits. The FMS was implemented during post season testing for a group of 62 professional football players by Kiesel and colleagues (2011). Based on the results of the FMS, participants were issued a specialized off-season workout plan. This plan included self and partner stretching, trigger point treatment to the affected muscles, and progressive corrective exercises issued and supervised by a strength and conditioning coach. During post season testing, 39 players were below the injury threshold score of 14 and 31 participants were free from bilateral asymmetries. Following the invention, only 7 players were below the injury threshold score and 42 players were free from asymmetries. Interestingly, Keisel and associates (2011) found the squat to be a primary predictor of failure (above injury predicting threshold) on the FMS. If the deep squat score was 1 or below, the intervention was unsuccessful for most participants, indicating that a more aggressive or individualized corrective protocol may be needed for these individuals (Keisel et al., 2011).

The FMS is a simple and cost effect way to identify deficits and asymmetries in movement patterns that can predict injury. Researchers agree that an FMS below 14 out of 21 increases the risk of suffering a noncontract injury. Although the clinician should be well versed in the screening, extensive training is not needed to produce a reliable assessment. Strength and movement training does not seem to change FMS score although this research has been limited to young, healthy, and active populations. In older populations, balance training though Tai Chi has shown positive results in increasing the FMS score. Further research is needed to examine what contributes to successful performance of movements on the FMS and how injury can be avoided in multiple populations. Although movement may be contraindicated during periods of decreased weight bearing, clinicians can use training techniques such as the cross-over effect during rehabilitation to maintain proper movement patterns.

The Cross-over Effect

The cross-over effect of strength, also known as cross education or the transfer effect, is an increase in strength of the untrained limb after unilateral training of the opposite limb (Farthing et al., 2007; Farthing & Chilibeck, 2003). Positive outcomes associated with a cross-over effect have been documented across the past century with a renewed interest in its application for rehabilitation (Barss, Pearcey, & Zehr, 2016; Farthing & Zehr, 2014; Zhou, 2000). Although it is understood that the cross-over effect is specific to the homologous muscle group, the mechanism(s) for the cross-over effect are not fully understood. It has been speculated that the response arises from supraspinal activation due primarily from a central drive (Dragert & Zehr, 2013; Farthing et al., 2007; Farthing & Chilibeck, 2003; Kidgell et al., 2015). Due to being a product of a positive adaptation in the nervous system, the cross-over effect can benefit those experiencing immobilization after injury and the lasting effects of stroke by increasing strength and muscle activation of the untrained or effected limb (Ehrensberger, Simpson, Broderick, & Monaghan, 2016; Lepley & Palmeieri-Smith, 2014; Magnus et al., 2013). Range of motion and balance are less studied skills that may also be transferred via the cross-over effect (Oliveira et al., 2013; Schlenstedt et al., 2016).

Mechanisms of the cross-over effect. Although not conclusive, it is speculated that the cross-over of strength is due to changes in brain activation (Farthing et al., 2007). There are two theories on the mechanisms of the cross-over effect. The first is a “spill-over” of neural information to the contralateral side during unilateral movements known as cross-activation (Ruddy & Carson, 2013). Supporting the theory of cross-activation, after unilateral strength training, muscle contraction of the untrained limb leads to an increased area of activation in the contralateral sensorimotor cortex and temporal lobe (Farthing et al., 2007). The second, the bilateral access model, are neuromuscular adaptations developed when learning unilateral movements which form blue prints, known as engrams, that can be accessed by the contralateral side (Carroll, Herbert, Munn, Lee, & Ganevia, 2006; Hendy & Lamon, 2017, Ruddy & Carson, 2013).

Unilateral strengthening also increases electromyography (EMG) activity during strength testing of the contralateral limb indicting a cross-over of strength adaptations and motor unit recruitment after 4 weeks of isometric training (Fimland et al., 2009). Increases in EMG supports the theory that the cross-over effect is due to enhanced neural drive to agonist muscles in the untrained limb (Fimland et al., 2009). It was speculated that this increase in cortical activation, not witnessed in control participants, can assist in avoiding strength deficits related to immobilization (Farthing et al., 2011) In contrast, supporting the Bilateral Access Model, Farthing and Chilibeck (2003) found that the cross-over effect was larger after unfamiliar training motions. The researchers used unfamiliar fast velocity training and a common slow velocity training and showed the fast velocity training produced the largest cross-over of strength, suggesting learning alters the magnitude of the cross-over (Farthing & Chilibeck, 2003).

Although more limited than neurological data, other evidence has pointed to fiber type and vascularization changes as possible mechanisms of the cross-over effect, specific to overuse exercise. After a 6-week protocol of electrically stimulated unilateral, high velocity contractions of both the soleus and gastrocnemius of rabbits, muscle samples revealed bilateral fiber and vascular changes as well as signs of bilateral muscle damage (Song, Forsgren, Liu, Yu, & Stål, 2014). Because it is possible that the cross-over is specific to the phenotype of the muscle, positive cross-over adaptations were pronounced in the gastrocnemius, whose action mimics that of the unloaded high intensity exercise utilized by Song et al. (2014). In contrast, fiber injury was more prevalent in the slow twitch soleus muscle, a muscle with an action that was not reflective of the high intensity, electrically stimulated exercise intervention. Interestingly, the unexercised limb experienced a shift towards a phenotype that was more efficient for high intensity activity while the control animals experienced no changes. In addition, the high intensity, electrically-stimulated movements lead to decreased cross-sectional area of both the exercised and unexercised limbs due to degradation occurring faster than protein synthesis as a possible result of overuse of the muscle and axonal loss in the muscle (Song et al., 2014). To counteract the damage, authors theorize that smaller muscle fibers expressing an embryotic gene suggested regeneration in both the exercised and unexercised limbs, which was not found in the control group (Song et al., 2014). Bilateral decreases in vascularization of the exercised and nonexercised limb of the training group may be due to the phenotypic shift in the muscles as an adaptation to intense exercise favoring type II muscle fibers (Song et al., 2014). Although these adaptations have not been shown in humans, it is important to consider that unilateral overuse can cause negative bilateral results due to muscle and nerve tissue degradation, while also showing positive signs of bilateral regeneration.

Cross-over effect and strength training. A consensus of studies has found 5-12 weeks to be optimal for the cross-over of strength (Dagert & Zehr, 2013; Lepley & Palmieri-Smith, 2014; Magnus et al., 2013; Munn et al., 2005). Eccentric training, or training which includes lengthening of the muscle fibers, has led to contralateral increases in strength in as early as 5 weeks due to increased strength gains experienced with eccentric training (Hortobágyi, Lambert, & Hill, 1997; Lepley & Palmieri-Smith, 2014) whereas up to 12 weeks are needed to demonstrate similar increases in strength following concentric training (Hortobágyi et al., 1997). Typically, training is performed three times per week and positive results have been documented following supervised and unsupervised training protocols (Dragert & Zehr, 2013; Lepley & Palmieri-Smith, 2014; Magnus et al, 2013).

The amount of strength cross-over is directly related to the amount of strength gained in the trained limb (Munn et al., 2005) and the velocity of training (Farthing & Chilibeck, 2003; Lepley & Palmieri-Smith, 2014). Farthing and Chilibeck (2003) found that training at a fast velocity (180° s^{-1}) resulted in an increase in strength of the contralateral limb at the same velocity after 8 weeks of isokinetic eccentric training of the elbow flexors in healthy, untrained individuals, whereas training at a slower velocity (30° s^{-1}) did not result in a significant cross-over. After isokinetic eccentric training of the quadriceps at 60 ^{o}/s, larger torques were produced during concentric testing at 60 ^{o}/s than 30 ^{o}/s, also suggesting a velocity cross-over response with training (Lepley & Palmieri-Smith, 2014).

At least three sets of each exercise are suggested during training sessions. Attempts with only one set have not been successful (Munn, et al., 2005). Also, there is a trend of high speed repetitions (1 second concentric, 1 second eccentric) having a larger cross-over effect than low speed repetitions (3 seconds concentric, 3 seconds eccentric) due to the larger increases in strength experienced with the faster movements (Munn, et al., 2005).

Although the peak torque of the untrained muscle remained constant after training in the Farthing and Chilibeck (2003) research, the concentric rate of torque development was significantly different in the untrained limb after training at a fast velocity. Fast velocity eccentric training lead to larger strength increases in the trained limb than the slow eccentric training group, which explains why fast velocity training lead to the largest cross-over. Farthing and Chilibeck (2003) speculated that since the cross-over was more evident with the fast, yet most unnatural, velocity, learning may play a large part in the cross-over. Therefore, there may be differences in the mechanisms which cause strength gains via traditional training compared to the cross-over effect.

Following 5 weeks of unilateral limb training, others have found that there are significant differences in strength between a healthy control group and the intervention group and a trend towards increased activation in the unexercised limb (Dragert & Zehr, 2011; Lepley & Palmieri-Smith, 2014). Similarly, the Hoffmann reflex, which measure muscular inhibition, has been shown to be lower in the untrained limb after 5 weeks of unilateral strength training (Dragert & Zehr, 2011). A reduction in excitability of the Hoffmann reflex indicates a reduction in excitability of antagonist muscles after training, which results in an increase force production of agonist muscles (Dragert & Zehr, 2011).

Using the cross-over effect as rehabilitation for orthopedic injury.

Researchers have attempted to generalize the positive strength gains from the cross-over effect in healthy populations to the clinical setting. The benefits of the cross-over effect are obvious with any injury where immobilization is required. The cross-over of strength and neuromuscular adaptations reported from unilateral training suggest the use of this rehabilitation technique for orthopedic injuries (Dragert & Zehr, 2013; Lepley & Palmieri-Smith, 2014) and those who experience strokes (Ehrensberger et al., 2016). If a clinician can help slow the loss of strength in an immobilized limb, the recovery time may be decreased. Concentric, eccentric, and isometric cross-over interventions have been studied to apply results to injury rehabilitation (Hortobágyi et al., 1997; Lepley & Palmieri-Smith, 2014; Magnus et al., 2013).

Immobilization can cause decreased muscle strength due to decreased muscle activation (Barss et al., 2016). It is already known that detraining will occur in a trained limb, but detraining will also occur in the nonexercised limb showing that the cross-over effect works in both directions (Shima et al., 2002). Shima and associates (2002) found two thirds of their subjects to experience detraining in the untrained limb 6 weeks after cessation of a 6-week lower leg cross-over training protocol. The magnitude of detraining is believed to be specific to the individual. Clinicians should consider these finds when prescribing rehabilitation during periods of immobilization because the non-involved limb is also at risk of detraining.

Following injury, there can be benefit not only from increasing strength bilaterally with unilateral training, but also from minimizing the decrease in bilateral strength that can occur with unilateral immobilization (Pearce, Hendy, Bowen, & Kidgell, 2013). Magnus et al. (2013) showed a decrease in nonfractured, non-immobilized arm strength from the control group after 9 weeks of immobilization. Magnus and colleagues (2013) speculated that the decreased use of the immobilized arm affected the healthy arm. Likewise, Farthing, Krentz, and Magnus (2009) demonstrated with healthy individuals that the casted arm would decrease in strength if the non-casted arm is not involved in an exercise protocol. These researchers trained the non-casted arm to minimize the decrease in strength of the casted arm.

Studies with healthy college-aged participants are providing evidence for the use of the cross-over effect after ACL surgery. Lepley and Palmieri-Smith (2014) studied 18 healthy participants randomized into intervention and control groups, and eccentrically trained the quadriceps on an isokinetic machine in hopes of improving eccentric strength and quadriceps activation in the unexercised limb. This study is unique in the manner quadriceps activation was quantified. The central activation ratio was used to compare maximal voluntary isometric contraction to maximal voluntary isometric contraction with a superimposed burst. This electric stimulus was used to differentiate torque differences between the maximal voluntary contraction and a contraction assisted by electric simulation (Lepley & Palmieri-Smith, 2014). This study resulted in a trend towards increased muscle activation in the untrained limb (Lepley & Palmieri-Smith, 2014).

The first successful attempt to apply the cross-over effect to an orthopedic injury was not until 2013. Magnus and associates (2013) used cross education as a rehabilitation technique with women who had distal radius fractures. Participants were randomly assigned to the control or intervention groups. Both groups completed standard physical therapy on the injured wrist as instructed by the orthopedic surgeon. The intervention group completed the same physical therapy as the control group, with the addition of strength training on the non-fractured arm for 26 weeks. Non-fractured arm training included individually progressed isometric hand grip strength from home and biweekly phone calls from the researchers to assess adherence to the additional strengthening program (Magnus et al., 2013).

The intervention group experienced a 38% increase in strength in the fractured arm from week 9 to week 12, compared to the control group that had a 4.4% increase (Magnus et al., 2013). Although there were not specific range of motion exercises in the training protocol of the intervention group, flexion/extension and supination/pronation were measured throughout the protocol. Flexion and extension active range of motion were significantly different at week 9 between the control group and the intervention group (Magnus et al., 2013). This study was the first of its kind to use participants with an injury to explore the benefits of the cross-over effect in a clinical setting. The positive effect of cross education on strength and range of motion following immobilization provides clinicians with an evidence-based example of a technique that has been around for over a century and its benefits are now being recognized in rehabilitation after strokes.

Using the cross-over effect as rehabilitation after stroke. Researchers have learned a lot about the cross-over effect from individuals post stroke due to a unilateral depressed neural environment. Restoring symmetry after stroke can provide independent living for individuals in this population. Although the idea seems promising, the effect of cross education on individuals who have experienced a stroke has rarely been studied. The small collection of published research suggests training the non-affected side can increase strength of the affect side and assist in restoring motor function (Ehrensberger et al., 2016). The cross-over effect is beneficial when the deficits on the affected side are too great to initiate a rehabilitation program (Farthing & Zehr, 2014).

Restoring a normal walking gait can benefit activities of daily living for these individuals; therefore, the focus of training is on plantar flexion and dorsiflexion. Bilateral plantar flexor and dorsiflexor strength can be increased with unilateral training of the less affected side (Dragert & Zehr, 2013; Shima et al., 2001). In addition, Dragert and associates (2013) found an increase in muscle activation of the tibialis anterior after utilizing the cross-over effect during training. An increase in tibialis anterior activation could decrease the foot dragging gait associated with stroke. From this study, three important findings were concluded: training time and duration can be minimal and can even be completed at home, co-activation of antagonist muscles can be reduced, and individuals who cannot produce any force on the more affected side have been shown to produce force after completing a cross education training protocol (Dragert & Zehr, 2013). Although the benefits of the cross-over effect to individuals post stroke are clearly stated, the research is sparse. More research is needed with this population as well as information on adherence and training constraints for both the patient and the clinician.

Balance training using the cross-over effect. Due to the conclusion that the cross-over effect is under neurologic control, the study of balance is a logical step in the progression to understand the application of this methodology. While research is limited, understanding the bilateral responses to unilateral balance training may help to prevent injuries and/or reduce recovery time in lower body injuries. In one study, 6 weeks of unilateral balance training enhanced responses to perturbations and increased muscle activation bilaterally in a healthy, young population (Oliveira et al., 2013). Balance training included single leg stance with and without head movement and single leg squats. Exercises progressed from the floor to a foam surfaces to a wobble board (Oliveira et al., 2013.) Balance was evaluated by measuring center of pressure changes and muscle activation using EMG during simulated perturbations. These findings provide support for the suggestion that supraspinal adaptations are responsible for cross education (Lagerquist, Zehr, & Docherty, 2006; Oliveira et al, 2013).

Furthermore, a 4-week at home unilateral balance protocol lead to increased postural control in the untrained leg of participants between 55 and 70 years of age (Schlenstedt et al., 2016). The balance protocol was similar to the protocol used by Oliveira et al. (2013), with single leg stances and progression from the floor to an uneven surface. Balance changes were determined by a decrease in center of pressure displacement (Schlenstedt et al., 2016). Interestingly, the increased balance ability persisted for up to 4 weeks post intervention making this an ideal rehabilitation technique for those with a unilateral lower body injury resulting from a fall (Schlenstedt el al., 2016). Due to the difficulty of methods to study neurological changes and of measuring balance, more research is needed in the area.

The use of the cross-over effect as a rehabilitation technique is showing promise through limited research. While much of the research uses a healthy population, and speculates the use of the cross-over effect with injured populations, a few studies have proven its efficacy with individuals following orthopedic injuries and stroke. Strength can be transferred to the opposite limb on both injured and uninjured individuals. Through the study of individuals with hemiplegia and the use of EMG, researchers have established the mechanism to be neural. The cross-over effect is a promising area of study for rehabilitation from injuries where weight bearing or balance training is contraindicated early in the recovery protocol.

Conclusions

Asymmetries and deficits in balance and movement patterns can lead to joint injury or reinjury. There are multiple assessments used to test both static and dynamic balance with emphasis placed on those that are cost effective and easy to administer. Similarly, the FMS was developed as a simple and cost-effective way to identify movement pattern deficits. Although both balance and movement patterns have been used to predict injury, there is still no definitive answer on what contributes most to the increased risk of injury seen with balance asymmetries or deficits in functional movement. Furthermore, it is unknown if balance ability is a component of proper functional movement patterns. Examining a connection between movement and balance and identifying the effects of a unilateral balance training program on bilateral balance ability and functional movement may lead to improved rehabilitation techniques after injury.

CHAPTER III

THE RELATIONSHIP BETWEEN FUNCTIONAL MOVEMENT AND BALANCE

Introduction

Movement involves changing positions of multiple joints and body segments (Cook, Burton, Kiesel, Rose, & Bryant, 2010). However, because the brain operates in patterns and not individual movements, movement patterns are often studied (Cook et al., 2010). Clinically, these movement patterns can be assessed quickly and simply using the Functional Movement Screening (FMS; Cook Burton, Hoogenboom, &Voight, 2014; Cook et al., 2010). The important of movement patterns to sport are not trivial as efficient athletic movements can enhance performance (Ransdell & Murray, 2016), while a deficit in movement patterns can predispose an individual to injury (Clark, Lucett, McGill, Montel & Sutton, 2018). Deficits may also result in long-term compensatory movements leading to a chronic cycle of injury and pain (Clark et al., 2018).

Data support an increased injury risk for those with a low FMS score (Letafatkar, Hadadnezhad, Shojaedin, & Mohamadi, 2014). Motivated by these data, researchers have attempted to identify components that contribute to improved functional movement patterns and examined different training programs to improve FMS scores. Thus far, strength and flexibility training may not be an effective ways to improve functional movement and reduce injury risk as measured by the FMS (Frost, Beach, Callaghan, & McGill, 2012; Okada, Huxel, & Nesser, 2011). Poor core stability is also not related to functional movement (Okada et al., 2011). Attempts to target muscle groups with stretching and strengthening while providing movement coaching and verbal cues were also unsuccessful in improving functional movement in football players (Kiesel, Plisky, & Butler, 2011). Balance training, a less researched intervention, may be a viable way to improve FMS scores since other methods have been unsuccessful.

Balance is defined as reactions of the body to avoid falls by maintaining center of body mass within limits of stability (Winter, 1995; Woollacott & Shumway-Cook, 1996). Postural control, which encompasses both static and dynamic components, is how the body predicts and reacts to maintain, recover, or achieve balance during activity (Pollock, Durward, Rower, & Paul, 2000). Similar to balance assessments, it is suggested that movement assessments be conducted statically and dynamically to show deficits in standing posture and identify potential overactive and underactive muscles (Clark et al., 2018). For example, 6 months of traditional Tai Chi has been shown to improve functional movement in older adults (Wang et al., 2016). Further, a simplified Tai Chi program that encompasses postural stability while maintaining muscular strength also improved FMS scores (Wang et al., 2016).

It is imperative to examine ways to improve the FMS score if the assessment will continue to be used as an injury risk assessment. Therefore, the purpose of this study was to examine relationships between functional movement and dynamic and static balance. Further, since training with a balance component has been shown to improve FMS scores, the secondary purpose was to predict FMS scores based on static and dynamic balance scores, controlling for age and history of lower body surgery, to examine the contribution of balance scores on functional movement. This information can assist clinicians whose goal is to improve FMS scores to reduce injury risk.

Methodology

Participants. The sample included 77 participants (men = 31; women = 46; average age = 42 ± 16 years). Participants completed a preparticipation questionnaire containing questions relative to their surgical history, acute injuries, dominant leg, vision, and vestibular system. Based on answers, individuals were excluded if they were experiencing pain or discomfort due to an acute lower body injury or reported any visual or vestibular deficits. Informed consent was provided by all participants and the study was approved by the University's Institutional Review Board (see Appendix A).

Instrumentation.

The Balance Error Scoring System (BESS). Static balance was assessed using the BESS. This test has moderate to good reliability and correlates with other balance assessments (Bell, Guskiewicz, Calk, & Padua, 2011). The BESS consists of three, 20 second stances scored on postural deviations. The testing stances include a double leg stance, a single leg stance on the non-dominant leg, and a tandem stance with the dominant leg in front. All stances are scored on a firm surface and on a foam surface, with eyes closed, and hands placed on the hips, for a total of six conditions. For each condition, one point was recorded for each error or deviation including: opening eyes, lifting hands off hips, stepping, stumbling, or falling out of position, hip abduction of more than 30°, or taking more than 5 seconds to return to the initial testing position after a deviation (Bell et al., 2011). A 10 is the maximum points per condition, with a total potential score of 60. Higher scores are indicative of decreased balance.

The Y-Balance Test (YBT). The YBT was used to measure dynamic balance, which is frequently used to predict lower extremity injuries and determine return to play after injury (Gribble, Hertel, & Plisky, 2012). The YBT includes three axes. The posterior axes are separate by 90°, while the anterior axis is separated from both posterior axes by 130°. Each axis is equipped with a sliding platform and measuring tape. Distance was measured to the nearest tenth of a centimeter after the participant reached the contralateral leg as far as possible and pushed the platform along each axis (Gribble et al., 2012.). The longest reach after four attempts for each direction was divided by leg length to create a normalized score in each direction. The normalized direction scores were then averaged to create a composite score for each limb. The composite score of the left and right limb were then averaged to create a total score for each participant (Chimera, Smith, & Warren, 2015).

FMS. Movements from the FMS that incorporated mobility of the lower body, core and lower body strength, and neuromuscular coordination were selected to assess functional movement. The five movements included the overhead squat, hurdle step, inline lunge, active straight-leg raise, and rotary stability (Cook et al., 2010). The movements were assessed according to the scoring system described by Cook and associates (2010). Each movement was scored with a range of zero to three. A score of zero for a movement indicated the participant experienced pain during the movement and that specific movement was ended. If the participant did not experience pain, but was unable to complete the movement, he or she received a score of one for that movement. If the participant completed the movement, but showed any compensatory movements, a score of two was assigned. If the participant was able to complete the movement with no pain or compensatory movements, a score of three was given (Cook et al., 2014; Cook et al., 2010). The hurdle step, inline lunge, active straight-leg raise, and rotary stability resulted in a score for both the right and left sides. The single lowest score for each movement was used to calculate the overall score. The highest total score across the five movements was 15.

Procedures. Upon arriving at the exercise science laboratory, participants read and signed the informed consent form and completed the preparticipation questionnaire. Prior to beginning the assessments, leg lengths, without shoes, were measured from the anterior iliac spine to the medial malleolus and from the tibial tuberosity to the floor (Gribble et al., 2012) followed by height and body mass measurements. Next, testing procedures were randomized by a number drawing and starting limb was counterbalanced by participant. Depending on the predetermined testing order, qualified participants were given instruction and an opportunity to practice the balance assessments or started the FMS. Participants watched an instructional video (www.move2perform.com) and completed the described warmup for the YBT as done by Smith, Chimera, and Warren (2014) and practiced briefly standing in each testing position for the BESS as demonstrated by the researcher. The FMS was completed by following instructional cues suggested by Cook and associates (2010) without practicing the movements.

BESS. During the BESS, participants completed six balance conditions with eyes closed and hands placed on the hips, each lasting 20 seconds. Participants were asked to stand with both feet together, followed by the single leg stance on the nondominant leg, and ending with a tandem stance with the dominant leg in front of the nondominant leg. Participants were told if they lost balance, removed hands from hips, or opened eyes, to return to the testing position as soon as possible. After completing the stances on a firm surface, the stances were repeated on a foam pad. Each condition was scored by the researcher based on the relevant deviations.

YBT. During the YBT, participants were instructed to stand on the center platform with the great toe aligned to the intersection of the axes and hands placed on the hips. Without shifting weight, the participant was instructed to bend the supporting leg's ankle, knee, and hip and, without lifting the heel, to reach the contralateral leg as far as possible and push the platform along the anterior axis. Each reach was recorded in centimeters to the nearest tenth. The process was repeated four times. These steps were then repeated for the posterior medial followed by the posterior lateral axes. The same process was repeated on the opposite limb. The longest reach for each direction was divided by leg length to create a normalized score in each direction. The normalized direction scores were then averaged to create a composite score for each leg. The composite score of the left and right limb were then averaged to create a total YBT score.

FMS. The FMS consisted of 5 movements that could be repeated up to three times, if necessary, for scoring. Each participant competed the overhead squat, hurdle step, inline lunge, straight-leg raise, and rotary stability in the same order. The hurdle step, inline lunge, straight-leg raise, and rotary stability were completed with both limbs and counterbalanced by participant. First, the participant was instructed to stand with feet shoulder width apart and hold a four-foot wooden dowel resting on the top of his or her head, with the elbows at 90 degrees of flexion. The participant was asked to lift the dowel straight over head with elbows straight and squat as low as possible with heels on the floor and head and chest facing forward. If any of the criteria were not met, the researcher placed a board under the heels of the participant and the motion was repeated.

Next, the participant completed the hurdle step. The hurdle was set to the height of the tibial tuberosity. The participant was instructed to place the dowel on the shoulders and stand directly behind the hurdle with toes touching the base and feet touching each other. The participant was then asked to step over the hurdle with a straight back, place the heel on the floor, and return to the starting position. This assessment was completed on both limbs.

The third assessment, the inline lunge, was completed by placing the toe of the back foot and the heel of the front foot approximately the tibia measurement from each other. The participant was then instructed to hold the dowel with both hands behind the back and complete a lunge by touching the back knee to the floor and return to the starting position.

The active straight-leg raise was completed with the participant supine on the treatment table with the testing board under the knees. The researcher held the dowel between the anterior iliac spine and the joint line of the knee. The participant was instructed to lift the test leg while keeping the knee straight and the opposite leg flat on the testing board. If the lateral malleolus of the testing limb did not pass the dowel, the dowel was moved to be in line with the malleolus and the criteria were evaluated. The assessment was completed on both limbs.

Lastly, rotary stability was measured with the participant starting in a quadruped position on a mat approximately 6 inches of the ground with the testing board between either hand and leg. The participant was asked to extend the shoulder and hip on the same side of the body then bring the elbow and the knee together. If the participant was unable to complete this movement, a diagonal pattern with opposite arm and leg was used. The assessment was completed bilaterally.

Statistical analyses. Given a moderate effect size, an a priori power computation indicated the analyses would be powered at 80% with a total of 85 participants (G*Power, Version 3.1). Descriptive statistics were calculated for all outcome variables and Pearson's correlations were calculated to examine the bivariate relationship between functional movement total score and the static and dynamic balance measures, respectively. Multiple linear regressions were used to predict FMS total score based on static (BESS total score) and dynamic (YBT total score) balance assessments when controlling for age and history of lower body surgery. One-tailed significance was set at an α level of $p < 0.05$ as it was hypothesized balance would have a positive impact on functional movement when controlling for age and when controlling for a history of lower body surgery. A Chi Square was used to analysis categorical risk assessments for the YBT and FMS and BESS and FMS, respectively. Statistics for the Social Sciences, Version 23.0 (Aramonk, NY: IBM Corp) was used to analyze the data.

Results

Due to research time constraints, the sample include 77 individuals from the general population aged 18-71 years. Descriptive statistics and Pearson's correlations among all study variables appear in Table 1. Both YBT, F (1, 75) = 74.35, MSE = 1.67, $p < .001$, $R^2 = .50$ and BESS, F (1, 75) = 35.53, MSE = 2.29, $p < .001$, $R^2 = .32$, individually, were significant predictors of FMS scores. The YBT and the BESS were both significant predictors of FMS, F (2,74) = 43.93, MSE = 1.56, $p < .001$, $R^2 = .54$. When controlling for age, the YBT and the BESS were still significant predictors of

FMS, *F Change* (2, 73) = 29.10, *MSE* = 1.58, $p < .001$, R^2 *Change* = .36. In addition, when controlling for a history of lower body surgery, the YBT and the BESS were still significant predictors of FMS *F Change* (2, 73) = 42.54, *MSE* = 1.58, $p < .001$, R^2 *Change* = .53. (see Table 2 for regression models).

The Chi-Square analysis indicated YBT risk, defined as an anterior reach difference between legs ≥ 4 cm, and FMS risk, defined by earning under 67% of possible FMS points, were not associated, $\chi^2(1, N = 77) = 1.20,$ $p = .273$, *Cramer's V* = .13. Those at a higher risk of injury as defined by the YBT may not be at a higher risk of injury according to the FMS. There was a significant association between BESS risk, defined as a score that ranks below "broadly normal" according to Iverson and Koehle (2013), and FMS risk, $\chi^2(1, N = 77) = 9.27,$ $p = .01$, *Cramer's V* = .35. Those who score below average, poor, or very poor on the BESS are more likely to be at risk of injury according to the FMS.

Table 1

Descriptive Statistics and Pearson Correlations for Outcome Variables

			Pearson's correlations			
Variable	*M*	*SD*	YBT	BESS	Age	LBS
FMS	10	2	.71*	-.57*	-.43*	-.10
YBT	84.6	9.6		-.55*	-.53*	-.15
BESS	17	8			.59*	.16
Age	42.3	16.2				.22*
LBS	0.23	0.43				

Note. * $p < .01$, $N = 77$. YBT = Y-Balance Test, BESS = Balance Error Scoring System, LBS = History of Lower Body Surgery.

Table 2

Linear Regression Models for Predicting FMS Scores

Model	Predictor	B	SE(B)	*B*	95% CI
1	(Constant)	1.80	1.76		-1.70, 5.31
	YBT	0.11*	0.02	0.57	0.07, 0.14
	BESS	-0.06*	0.02	-0.26	-0.10, -0.02
2	(Constant)	1.47	1.95		-2.41, 5.35
	Age	0.01	0.01	0.04	-0.02, 0.03
	YBT	0.11*	0.02	0.58	0.07, 0.15
	BESS	-0.06*	0.02	-0.27	-0.11, -0.02
3	(Constant)	1.77	1.78		-1.77, 5.31
	LBS	0.09	0.34	0.02	-0.60, 0.77
	YBT	0.11*	0.02	0.57	0.07, 0.14
	BESS	-0.06*	0.02	-0.26	-0.10, -0.02

Note. * $p < .01$, $N = 77$. YBT = Y-Balance Test, BESS = Balance Error Scoring System, LBS = History of Lower Body Surgery.

Discussion

The relationships between the FMS and YBT scores and the FMS and BESS scores, were examined to improve understanding of the components of functional movement associated with balance. Overall, the FMS score was associated with both static (BESS) and dynamic balance (YBT). While 32.1% of the variability in FMS was predicted by the BESS, the analysis predicted 49.8% of the variability in FMS based on the YBT. This indicates that functional movement is influenced by dynamic balance ability to a greater extent than static balance ability. This research is important to the field as it provides clinicians with an understanding of physical factors that contribute to decreased functional movement scores. From a risk of injury standpoint, these data highlight a therapeutic window of opportunity as an individual with an at-risk FMS score may also have decreased dynamic and static balance ability.

The inclusion of the general population in the study sample was important due to the variety of populations where the FMS is utilized including the Coast Guard (Cosio-Lima et al., 2016), recreational athletes, (Letafatkar et al., 2014), youth hockey players (Parenteau-G et al., 2014), professional athletes (Kiesel et al., 2009), firefighters (Frost et al., 2012), older adults (Wang et al., 2016), and within tactical occupations (Glass & Ross, 2015).To adhere to this principle and allow the results to be applicable to the general population, in the current study, only those who had pain doing activities of daily living were excluded from participation, allowing larger variability in all assessment scores. Furthermore, the sample was not specific to sport participation or occupations and participants were not excluded based on history of orthopedic injury, arthritis, or chronic medical conditions. Kelleher et al. (2017) excluded individuals with joint problems or health conditions and concluded that dynamic postural control, as measured by the YBT, represented only a small component of FMS scores. Although both the BESS and the YBT have been shown to be sensitive to those with a history of lower body injury (Docherty, McLeod, & Shultz, 2006; Olmsted, Carcia, Hertel, & Shultz, 2002), the current results revealed that history of lower body surgery did not change the relationship between balance and functional movement (see Table 2), indicating that the research is applicable to populations with a history of lower body orthopedic injury. Hence from a clinical standpoint, this work suggests that clinicians should investigate the probability of individuals with a low FMS score to have balance deficits, regardless of injury history.

The importance of the YBT and FMS in predicting noncontact injury (Cosio-Lima et al., 2016; Plisky et al., 2006) has been shown when creating injury prediction algorithms (Lehr et al., 2013). Researchers suggested using these assessments during preparticipation screenings and as return to play assessments after injury, but it is unknown if an individual can change his or her risk category after initially scoring low on the FMS (Lehr et al., 2013). Many researchers have attempted to use exercise interventions to improve FMS scores, and therefore, reduce the risk of injury (Frost et al., 2012; Kiesel et al., 2011). While professional athletes have increased FMS scores after completion of personalized off-season training protocols (Kiesel et al., 2011), this may not be a feasible option for all populations or clinicians. Researchers have examined multiple group exercise techniques such training focused on neuromuscular control and training focused on strength and fitness finding that neither 12-week training method improved FMS scores in firefighters (Forst et al., 2012). Interestingly, 6 months of Tai Chi, a combination of strength and balance training, has led to improved FMS scores in older adults (Wang et al., 2016) supporting that balance is a modifiable component of functional movement.

Because the YBT is effective in identifying those with a history of lower body injury, predicting lower body injury, and is sensitive to lower body training (Gribble et al., 2012), only the lower body movements of the FMS were included in this study. By examining only lower body movements, this work provides the clinician with a starting point to develop interventions to improve overall FMS score. The exclusion of the upper body components of the FMS in the present study may have also attributed to the stronger relationship between the FMS and the YBT than in the Kelleher et al. (2017) investigation. Kelleher and associations (2017) found only a weak relationship between FMS scores and individual reach directions on the YBT and no correlation between FMS and YBT composite scores. This emphasizes the importance of focusing on specific movements versus the total score of the FMS. In the current study, the assessment of static balance via the BESS was also a predictor of the FMS score. This finding supports the claim that functional movement should be examined both statically and dynamically (Clark et al., 2018) eluding to the possibility that proper functional movement is dependent on sufficient static and dynamic balance ability.

An early example of the potential to impact FMS scores and therefore, decrease injury risk, by focusing on balance training or interventions, are data from Stanek, Dogg, Kelly, Wolfe, and Ryan (2016) who used the FMS Pro360 (Functional Movement Systems, www.functionalmovement.com). This is a software program that develops individualized static and dynamic motor control training protocols based on a person’s FMS score. Stanek and associates (2016) examined the effects of 8 weeks of training as prescribed by the FMS 360Pro program and found an increase in FMS scores. Based on Stanek et al. (2016) and current data, there is growing support for the inclusion of balance training to improve FMS scores and the possibility of reducing injury risk.

Limitations to this study include limited variation in FMS scores with no one scoring below five points. It should also be noted that while the researchers were certified athletic trainers who regularly administer the FMS, they were not FMS certified. Although FMS scores have been found to be consistent between assessors with varying degrees of experience including those without FMS certification (Smith et al., 2013), clinicians may benefit from FMS training to ensure proper scoring. Furthermore, injury risk according to the FMS cannot be directly compared to injury risk in other studies since this study only included five of the seven FMS movements. Further research is needed on specific balance training interventions to positively modify FMS scores.

To conclude, both YBT and BESS explained a portion of lower body FMS scores, showing static and dynamic balance are vital components of the performance of the lower body functional movements. For the first time, this work focused only on the lower body movements of the FMS, and in doing so, found that balance, specifically dynamic balance, is a large component of functional movement. These results can be used to develop training or injury rehabilitation protocols to improve functional movement. This study provides a starting point for future research and clinical work by establishing the contribution of both static and dynamic balance to functional movement. Clinicians should use this information as a guide when developing training to improve functional movement.

CHAPTER III REFERENCES

Bell, D. R., Guskiewicz, K. M., Calk, M. A., & Padua, D. A. (2011). Systematic review of the balance error scoring system. *Sports Health*, *3*(3), 287-295. doi: 10.1177/1941738111403122

Chimera, N. J., Smith, C. A., & Warren, M. (2015). Injury history, sex, and performance on the functional movement screening and Y balance test. *Journal of Athletic Training, 50*(5), 475-485. doi: 10.4085-6050-49.6.02

Clark, M. A., Lucett, S. C., McGill, E., Montel, I., & Sutton, B. (Eds.). (2018). *NASM Essentials of personal fitness training.* Burlington, MA: Jones & Bartlett Learning.

Cook, G., Burton, L., Hoogenboom, B. J., &Voight, M. (2014). Functional movement screening: The use of fundamental movements as an assessment of functional-Part 2. *The International Journal of Sports Physical Therapy, 9*(4), 549-563.

Cook, G., Burton, L. Kiesel, K., Rose, G., & Bryant, M. F. (2010). *Movement: Functional movement systems screening, assessment and corrective strategies*. Aptos, CA: On Target Publications.

Cossio-Lima, L., Knapik, J. J., Shumway, S., Reynolds, K., Lee, Y., Greska, E., & Hampton, M., (2016). Associations between functional movement screening, the Y balance test and injuries in coast guard training. *Military in Medicine*, *181*, 643-648. doi: 10.7205/MILMED-D-15-00208

Docherty, C. L., Valovich McLeod, T. C., Shultz, S. J. (2006). Postural control deficits in participants with functional ankle instability as measured by the balance error scoring system. *Clinical Journal of Sports Medicine 16*(3), 203-208.

Frost, D. M., Beach, T. A. C., Callaghan, J. P., & McGill, S. M. (2012). Using the functional movement screen to evaluate the effectiveness of training. *Journal of Strength and Conditioning Research, 16*(6), 1620-1630.

Gribble. P. A., Hertel, J., & Plisky, P. (2012). Using the star excursion balance test to assess dynamic postural-control deficits and outcomes in lower extremity injury: A literature and systematic review. *Journal of Athletic Training, 47*(3), 339-357. doi: 10.4085/1062-6050-47.3.08

Glass, S. M., & Ross, S. E. (2015). Modified functional movement screening as a predictor of tactical performance potential in recreationally active adults. *International Journal of Sports Physical Therapy,* 10(5), 612-621.

Harrison, L. J., Lepley, L. K., Fuller, D. J., & Caputo, J. L. (2017). [Cross-over effect of balance training after knee surgery: A pilot study]. Unpublished data.

Iverson, G. L., & Koehle, M. S. (2013). Normative data for the balance error scoring system in adults. *Rehabilitation Research and Practice,* 1-5.

Kelleher, L. K., Frayne, R. J., Beach, T. A. C., Higgins, J. M, Johnson, A. M., & Dickey, J. P. (2017). Relationship between functional movement screen score and y-balance test reach distances. *International Journal of Human Movement and Sports Sciences,* 5(3), 51-56. doi: 10.13189/saj.2017.050302

Kiesel, K., Plisky, P., & Bulter, R. (2011). Functional movement test scores improve following a standardized off-season intervention program in professional football players. *Scandinavian Journal of Medicine & Science in Sports, 21*, 287-292. doi:10.1111/j.1600-0838.2009.01038.x

Lehr, M. E., Plisky, P. J., Butler, R. J., Fink, M. L., Kiesel, K. B. & Underwood, F. B. (2013). Field-expedient screening and injury risk algorithm categories as predictors of noncontact lower extremity injury. *Scandinavian Journal of Medicine & Science in Sports,* 23, 225-232.

Letafatkar, A., Hadadnezhad, M., Shojaedin, S., & Mohamadi, E. (2014). Relationship between functional movement screening score and history of injury. *The International Journal of Sports Physical Therapy, 9*(1), 21-27.

Okada, T., Huxel, K. C., & Nesser, T. W. (2011). Relationship between core stability, functional movement, and performance. *Journal of Strength and Conditioning Research, 25*(1), 252-261.

Olmsted, L. C., Carcia, C. R., Hertel, J., & Shultz, S. J. (2002). Efficacy of the star excursion balance tests in detecting reach deficits in subjects with chronic ankle instability. *Journal of Athletic Training, 37*(4), 501-506.

Parenteau-G, E. P., Gaudreault, N., Chambers, S., Boisvert C., Grenier, A., Gagné, G., & Balg, F. (2014). Functional movement screen test: A reliable screening test for young elite ice hockey players. *Physical Therapy in Sport, 13,* 169-175. doi: 10.1016/j.ptsp.2013.10.001

Pollock, A. S., Durward, B. R., Rower, P. J., & Paul, J. P. (2000) What is balance? *Clinical Rehabilitation, 14*, 402-406.

Ransdell, L., & Murray, T. (2016). Functional movement screening: An important tool for female athletes. *Strength and Conditioning Journal, 38*(2), 40-48.

Smith, C. A., Chimera, N. J., & Warren, M. (2014). Association of the y balance test reach asymmetry and injury in division I athletes. *Medicine & Science in Sports & Exercise,* 136-141. doi: 10.1249/MSS.0000000000000380

Stanek, J. M., Dogg, D. J., Kelly, A. R., Wolfe, A. M., & Swenson, R. A. (2017). Active duty firefighters can improve functional movement (FMS) scores following an 8-week individualized client workout program. *Work, 56*, 213-220. doi: 10.3233/WOR-172493

Wang, H., Wei, A., Lu, Y., Chen, W., Lu, Y. Liu., Y. . . . Zou, L. (2016). Simplified tai chi program training versus traditional tai chi on the functional movement screening in older adults. *Evidence-Based Complementary and Alternative Medicine*, 1-6. doi: 10.1155/2016/5867810

Winter, D. A. (1995). Human balance and posture control during standing and walking. *Gait & Posture, 3*, 193-214.

Woollacott M. H., & Shumway-Cook, A. (1996) Concepts and methods for assessing postural control. *Journal of Aging and Physical Activity, 4*, 214-233.

APPENDIX FOR STUDY I

APPENDIX A

IRB Approval Letter

IRB
INSTITUTIONAL REVIEW BOARD
Office of Research
Compliance, 010A
Sam Ingram Building,
2269 Middle
Tennessee Blvd
Murfreesboro, TN
37129

MIDDLE TENNESSEE STATE UNIVERSITY

IRBN001 - EXPEDITED PROTOCOL APPROVAL NOTICE

Thursday, February 08, 2018

Principal Investigator	**Layci Harrison** (Student)
Faculty Advisor	Jenn Caputo
Co-Investigators	Sandra Stevens, John Coons, Dana Fuller, Linsey Leplay (Connecticut Children's Medical Center) and Dave Clark
Investigator Email(s)	*ljw3g@mtmail.mtsu.edu;* *jenn.caputo@mtsu.edu;* *lindsey.lepley@uconn.edu*
Department	Health and Human Performance
Protocol Title	***The relationship between functional movements and balance and unilateral balance training in those with anterior reach asymmetry***
Protocol ID	**18-2137**

Dear Investigator(s),

The above identified research proposal has been reviewed by the MTSU Institutional Review Board (IRB) through the **EXPEDITED** mechanism under 45 CFR 46.110 and 21 CFR 56.110 within the category *(4) Collection of data through noninvasive procedures* A summary of the IRB action and other particulars in regard to this protocol application is tabulated below:

IRB Action	APPROVED for one year from the date of this notification
Date of expiration	**2/28/2019**

Participant Size	85 (EIGHTY FIVE)
Participant Pool	**General adults (18 to 75 years old)**
Exceptions	1. Recruitment of participants over 65 years extending to 75 years of age is permitted AFTER the subjects pass the exclusion criteria (on file). . Collection identifiable information to communicate and schedule the training is permitted.
Restrictions	**. Mandatory signed informed consent; The participants must be clearly notified that enrollment is voluntary with ability to withdraw at anytime without retribution** **. Mandatory safety monitoring; The participants within the age 65-75 MUST be given additional protection.** **3. The participant enrollment must include rigorous exclusion screening.** **. Identifiable information collected for project scheduling purpose must be destroyed after data processing.**
Comments	The study subjects do not fit within the "vulnerable subjects" as defined by 45 CFR 46. But the participants may be subject to vulnerablity. Therefore, the investigating team will ensure that the subjects clearly know their rights on voluntary withdrawal and autonomy in deciding to participate.

This protocol can be continued for up to THREE years (**2/28/2021**) by obtaining a continuation approval prior to **2/28/2019**. Refer to the following schedule to plan your annual project reports and be aware that you may not receive a separate reminder to complete your continuing reviews. Failure in obtaining an approval for continuation will automatically result in cancellation of this protocol. Moreover, the completion of this study MUST be notified to the Office of Compliance by filing a final report in order to close-out the protocol.

Continuing Review Schedule:

Reporting Period	Requisition Deadline	IRB Comments
First year report	1/31/2019	NOT COMPLETED
Second year report	1/31/2020	NOT COMPLETED
Final report	1/31/2021	NOT COMPLETED

Post-approval Protocol Amendments:

Date	**Amendment(s)**	**IRB Comments**
NONE	NONE.	NONE

The investigator(s) indicated in this notification should read and abide by all of the post-approval conditions imposed with this approval. Refer to the post-approval guidelines posted in the MTSU IRB's website. Any unanticipated harms to participants or adverse events must be reported to the Office of Compliance at (615) 494-8918 within 48 hours of the incident. Amendments to this protocol must be approved by the IRB. Inclusion of new researchers must also be approved by the Office of Compliance before they begin to work on the project.

All of the research-related records, which include signed consent forms, investigator information and other documents related to the study, must be retained by the PI or the faculty advisor (if the PI is a student) at the secure location mentioned in the protocol application. The data storage must be maintained for at least three (3) years after study completion. Subsequently, the researcher may destroy the data in a manner that maintains confidentiality and anonymity. IRB reserves the right to modify, change or cancel the terms of this letter without prior notice. Be advised that IRB also reserves the right to inspect or audit your records if needed.

Sincerely,

Institutional Review Board
Middle Tennessee State University

Quick Links:

Click here for a detailed list of the post-approval responsibilities. More information on expedited procedures can be found here.

CHAPTER IV

THE EFFECT OF UNILATERAL BALANCE TRAINING USING THE CROSS-OVER EFFECT ON BILATERAL ANTERIOR REACH ON THOSE WITH AN ANTERIOR REACH ASYMMETRY

Introduction

Balance is frequently studied due to its importance to many sport-related skills and activities of daily living (Haywood & Getchell, 2009). Balance can be assessed and trained in two ways: static, or unmoving positions and activities, and dynamic or activities requiring maintenance of balance during movement (Haywood & Getchell, 2009). Most movements require both static and dynamic balance ability and both can be hindered after injury (Evans, Hertel, & Sebastianelli, 2004). To protect joints from further or recurrent injury, balance must be regained during injury rehabilitation (Holme et al., 1999; Mattacola & Dwyer, 2002; Wikstrom, Naik, Lodha, & Cauraugh, 2009).

After injury, an asymmetry in balance across limbs is common (Evans et al., 2004), with both the injured and uninjured limbs having a balance deficit (Zätterström, Fridén, Lindstrand, & Moritz, 1994). Although balance training is common during rehabilitation for joint injuries, the inclusion of balance training for the uninjured limb is not common practice. Restoring balance in both limbs is warranted as researchers have shown that a bilateral reach asymmetry of just 4 cm can increase the risk of injury (Plisky, Rauh, Kaminsky, & Underwood, 2006; Smith, Chimera, & Warren, 2014). Hence, restoring symmetry between the limbs could reduce injury or re-injury.

Frequently, unilateral weight bearing and advanced balance training may be contradicted due to injury, which makes it difficult to prevent or correct a balance deficit. The cross-over effect is an increase in strength or balance of the untrained limb after unilateral training of the opposite limb (Farthing, Borowsky, Chilibeck, Binsted, & Sarty, 2007; Farthing & Chilibeck, 2003). Although this training technique has been around for over a century, its popularity is increasing in injury rehabilitation (Barss, Pearcey, & Zehr, 2016; Farthing & Zehr, 2014; Zhou, 2000). Due to the neural mechanism believed to control the cross-over effect (Carroll, Herbert, Munn, Lee, & Gandevia, 2006) and the decrease in balance ability typically recorded after joint injury (Wikstrom et al., 2009), balance training could provide positive results in decreasing recurrent injuries by reducing the chances of developing a balance asymmetry.

Although frequently studied in strength training (Farthing & Chilibeck, 2003; Fimland et al., 2009; Hortobágyi, Lambert, & Jeffrey, 1997; Lepley & Palmieri-Smith, 2014), there is less research on the cross-over of balance training. Furthermore, multiple researchers have agreed that balance deficits and an anterior research asymmetry increases the chance of injury or reinjury (Plisky et al., 2006; Smith et al., 2014). Because joint injury can lead to a decreased balance ability on both the injured and uninjured side (Zätterström et al., 1994), starting balance training immediately after injury is crucial. To examine the possibility of starting balance training soon after injury to prevent or correct bilateral asymmetries using the cross-over effect, the purpose of this study is to examine the effects of unilateral balance training on bilateral anterior reach in those with a bilateral asymmetry in anterior reach.

Methodology

Participants. The sample included 16 participants (men = 6; women = 10; average age = 42 ± 15) randomly assigned to the training group or the control group. Participants completed a preparticipation questionnaire containing questions relative to their surgical history, acute injuries, dominant leg, vision, and vestibular system and the International Physical Activity Questionnaire (Craig et al., 2003). Based on answers, individuals were excluded if they were experiencing pain or discomfort due to an acute lower body injury or reported any visual or vestibular deficits. Further, to be included in the sample participants had to have a bilateral anterior asymmetry greater than 4 cm according to the Y-Balance Test (YBT) because these individuals are at an elevated risk of noncontact injury (Plisky et al., 2006; Smith et al., 2014). Informed consent was collected from all participants and the study was approved by the University's Institutional Review Board (see Appendix A).

Instrumentation.

The Y-Balance Test (YBT). The YBT, which is frequently used to predict lower extremity injuries and determine return to play after injury, was used as a screening assessment for dynamic balance (Gribble, Hertel, & Plisky, 2012). The YBT includes three axes. The posterior axes are separate by 90°, while the anterior axis is separated from both posterior axes by 130°. Each axis is equipped with a sliding platform and measuring tape. During the test, anterior research distance was measured to the nearest tenth of a centimeter after the participant reached the contralateral leg as far as possible and push the platform along each axis. The longest reach after four attempts was recorded. To be eligible to proceed to the training portion of the study, participants had to have an anterior reach asymmetry greater than 4 cm.

Procedures.

Testing protocol. Upon arriving at the lab, participants read and signed the informed consent form, completed the preparticipation questionnaire and the International Physical Activity Questionnaire (Craig et al., 2003), and completed the pre-training balance testing. Prior to beginning the assessment, leg lengths, without shoes, were measured from the anterior iliac spine to the medial malleolus. Participants watched an instructional video on the YBT (www.move2perform.com) and completed the described warmup according to the procedures of Smith et al. (2014). The starting limb on the YBT was counterbalanced by participant.

During the YBT, participants were instructed to stand on the center platform with the great toe aligned to the intersection of the axes and hands placed on the hips. Without shifting weight, the participant was instructed to bend the supporting leg's ankle, knee, and hip and, without lifting the heel, to reach the contralateral leg as far as possible and push the platform along the anterior axis. Each reach was recorded in centimeters to the nearest tenth. The process was repeated four times. The same process was repeated on the opposite limb. The longest anterior reach for each limb was recorded. (Gribble et al., 2012; Smith et al., 2014). If participants had greater than a 4-cm anterior asymmetry they were randomly assigned to the training group or the control group by a number drawing. Participants were asked to maintain their current physical activity level throughout the study. Regardless of group assignment, anterior reach was reassessed at the end of week 3 and 5 by a researcher blinded to group assignment.

Training protocol. Single leg balance training was completed by participants in the training group on the limb with the farther (better) anterior reach. The training intervention included three sessions per week for 5 weeks for a total of 15 sessions (Sarabon, 2012). Each session was separated by 24-72 hours. The balance training exercises were specific to improving the anterior reach and included exercises and techniques from the National Strength and Conditioning Association’s (NSCA) Balance Training Protocol (Sarabon, 2012) and Mattacola and Dwyer (2002). The exercises included single leg stances, lunges, and perturbations. Training progressed from the floor, to a foam pad, to a Bosu ball® as the participant was able to complete the task on each surface without losing balance. Progression was specific to each participant and each exercise. The training protocol appears in Table 1.

Table 1

Balance Training Protocol

Exercise	Number of sets x repetitions
Forward lunges with the TL forward	3 x 10
SL balance with anterior perturbations self-administered by the participant via a Theraband® on the attached to an unmoving surface	3 x 10
SL stance while reaching forward for objects (cones) on the floor	3 x 10
SL while tapping anterior targets on the floor with the contralateral limb	3 x 10
SL stance while moving the body in a circular motion	3 x 10 repetitions (clockwise and counterclockwise)

Note: TL = training leg; SL = single leg. Training protocol was 3 sessions per week for 5 weeks. Participants progressed surfaces as they are able to complete each exercise without losing balance.

Statistical analyses. A previous pilot study showed moderate to strong effect sizes for the cross-over of balance ability with 10 participants (Harrison, Lepley, Fuller, & Caputo, 2017). Independent samples *t* tests were used to confirm the training and control groups had similar characteristics at pretesting. To document outside physical activity levels remained constant throughout training and did not differ y group, a 2 x 2 (group x time) RM ANOVA compared physical activity in moderate and vigorous METS at the beginning and end of the balance training protocol according to the International Physical Activity Questionnaire. To determine the effect of balance training on anterior reach of the trained limb, a 2 x 3 (group x time) RM ANOVA was conducted to examine the interaction of group and testing session on the trained leg of the training group and matched leg of the control group. To determine the magnitude of the cross-over effect of the anterior reach to the untrained leg, a 2 x 3 (group x time) RM ANOVA was used to examine the interaction of group and testing session on the untrained and matched limb of the control group. An alpha of $p < .05$ was used. Statistics for the Social Sciences, Version 23.0 (Aramonk, NY: IBM Corp) was used to analyze the data.

Results

This study included 16 participants in 2 groups (8 training, 8 control). There was no difference in participant age ($t_{14} = -0.77$, $p = .457$) height ($t_{14} = -1.02$, $p = .324$), body mass ($t_{14} = -1.56$, $p = .141$), preparticipation physical activity level ($t_{14} = -0.79$, $p = .446$), anterior reach of the trained leg (leg with better balance ability), ($t_{14} = -0.58$, $p = .569$), or the untrained leg (leg with decreased balance ability) ($t_{14} = -0.37$, $p = .716$) between groups, suggesting successful randomization. Physical activity remained constant throughout the intervention with a lack of significant interaction between group and time, *F* (1, 14) = 0.56, *MSE* = 993757.31, *G-G* $p = .467$, $n^2_p = .038$.

The interaction between group and time for the trained leg was not significant *F* (1.91, 26.71) = 0.74, *MSE* = 8.03, *G-G* $p = .482$, $n^2_p = .050$ indicating that training was not effective at improving anterior reach of the trained leg (see Table 2). There was also not a significant interaction between group and time for the untrained leg *F* (1.67, 23.35) = 0.80, *MSE* = 11.83, *G-G* $p = .442$, $n^2_p = .054$ showing there was no cross-over of balance ability to the untrained leg (see Table 2). Changes in anterior reach for both limbs are displayed in Figure 1.

Table 2

Descriptive Statistics for Anterior Reach

		Trained/Matched leg (cm)		Untrained/Matched leg (cm)	
Group	Time point	*M*	*SD*	*M*	*SD*
Training	Pre	59.4	8.0	53.0	8.8
(*n* = 8)	Mid	60.1	11.1	58.4	11.5
	Post	60.1	10.1	58.1	12.1
Control	Pre	57.0	8.3	51.4	7.8
(*n* = 8)	Mid	57.1	7.2	56.4	7.5
	Post	55.4	8.8	53.9	6.6

Note. *M* = Mean, *SD* = standard deviation.

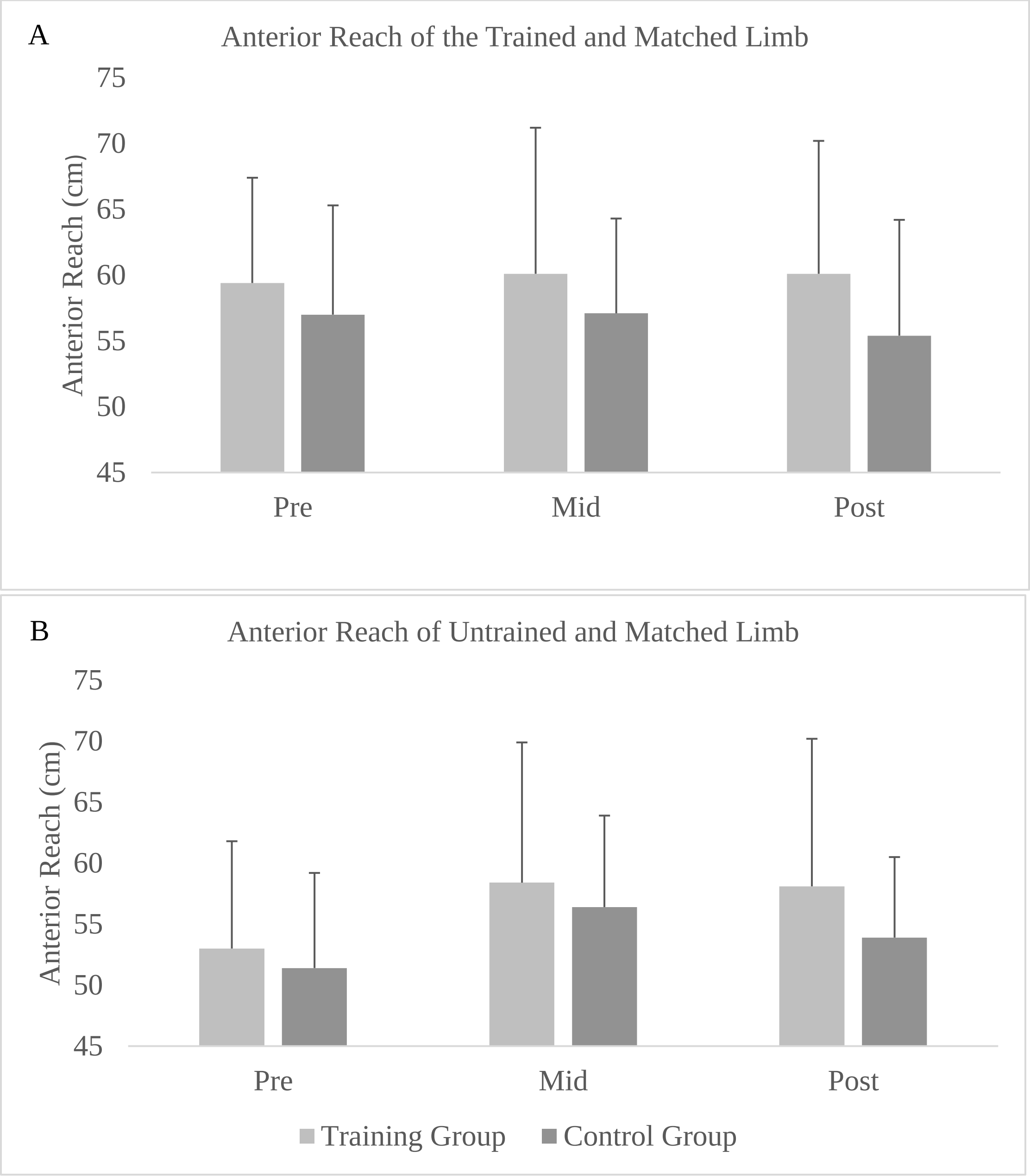

Figure 1. Anterior reach of trained and untrained limb compared to the matched limb. The light gray boxes represent the training group and the dark gray boxes represent the control group. A. This graph shows changes over 5 weeks in anterior reach of the trained leg in the training group compared to the matched leg in the control group. B. This graph shows changes in the untrained leg of the training group compared to the matched leg in the control group.

Discussion

The aim of this study was to explore the transfer of balance changes from one leg to the other following 5 weeks of training the leg with better anterior reach score on the YBT. Another goal was to expand information available for improving anterior reach according to the YBT in an effort to reduce injury risk while exploring the possibility of using the cross-over effect as an injury rehabilitation technique. The main finding of this study was that the training program did not improve anterior reach of the trained leg, and as a result, did not improve anterior reach of the untrained leg.

The individuals in this study had an anterior reach asymmetry (> 4 cm) for the purpose of modeling individuals who may have an asymmetry following a lower body injury. Anterior reach, as measured by the YBT, has been studied for its ability to predict injury (Plisky et al., 2006; Smith et al., 2014). An anterior reach deficit > 4 cm indicates an increased risk of experiencing a noncontact injury (Smith et al., 2014). Because joint injuries result in decreased balance ability (Evans et al., 2004) due to tissue damage and swelling that effect sensory input in the joint (Clark, Lucett, McGill, Montel, & Sutton, 2018), balance training is included in injury rehabilitation to improve joint stability (Holme et al., 1999; McKeon & Hertel, 2008; Wikstrom et al., 2009). Balance asymmetries present after surgery (Zult et al., 2018) may put individuals at an elevated risk of injury (Plisky et al., 2006; Smith et al., 2014), therefore, balance ability should be restored prior to the individual progressing to challenging rehabilitation (Mattacol & Dwyer, 2002).

While correcting this deficit in YBT anterior reach could prevent noncontact injuries, to the knowledge of the researchers, there is not an established protocol to improve anterior reach. Likewise, the 5-week balance training protocol employed in the current investigation did not improve anterior reach. Similar to our work, others have also been unsuccessful at finding an effective training protocol to reduce this asymmetry (Benis, Bonator, & Torre, 2016; Filipa, Byrnes, Paterno, Myer, & Hewett, 2010). Filipa and associates (2010), for example, focused on 8 weeks of lower body and core strengthening while Benis and associates (2016) focused on neuromuscular training in the form of progressive lunges and planks. While these interventions were successful at improving the YBT composite scores and posterior reach, neither was successful at improving anterior reach (Benis et al., 2016; Filipa et al., 2010). As such as effective intervention strategy to improve anterior reach remains elusive.

While the YBT is a commonly used dynamic balance assessment and is used to detect changes in balance due to training and rehabilitation (Filipa et al., 2010; Gribble et al., 2012; Smith et al., 2014), anterior reach may not be a strong measure of dynamic balance. Anterior reach may be dependent on a combination of hip range of motion (Benis et al., 2016) and strength of the knee flexors (Lee, Kim, Ha, & Oh, 2014). When developing a protocol to improve anterior reach, and therefore decrease injury, clinicians should consider including eccentric training of the quadriceps (Lee et al., 2014) and stretching of the large muscle groups surrounding the hip (Benis et al, 2016).

Although there were no significant improvements in balance ability, as measured by anterior reach of the YBT, the protocol did incorporate balance training 3 times a week for 5 weeks while progressing to unstable surfaces (Mckeon & Hertel, 2008; Sarabon, 2012). Other studies have shown no balance improvements with up to 6 months of balance training after injury (Risberg, Holm, Myklebust, & Engebretsen**,** 2007;

Zätterström et al., 1994), but positive evidence has been shown in the form of increased perceived function (Risberg et al., 2007) and improvement in activities such as walking, stair climbing, and general activity (Risberg et al., 2007). From these data, the researchers suggest including progression of reach distance as well as changing surfaces. For example, with exercises requiring forward reach toward a target (see Table 1), the clinicians could use increased reach distance as a progression of the rehabilitation exercise. Measures of perceived function and activities of daily living may also be beneficial inclusions in future work.

The cross-over effect, defined as an increase in strength of the contralateral limb after training (Farthing & Chilibeck, 2003), has shown possible benefits to injury rehabilitation (Hortobágyi et al., 1997; Lepley & Palmieri-Smith, 2014; Magnus et al., 2013). Primarily studied with strength training (Lepley & Palmieri-Smith, 2014; Magnus et al., 2013), less research is available on balance training. Adaptations due to the cross-over effect have been demonstrated using EMG (Fimland et al., 2009). Fimland and associates (2009) were able to see increases in motor unit recruitment after 4 weeks of isometric training. Although individuals in this study were not experiencing symptoms of an acute injury, those with a history of lower body orthopedic surgery were not excluded. Due to history of lower body surgery, it is possible that those participating were experiencing balance deficits in both the injured and contralateral limb (Zätterström et al., 1994; Evans et al., 2004) leading to the present asymmetry (Gardinier, Manel, Buchanan, & Synder-Mackler, 2012) and a decrease in the ability of the cross-over to occur (Zult et al., 2018).

The impact of the cross-over effect on balance is controversial. Schlenstedt, Arnold, Mancini, Deuschl, and Weisser (2016) conducted a 4 week at home unilateral balance training program. The progressive training program included multiple variations on single squats. Although the researchers demonstrated this training protocol was able to increase balance ability via anterior posterior center of pressure changes for the trained leg, the untrained leg had insignificant improvements. Oliveira, Silva, Farina, and Kersting (2013) showed similar results with minimal nonsignificant changes in the untrained limb after 6 weeks of perturbation training. Similarly, Zult and associates (2018) explored the efficacy of the using the cross-over effect for rehabilitation after anterior cruciate ligament reconstruction. While focusing specifically of neuromuscular outcomes, they found that the cross-over effect did not enhance a standard rehabilitation program for anterior cruciate ligament reconstruction. The central activation ratio of the quadriceps was, in fact, decreased in those who completed additional eccentric strengthening on the uninjured side showing a decrease in the speed of activation of the quadriceps. Similar to the current study, the findings suggest the limited ability of the cross-over effect with balance training.

This study included limitations in the training protocol with an inability to improve anterior reach. The absence of increased anterior reach on the trained leg may be explained by a few possibilities. First, the lack of cross-over of anterior reach to the untrained leg may have affected the results. The amount of the cross-over of strength is directly related to the amount of stregnth gained in the limb (Munn, Herbert, Hancock, & Gandevia, 2005), therefore, prior to examining the effect of the cross-over when attempting to reduce injury risk, a protocol to improve anterior reach should be created. It is also possible that the protocol should have been longer and conducted at a higher intensity. The researchers found intensity to be difficult to control. For example, fear of falling could have affected the intensity of balance training. Furthermore, participants were not matched based on history of orthopedic injury. A decrease in the neural environment as related to injury and tissue disruption could have affected the adaptation of balance ability in both limbs. Lastly, future research with anterior reach should include an additional balance assessment to explore the ability of anterior each alone to assess balance, as well as measurements of hip range of motion and quadricep strength.

To conclude, this balance training was unable to elicit an increase in balance to the trained or contralateral leg as measured by anterior reach on the YBT. This information is important as a training protocol is still needed to reduce anterior asymmetries in hopes of reducing injury risk. Furthermore, due to controversial findings when studying the cross-over of balance training, this research provides the opportunity for further research in specific protocols as well as additional outcome measurements for balance training.

CHAPTER IV REFERENCES

Barss, T. S., Pearcey, G. E. P., & Zehr, E. P. (2016). Cross-education of strength and skill: An old idea with applications in the aging nervous system. *Yale Journal of Biology and Medicine, 89*, 81-86.

Benis, R., Bonato, M., &Torre, A. L., (2016). Elite female basketball players' body-weight neuromuscular training and performance on the Y-balance test. *Journal of Athletic Training, 51*(9), 688-698. doi: 10.4085/1062-6050-51.12.03

Carroll, T. J., Herbert, R. D., Munn, J., Lee, M., & Gandevia, S. C. (2006). Contralateral effects of unilateral strength training: evidence and possible mechanisms. *Journal of Applied Physiology, 101*, 1514-1522. doi: 10.1152/japplphysiol.00531.2006

Clark, M. A., Lucett, S. C., McGill, E., Montel, I. & Sutton, B. (Eds.). (2018). *NASM Essentials of personal fitness training.* Burlington, MA: Jones & Bartlett Learning.

Craig, C. L., Marshall, A. L., Bauman, A. E., Booth, M. L. Ainsworth, B, E. Pratt, M., . . . Oja, P. (2003). International physical activity questionnaire: 12-country reliability and validity. *Medicine & Science in Sport & Exercise, 35*(8), 1381-1395. doi: 0195-9131/03/3508-1381

Evans, T., Hertel, J., & Sebastianelli, W. (2004). Bilateral deficits in postural control following lateral ankle sprain. *Foot & Ankle International, 25*(11), 833-839.

Farthing, J. P., Borowsky, R., Chilibeck, P. D., Binsted, G., & Sarty, G. E. (2007). Neuro-physiology adaptations associated with cross-education of strength. *Brain Topography, 20*, 77-88. doi: 10.1007/s10548-007-0033-2

Farthing, J. P., & Chilibeck, P. D. (2003). The effect of eccentric training at different velocities on cross-education. *European Journal of Applied Physiology, 89*, 570-577. doi: 10.1007/s00421-003-0841-3

Farthing, J. P., & Zehr, E. P. (2014). Restoring symmetric: Clinical applications of cross education. *Exercise and Sports Medicine Reviews*, *42*(2), 70-75.

Filipa, A., Byrnes, R., Paterno, M. V., Myer, G. D., & Hewett, T. E. (2010). Neuromuscular training improves performance on the star excursion balance test in young female athletes. *Journal of Orthopaedic & Sports Physical Therapy, 40*(9), 551-558.

Fimland, M. S. Helgerud, J., Solstad, G. M., Iversen, V. M., Leivseth, G., & Hoff, J. (2009). Neural adaptations underlying cross-education after unilateral strength training. *European Journal of Applied Physiology, 107*, 723-730. doi: 10.1007/s00421-009-1190-7

Gardinier, E. S., Manal, K., Buchanan, T. S., & Snyder-Mackler, L. (2012). Gait and neuromuscular asymmetries after acute anterior cruciate ligament rupture. *Medicine & Science in Sports & Exercise,* 1490-1496. doi: 10.1249/MSS.0b013e31824d2783

Gribble. P. A., Hertel, J., & Plisky, P. (2012). Using the star excursion balance test to assess dynamic postural-control deficits and outcomes in lower extremity injury: A literature and systematic review. *Journal of Athletic Training, 47*(3), 339-357. doi: 10.4085/1062-6050-47.3.08

Harrison, L. J., Lepley, L. K., Fuller, D. J., & Caputo, J. L. (2017). [Cross-over effect of balance training after knee surgery: A pilot study]. Unpublished data.

Haywood, K. M., & Getchell, N. (2009). *Life Span Motor Development*. J. P. Wright, M. Schwarzentraub, K. G. Fritz, & N. Gleeson. (Eds.). Champaign, IL: Human Kinetics.

Holme, E., Magnusson, S. P., Becher, K., Bieler, T., Aagaard, P., & Kjaer, M. (1999). The effect of supervised rehabilitation on strength, postural sway, position sense and re-injury risk after acute ankle ligament sprain. *Scandinavian Journal of Medicine & Science in Sports, 9*, 104-109.

Hortobágyi, T., Lambert, N. J., & Hill, P. (1997). Greater cross education following training with muscle lengthening than shortening. *Medicine & Science in Sport & Exercise*, *29*(1), 107-112.

Lee, D. K., Kim, G. M., Ha, S. M., & Oh, J. S. (2014). Correlation of the Y-balance test with lower-limb strength of adult women. *Journal of Physical Therapy Science, 26*(5), 614-642

Lepley, L. K., & Palmieri-Smith, R. M. (2014). Cross-education strength and activation after eccentric exercise. *Journal of Athletic Training, 49*(5), 582-589. doi: 10.4085/1062-6050-49.3.24

Magnus, R. A. C., Arnold, C. M., Johnston, G., Haas, D. H., Basran, J., Krentz, J.W., & Farthing, J. P. (2013). Cross-education for improving strength and mobility after distal radius fractures: a randomized controlled trial. *Archives of Physical Medicine and Rehabilitation*, *94*, 1247-1255. doi: 10.1016/j.apmr.2013.03.005

Mattacola, C. G., & Dwyer M. K. (2002). Rehabilitation of the ankle after acute sprain or chronic instability. *Journal of Athletic Training, 37*(4), 413-429.

McKeon, P. O., & Hertel, J. (2008). Systematic review of postural control and lateral ankle instability, part II: Is balance training clinically effective? *Journal of Athletic Training, 43*(3), 305-315.

Munn, J., Herbert, R. D., Hancock, M. J., & Gandevia, S. C. (2005). Training with unilateral resistance exercise increases contralateral strength. *Journal of Applied Physiology, 99*, 1880-1884. doi: 10.1152/japplphysiol.00559.2005

Oliveira, A. S. C., Silva, B. P., Farina, D., & Kersting, U. G. (2013). Unilateral balance training enhances neuromuscular reactions to perturbations in the trained and contralateral limb. *Gait and Posture, 38*, 894-899. doi:10.1016/ j.gaitpost.2013.04.015

Plisky P. J., Rauh, M. J. Kaminski, T. W., & Underwood, F. B. (2006). Star excursion balance test as a predictor of lower extremity injury in high school basketball players. *Journal of Orthopaedic & Sports Physical Therapy, 36*(12), 911-919.

Risberg, M. A., Holm, I., Myklebust, G., & Engebretsen, L. (2007). Neuromuscular training versus strength training during first 6 months after anterior cruciate ligament reconstruction: A randomized clinical trial. *Physical Therapy, 87*(6), 737-750.

Sarabon, N. (2012), Balance and stability training. In J. R. Hoffman (Ed.), *NSCA's Guide to Program Design* (pp. 185-211). Champaign, IL: Human Kinetics.

Schlenstedt, C., Arnold, M., Mancini, M., Deuschl, G., & Weisser, B. (2016). The effect of unilateral balance training on postural control of the contralateral limb. *Journal of Sports Science, 33*(22), 2265-2271. doi: 10.1080/02640414.2016.1265660

Smith, C. A., Chimera, N. J., & Warren, M. (2014). Association of the Y balance test reach asymmetry and injury in division I athletes. *Medicine & Science in Sports & Exercise,* 136-141. doi: 10.1249/MSS.0000000000000380

Wikstrom, E. A., Naik, S., Lodha, N., & Cauraugh, J. H. (2009). Balance capabilities after lateral ankle trauma and intervention: A meta-analysis. *Medicine & Science in Sports & Exercise*, 1287-1295. doi: 10.1249/MSS.0b013e318196cbc6

Zätterström, R., Fridén, T., Lindstrand, A., & Moritz, U. (1994). The effect of physiotherapy on standing balance in chronic anterior cruciate ligament insufficiency. *The American Journal of Sports Medicine, 22*(4), 531-536.

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

Zult, T., Gokeler, A., van Raay, J. J. A. M Brouwer, R. W., Zijdewind, I., Farthing, J. P., & Hortobágyi, T (2018). Cross-education does not accelerate the rehabilitation of neuromuscular functionals after ACL reconstruction: a randomized controlled clinical trial. *European Journal of Applied Physiology.* doi:10.1007/s00421-018-3892-1

APPENDIX FOR STUDY II

APPENDIX A

IRB Approval Letter

IRB
INSTITUTIONAL REVIEW BOARD
Office of Research
Compliance, 010A
Sam Ingram Building,
2269 Middle
Tennessee Blvd
Murfreesboro, TN
37129

IRBN001 - EXPEDITED PROTOCOL APPROVAL NOTICE

Thursday, February 08, 2018

Principal Investigator	**Layci Harrison** (Student)
Faculty Advisor	Jenn Caputo
Co-Investigators	Sandra Stevens, John Coons, Dana Fuller, Linsey Leplay (Connecticut Children's Medical Center) and Dave Clark
Investigator Email(s)	*ljw3g@mtmail.mtsu.edu;* *jenn.caputo@mtsu.edu;* *lindsey.lepley@uconn.edu*
Department	Health and Human Performance
Protocol Title	***The relationship between functional movements and balance and unilateral balance training in those with anterior reach asymmetry***
Protocol ID	**18-2137**

Dear Investigator(s),

The above identified research proposal has been reviewed by the MTSU Institutional Review Board (IRB) through the **EXPEDITED** mechanism under 45 CFR 46.110 and 21 CFR 56.110 within the category *(4) Collection of data through noninvasive procedures* A summary of the IRB action and other particulars in regard to this protocol application is tabulated below:

IRB Action	APPROVED for one year from the date of this notification
Date of expiration	**2/28/2019**

Participant Size	85 (EIGHTY FIVE)
Participant Pool	**General adults (18 to 75 years old)**
Exceptions	3. Recruitment of participants over 65 years extending to 75 years of age is permitted AFTER the subjects pass the exclusion criteria (on file). . Collection identifiable information to communicate and schedule the training is permitted.
Restrictions	**. Mandatory signed informed consent; The participants must be clearly notified that enrollment is voluntary with ability to withdraw at anytime without retribution** **. Mandatory safety monitoring; The participants within the age 65-75 MUST be given additional protection.** **7. The participant enrollment must include rigorous exclusion screening.** **. Identifiable information collected for project scheduling purpose must be destroyed after data processing.**
Comments	The study subjects do not fit within the "vulnerable subjects" as defined by 45 CFR 46. But the participants may be subject to vulnerablity. Therefore, the investigating team will ensure that the subjects clearly know their rights on voluntary withdrawal and autonomy in deciding to participate.

This protocol can be continued for up to THREE years (**2/28/2021**) by obtaining a continuation approval prior to **2/28/2019**. Refer to the following schedule to plan your annual project reports and be aware that you may not receive a separate reminder to complete your continuing reviews. Failure in obtaining an approval for continuation will automatically result in cancellation of this protocol. Moreover, the completion of this study MUST be notified to the Office of Compliance by filing a final report in order to close-out the protocol.

Continuing Review Schedule:

Reporting Period	Requisition Deadline	IRB Comments
First year report	1/31/2019	NOT COMPLETED
Second year report	1/31/2020	NOT COMPLETED
Final report	1/31/2021	NOT COMPLETED

Post-approval Protocol Amendments:

Date	**Amendment(s)**	**IRB Comments**
NONE	NONE.	NONE

The investigator(s) indicated in this notification should read and abide by all of the post-approval conditions imposed with this approval. Refer to the post-approval guidelines posted in the MTSU IRB's website. Any unanticipated harms to participants or adverse events must be reported to the Office of Compliance at (615) 494-8918 within 48 hours of the incident. Amendments to this protocol must be approved by the IRB. Inclusion of new researchers must also be approved by the Office of Compliance before they begin to work on the project.

All of the research-related records, which include signed consent forms, investigator information and other documents related to the study, must be retained by the PI or the faculty advisor (if the PI is a student) at the secure location mentioned in the protocol application. The data storage must be maintained for at least three (3) years after study completion. Subsequently, the researcher may destroy the data in a manner that maintains confidentiality and anonymity. IRB reserves the right to modify, change or cancel the terms of this letter without prior notice. Be advised that IRB also reserves the right to inspect or audit your records if needed.

Sincerely,

Institutional Review Board
Middle Tennessee State University

Quick Links:

Click here for a detailed list of the post-approval responsibilities. More information on expedited procedures can be found here.

CHAPTER V

OVERALL CONCLUSIONS

The relationship of balance to functional movement as well as the impact of balance training on those with an anterior reach asymmetry were investigated in this dissertation. Functional movement and anterior reach have both been used to predict injury, therefore, the study of both is important in reducing injury risk. In the first study, the contribution of static and dynamic balance on functional movement was explored. The second study explored the effects of cross-over balance training on anterior reach of both the trained and untrained leg in those with balance asymmetry.

In the first study, functional movement was assessed using five of the seven FMS movements. The movements focused on lower body and core strength. Both static and dynamic balance were found to be predictors of FMS performance. However, dynamic balance (YBT scores) had a larger impact on FMS while predicting almost 50% of the variation in FMS score. When controlling for injury history, both static (BESS scores) and dynamic balance were still predictors of FMS. There was also a significant association between scoring below normal on the BESS and being categorized as at-risk according to FMS, meaning those at a higher risk of injury according to the FMS may have below normal static balance ability. Individuals who participated in this study were not excluded based on injury history or other medical conditions allowing this research to be applicable to the general population as well as those with a history of injury. This research provides a starting point for clinicians to develop injury rehabilitation protocols to reduce injury risk.

The aim of the second study was to explore the cross-over of anterior reach from the trained leg to the untrained leg after 5 weeks of single leg balance training. This study included participants with an anterior reach asymmetry on the YBT. Individuals with an anterior reach asymmetry are at elevated risk of injury (Plisky et al., 2006; Smith et al., 2014), making it imperative to identify training techniques to decrease anterior reach asymmetry on the YBT. The leg with the better balance was trained, simulating participants after a lower body injury, to examine the cross-over effect of balance training. Training focused on exercises which required anterior movement. Anterior reach did not improve on the trained or untrained leg indicating the training was unable to elicit an improvement in anterior reach and, therefore, unable to cross-over balance ability to the untrained leg.

After injury, balance deficits (Evans et al., 2004) and balance asymmetries that can lead to increased risk of injury are common (Plisky et al., 2006; Smith et al., 2014). Researchers have been unsuccessful at reducing anterior reach asymmetry (Benis et al., 2016; Filipa et al., 2010) and there is not an established protocol to improve anterior reach. It is possible that the anterior reach portion of the YBT may depend on hip range of motion (Benis et al., 2016) and strength of the knee flexors (Lee et al., 2014).

In conclusion, the results of this dissertation provide clinicians with information to assist those at an elevated risk of injury according cutoff on the FMS and the YBT. While balance training may be a critical component to functional movement, the risk of injury due to asymmetry of anterior reach on the YBT cannot be corrected by the balance training conducted in this study. Further research is needed to find training protocols to improve anterior reach in those with an elevated risk of noncontract injury according to the YBT.

DISSERTATION REFERENCES

Alexander. N. B. (1994). Postural control in older adults. *Geriatric Bioscience, 42*, 93-108.

Barss, T. S., Pearcey, G. E. P., & Zehr, E. P. (2016). Cross-education of strength and skill: An old idea with applications in the aging nervous system. *Yale Journal of Biology and Medicine, 89*, 81-86.

Bell, D. R., Guskiewicz, K. M., Calk, M. A., & Padua, D. A. (2011). Systematic review of the balance error scoring system. *Sports Health, 3*(3), 287-295. doi: 10.1177/1941738111403122

Bock, C., Stierli, M., Hinton, B., & Orr, R. (2016). The functional movement screen as a predictor of police recruit occupational task performance. *Journal of Bodywork & Movement Therapies, 20*, 310-315. doi: 10.1016/j/jbmt.2015.11.006

Bonetti, L. V., Schneider, A., P., K., Barbosa, S., Ilha, J., & Faccioni-Heuser, M., C. (2015). Balance and coordination training and endurance training after nerve injury. *Muscle Nerve, 51*, 83-91. doi: 10.1002/mus.24268

Carroll, T. J., Herbert, R. D., Munn, J., Lee, M., & Gandevia, S. C. (2006). Contralateral effects of unilateral strength training: evidence and possible mechanisms. *Journal of Applied Physiology, 101*, 1514-1522. doi: 10.1152/japplphysiol.00531.2006

Chaiwanichsiri, D., Lorprayoon, E., & Noomanoch, L. (2005). Star excursion balance training: Effects on ankle functional stability after ankle sprain. *Journal of the Medical Association of Thailand, 88*(Suppl. 4), 90-93.

Chalmers, S., Fuller, J. T., Debenedictis, T. A., Townsley, S. Lynagh, M., Gleeson, C., . . . Magarey, M. (2017). Asymmetry during preseason functional movement screening testing is associated with injury during a junior Australian football season. *Journal of Science and Medicine in Sport, 20*, 653-657. doi: 10.1016/j.jsams.2016.12.076

Chimera, N. J., Smith, C. A., & Warren, M. (2015). Injury history, sex, and performance on the functional movement screening and Y balance test. *Journal of Athletic Training, 50*(5), 475-485. doi: 10.4085-6050-49.6.02

Clark, M. A., Lucett, S. C., McGill, E., Montel, I. & Sutton, B. (Eds.). (2018). *NASM Essentials of Personal Fitness Training.* Burlington, MA: Jones & Bartlett Learning.

Cook, G., Burton, L., Hoogenboom, B. J., &Voight, M. (2014). Functional movement screening: The use of fundamental movements as an assessment of function-Part 2. *The International Journal of Sports Physical Therapy, 9*(4), 549-563.

Cook, G., Burton, L. Kiesel, K., Rose, G., & Bryant, M. F. (2010). *Movement: Functional Movement Systems Screening, Assessment and Corrective Strategies*. Aptos, CA: On Target Publications.

Cooper, R. L., Taylor, N. F., & Feller, J. A. (2005). A randomized controlled trial of proprioceptive and balance training after surgical reconstruction of the anterior cruciate ligament. *Research in Sports Medicine, 13*, 217-230. doi: 10.1080/15438620500222547

Cosio-Lima, L., Knapik, J. J., Shumway, S., Reynolds, K., Lee, Y., Greska, E., & Hampton, M. (2016). Associations between functional movement screening, the Y balance test and injuries in coast guard training. *Military Medicine, 181*, 643-648. doi: 10.7205/MILMED-D-15-00208

Docherty, C. L., Valovich McLeod, T. C., Shultz, S. J. (2006). Postural control deficits in participants with functional ankle instability as measured by the balance error scoring system. *Clinical Journal of Sports Medicine 16*(3), 203-208.

Dragert, K., & Zehr, E. P. (2011). Bilateral neuromuscular plasticity from unilateral training of the ankle dorsiflexors. *Experimental Brain Research, 208,* 217-227. doi: 10.1007/s00221-010-2472-3

Dragert, K., & Zehr, E. P. (2013). High-intensity unilateral dorsiflexor resistance training results in bilateral neuromuscular plasticity after stroke. *Experimental Brain Research, 225,* 93-104. doi: 10.1007/s00221-012-3351-x

Ehrensberger, M., Simpson, D., Broderick, P., & Monaghan, K. (2016). Cross-education of strength has a positive impact on post-stroke rehabilitation: A systematic literature review. *Topics in Stroke Rehabilitation, 23*(2), 126-134. doi: 10.1179/1945511915Y.0000000016

Evans, T., Hertel, J., & Sebastianelli, W. (2004). Bilateral deficits in postural control following lateral ankle sprain. *Foot & Ankle International, 25*(11), 833-839.

Farthing, J. P., Borowsky, R., Chilibeck, P. D., Binsted, G., & Sarty, G. E. (2007). Neuro-physiology adaptations associated with cross-education of strength. *Brain Topography, 20*, 77-88. doi: 10.1007/s10548-007-0033-2

Farthing, J. P., & Chilibeck, P. D. (2003). The effect of eccentric training at different velocities on cross-education. *European Journal of Applied Physiology, 89,* 570-577. doi: 10.1007/s00421-003-0841-3

Farthing, J. P., Krentz, J. R., & Magnus, C. A. (2009). Strength training the free limb attenuate strength loss during unilateral immobilization. *Journal of Applied Physiology, 106*, 830-836. doi:10.1152/japplphysiol.91331.2008

Farthing, J. P., & Zehr, E. P. (2014). Restoring symmetric: Clinical applications of cross education. *Exercise and Sports Medicine Reviews*, *42*(2), 70-75.

Filipa, A., Byrnes, R., Paterno, M. V., Myer, G. D., & Hewett, T. E. (2010). Neuromuscular training improves performance on the star excursion balance test in young female athletes. *Journal of Orthopaedic & Sports Physical Therapy, 40*(9), 551-558.

Fimland, M. S. Helgerud, J., Solstad, G. M., Iversen, V. M., Leivseth, G., & Hoff, J. (2009). Neural adaptations underlying cross-education after unilateral strength training. *European Journal of Applied Physiology, 107,* 723-730. doi: 10.1007/s00421-009-1190-7

Frost, D. M., Beach, T. A. C., Callaghan, J. P., & McGill, S. M. (2012). Using the functional movement screen to evaluate the effectiveness of training. *Journal of Strength and Conditioning Research, 16*(6), 1620-1630.

Gribble. P. A., Hertel, J., & Plisky, P. (2012). Using the star excursion balance test to assess dynamic postural-control deficits and outcomes in lower extremity injury: A literature and systematic review. *Journal of Athletic Training, 47*(3), 339-357. doi: 10.4085/1062-6050-47.3.08

Gok, H., Geler-Kulcu, D., & Alptekin, N. (2008). Efficacy of treatment with kinaesthetic ability training device on balance and mobility after stroke: A randomized control study. *Clinical Rehabilitation, 22*, 922-930.

Haywood, K. M., & Getchell, N. (2009). *Life Span Motor Development*. J. P. Wright, M. Schwarzentraub, K. G. Fritz, & N. Gleeson. (Eds.). Champaign, IL: Human Kinetics.

Hendy, A. M., & Lamon, S. (2017). The cross-education phenomenon: Brain and beyond. *Frontiers in Physiology, 8,* 1-9. doi: 10.3389/fphys.2017.00297

Herrington, L., Hatcher, J., Hatcher, A., & McNicholas, M. (2009). A comparison of star excursion balance test reach distances between ACL deficient patients and asymptomatic controls. *The Knee, 16,* 149-152. doi: 10.1016/j.knee,2008.10.004

Holme, E., Magnusson, S. P., Becher, K., Bieler, T., Aagaard, P., & Kjaer, M. (1999). The effect of supervised rehabilitation on strength, postural sway, position sense and re-injury risk after acute ankle ligament sprain. *Scandinavian Journal of Medicine & Science in Sports, 9*, 104-109.

Horak, F. B. (1997). Clinical assessment of balance disorders. *Gait & Posture, 6*, 76-84.

Hortobágyi, T., Lambert, N. J., & Hill, P. (1997). Greater cross education following training with muscle lengthening than shortening. *Medicine & Science in Sport & Exercise, 29*(1), 107-112.

Hunt, T. N., Ferrara, M. S., Bornstein, R. A., & Baumgartner, T. A. (2009). The reliability of the modified balance error scoring system. *Clinical Journal of Sports Medicine, 19*(6), 471-475.

Kidgell, D. J., Frazer, A. K., Rantalainen, T., Ruotsalainen, I., Ahtiainen, J., Avela, J., & Howatson, G. (2015). Increased cross-education of muscle strength and reduced corticospinal inhibition following eccentric strength training. *Neuroscience, 300,* 556-575. doi: 10.1016/j.neuroscience.2015.05.057

Kiesel, K., Plisky, P., & Bulter, R. (2011). Functional movement test scores improve following a standardized off-season intervention program in professional football players. *Scandinavian Journal of Medicine & Science in Sports*, *21*, 287-292. doi:10.1111/j.1600-0838.2009.01038.x

Lagerquist, O., Zehr, E. P., & Docherty, D. (2006). Increased spinal reflex excitability is not associated with neural plasticity underlying the cross-education effect. *Journal of Applied Physiology*, *100*, 83-90. doi: 10.1152/ jappliphysiol.00533.2005

Lephart, S. M., Pincivero, D. M., Giraldo, J. L., & Fu, F. H. (1997). The role of proprioception in the management and rehabilitation of athletic injuries. *The American Journal of Sports Medicine, 25*(1), 130-137.

Lepley, L. K., & Palmieri-Smith, R. M. (2014). Cross-education strength and activation after eccentric exercise. *Journal of Athletic Training*, *49*(5), 582-589. doi: 10.4085/1062-6050-49.3.24

Letafatkar, A., Hadadnezhad, M., Shojaedin, S., & Mohamadi, E. (2014). Relationship between functional movement screening score and history of injury. *The International Journal of Sports Physical Therapy*, *9*(1), 21-27.

Magnus, R. A. C., Arnold, C. M., Johnston, G., Haas, D. H., Basran, J., Krentz, J.W., & Farthing, J. P. (2013). Cross-education for improving strength and mobility after distal radius fractures: a randomized controlled trial. *Archives of Physical Medicine and Rehabilitation*, *94*, 1247-1255. doi: 10.1016/j.apmr.2013.03.005

Mancini, M., & Horak, F. B. (2010). The relevance of clinical balance assessment tools to differentiate balance deficits. *European Journal of Physical Rehabilitation Medicine, 46*(2), 239-248.

Mattacola, C. G., & Dwyer M. K. (2002). Rehabilitation of the ankle after acute sprain or chronic instability. *Journal of Athletic Training, 37*(4), 413-429.

McKeon, P. O., & Hertel, J. (2008). Systematic review of postural control and lateral ankle instability, part II: Is balance training clinically effective? *Journal of Athletic Training, 43*(3), 305-315.

Miklitsch, C., Krewer, C., Freivogel, S., & Steube, D., (2013). Effects of predefined mini-trampoline training programme on balance, mobility and activities of daily living after stroke: A randomized controlled pilot study. *Clinical Rehabilitation, 27*(1), 939-947. doi: 10.1177/0269215513485591

Miller, M. M., Trapp, J. L., Post, E. G., Trigsted, S. M., McGuine, T. A., Brooks, M. A., & Bell, D. R. (2017). The effects of specialization and sex on anterior Y-balance performance in high school athletes. *Sports Health, 9*(4), 375-382. doi: 10.1177/1941738117703400

Munn, J., Herbert, R. D., Hancock, M. J., & Gandevia, S. C. (2005). Training with unilateral resistance exercise increases contralateral strength. *Journal of Applied Physiology*, *99*, 1880-1884. doi: 10.1152/japplphysiol.00559.2005

Needle, A. R., Lepley, A. S., & Grooms, D. R. (2017). Central nervous system adaptation after ligamentous injury: A summary of theories, evidence, and clinical interpretation. *Sports Medicine, 47*, 1271-1288. doi: 10.1007/s40279-016-0666-y

Okada, T., Huxel, K. C., & Nesser, T. W. (2011). Relationship between core stability, functional movement, and performance. *Journal of Strength and Conditioning Research, 25*(1), 252-261.

Onate J. A., Dewey, T., Kollock, R. O., Thomas, K. S., Van Lunen, B. L., Demaio, M., & Rigler, S. I. (2012). Real-time intersession and interrater reliability of the functional movement screen. *Journal of Strength and Conditioning Research, 26*(2), 408-415.

Oliveira, A. S. C., Silva, B. P., Farina, D., & Kersting, U. G. (2013). Unilateral balance training enhances neuromuscular reactions to perturbations in the trained and contralateral limb. *Gait and Posture, 38*, 894-899. doi: 10.1016/j.gaitpost.2013.04.015

Olmsted, L. C., Carcia, C. R., Hertel, J., & Shultz, S. J. (2002). Efficacy of the star excursion balance tests in detecting reach deficits in subjects with chronic ankle instability. *Journal of Athletic Training, 37*(4), 501-506.

Parenteau-G, E. P., Gaudreault, N., Chambers, S., Boisvert C., Grenier, A., Gagné, G., & Balg, F. (2014). Functional movement screen test: A reliable screening test for young elite ice hockey players. *Physical Therapy in Sport, 13*, 169-175. doi: 10.1016/j.ptsp.2013.10.001

Pearce, A. J., Hendy, A., Bowen, W. A., & Kidgell, D. J. (2013). Corticospinal adaptations and strength maintenance in the immobilized arm following 3 weeks unilateral strength training. *Scandinavian Journal of Medicine & Science in Sports*, *23*, 740-748. doi: 10.1111/j.1600-0838.2012.01453.x

Plisky P. J., Rauh, M. J. Kaminski, T. W., & Underwood, F. B. (2006). Star excursion balance test as a predictor of lower extremity injury in high school basketball players. *Journal of Orthopaedic & Sports Physical Therapy, 36*(12), 911-919.

Pollock, A. S., Durward, B. R., Rower, P. J., & Paul, J. P. (2000) What is balance? *Clinical Rehabilitation, 14*, 402-406.

Ransdell, L., & Murray, T. (2016). Functional movement screening: An important tool for female athletes. *Strength and Conditioning Journal, 38*(2), 40-48.

Risberg, M. A., Holm, I., Myklebust, G., & Engebretsen, L. (2007). Neuromuscular training versus strength training during first 6 months after anterior cruciate ligament reconstruction: A randomized clinical trial. *Physical Therapy, 87*(6), 737-750.

Ruddy, K. L., & Carson, R. G. (2013). Neural pathways mediating cross education of motor function. *Frontiers in Human Neuroscience, 7*, 1-22. doi: 10.3389/fnhum.2013.00397

Sarabon, N. (2012), Balance and stability training. In J. R. Hoffman (Ed.), *NSCA's Guide to Program Design* (pp. 185-211). Champaign, IL: Human Kinetics.

Schlenstedt, C., Arnold, M., Mancini, M., Deuschl, G., & Weisser, B. (2016). The effect of unilateral balance training on postural control of the contralateral limb. *Journal of Sports Science, 33*(22), 2265-2271. doi: 10.1080/02640414.2016.1265660

Shima, N., Ishida, K., Katayama, K., Morotome, Y., Sato, Y., & Miyamura, M. (2002). Cross education of muscular strength during unilateral resistance training and detraining. *European Journal of Applied Physiology, 86,* 287-294. doi: 10.1007/s00421-001-0559-z

Shultz, R., Anderson, S. C., Methson, G. O., Marcello, B., & Besier, T. (2013). Test-retest and interrater reliability of the functional movement screen. *Journal of Athletic Training, 48*(3), 331-336. doi: 10.4085/1062-6050-48.2.11

Smith, C. A., Chimera, N. J., & Warren, M. (2014). Association of the y balance test reach asymmetry and injury in division I athletes. *Medicine & Science in Sports & Exercise,* 136-141. doi: 10.1249/MSS.0000000000000380

Song, Y., Forsgren, S., Liu, J., Yu, J., & Stål, P. (2014). Unilateral muscle overuse causes bilateral changes in muscle fiber composition and vascular supply. *PLos ONE, 9*(12), 1-27. doi: 10.1371/journal.pone.0116455

Taube, W., & Gollhofer, A. (2013). Postural control and balance training. In J. Nielsen, A. Gollhofer, & W. Taube (Eds.), *Routledge handbook of motor control and motor learning* (pp. 152-273). Oxon: Routledge.

Teyhen, D. S., Shaffer, S. W., Lorenson, C. L., Halfpap, J. P., Donofry, D. F., Walker, M. J., . . . Childs, J. D. (2012). The functional movement screen: A reliability study. *Journal of Orthopaedic & Sports Physical Therapy, 42*(6), 530-540.

Valovich, T. C. Perrin, D. H., & Gansneder, B. M. (2003). Repeat administration elicits a practice effect with balance error scoring system but not with standardized assessment of concussion in high school athletes. *Journal of Athletic Training, 38*(1), 51-56.

Wang, H., Wei, A., Lu, Y., Chen, W., Lu, Y. Liu., Y. . . . Zou, L. (2016). Simplified tai chi program training versus traditional tai chi on the functional movement screening in older adults. *Evidence-Based Complementary and Alternative Medicine*, 1-6. doi: 10.1155/2016/5867810

Wester, J. U., Jespersen, S. M., Nielsen, K. D., & Neumann, L. (1996). Wobble board training after partial sprains of the lateral ligaments of the ankle: A prospective randomized study. *Journal of Othopaedic & Sports Physical Therapy, 23*(5), 332-336.

Wikstrom, E. A., Naik, S., Lodha, N., & Cauraugh, J. H. (2009). Balance capabilities after lateral ankle trauma and intervention: A meta-analysis. *Medicine & Science in Sports & Exercise,* 1287-1295. doi: 10.1249/MSS.0b013e318196cbc6

Wilkins, J. C., McLeod, T. C. V. Perrin, D. H., & Gansneder, B. M. (2004). Performance on the balance error scoring system decreases after fatigue. *Journal of Athletic Training, 39*(2), 159-161.

Winter, D. A. (1995). Human balance and posture control during standing and walking. *Gait & Posture, 3*, 193-214.

Woollacott M. H., & Shumway-Cook, A. (1996) Concepts and methods for assessing postural control. *Journal of Aging and Physical Activity, 4,* 214-233.

Zätterström, R., Fridén, T., Lindstrand, A., & Moritz, U. (1994). The effect of physiotherapy on standing balance in chronic anterior cruciate ligament insufficiency. *The American Journal of Sports Medicine, 22*(4), 531-536.

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