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The effects of a short-term, unilateral, lower-body resistance training program on balance in college-aged resistance-trained participants

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The Effects of a Short-Term, Unilateral, Lower-Body Resistance Training Program on Balance in College-Aged Resistance-Trained Participants

by

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ABSTRACT

Purpose: The purpose of this study was to investigate whether a short-term, unilateral, lower-body resistance training program would significantly improve static and dynamic balance in experienced college-aged resistance-trained participants when compared to a control group's regular, bilateral lower-body resistance training program. **Participants:** A total of twenty-four participants were recruited to participate in the study. Four participants ended up dropping out due to injury and time constraints, leaving the final total sample size at twenty. **Methods:** Participants completed a series of three questionnaires (International Fitness Scale, International Physical Activity, and Sociodemographic Questionnaire) and the informed consent. The participants were randomly divided using the ABBA method, splitting them into two groups (UTG) Unilateral Training Group (n = 10), (CG) Control Group (n = 10). The UTG was given a unilateral lower-body resistance training program to perform twice a week for six weeks, whereas the CG continued their regular lower-body program. The participants in the UTG performed ten total training sessions over the course of six weeks. **Measures:** Pre- and post-testing was performed on the Biodex Balance System SD in the biomechanics laboratory. The Postural Stability test was used to assess unilateral static balance, and the Athlete Single Leg Stability test was used to assess unilateral dynamic balance. **Analysis:** An *a priori* power analysis was conducted to determine sample size. A series of two-way mixed methods ANOVAs were used to assess a group by time interaction on static and dynamic balance. Independent and dependent samples t-tests were used to determine post-hoc simple main effects. Data were analyzed using IBM SPSS version 25 with an established alpha level of 0.05. **Conclusion:** The UTG's program was effective for improving pre to post static and dynamic balance over time compared to the CG's regular program.

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CHAPTER 1

Summary

Background

In recent years, the use of unilateral exercises such as modified split squats, step-ups, and pistol squats have gained popularity in the strength and conditioning field. Unilateral leg training is a movement in which one leg produces force while the free leg either plays a minimal role in force production or is used to help maintain balance (Howe, Goodwin, & Blagrove, 2014). Unilateral exercises have been primarily incorporated into lower-body resistance training programs as accessory exercises (Boyle, 2005; Howe et al., 2014). Most athletes and fitness enthusiasts feel more comfortable performing bilateral movement patterns such as the back squat due to more stable base of support. However, a significant amount of unilateral work is performed by most individuals during normal daily activities. Walking has a continuous, cyclical motor pattern, but when it is split into phases the body is supported on one leg during mid-stance (Bartlett, 2007). This mid-stance phase occurs in everyday activities such as walking up and down stairs, walking, jogging, and running. Unilateral movement can also be related to people who play sports, in which most jumping, bounding, landing, change in direction or propulsive cutting motions are performed on one leg (McCurdy & Langford, 2005; Gonzalo-Skok et al., 2016; Nijem, 2016). According to Howe et al. (2014) unilateral training increases the recruitment of muscle fibers in stabilizer muscles, decreases compressive loads on the spine, fixes asymmetries and imbalances, and is beneficial in injury prevention when compared to bilateral training. Therefore, if unilateral movements play such an important role in basic human locomotion, then an exclusively unilateral exercise program could be implemented to improve static and dynamic balance in experienced college-aged resistance trained participants.

Statement of Problem

An exclusively unilateral, lower-body training program may show superior results in improving both static and dynamic balance compared to an exclusively bilateral, lower-body training program.

Purpose of Study

The purpose of this study was to investigate whether a short-term, exclusively unilateral, lower-body resistance training program will significantly improve static and dynamic balance in experienced college-aged resistance trained participants when compared to a control group's regular, bilateral lower-body resistance training program.

Hypothesis

It was hypothesized that the participants randomly assigned to the unilateral resistance training group would significantly improve static balance in both dominant and non-dominant legs compared to the control group.

It was hypothesized that the participants randomly assigned to the unilateral resistance training group would significantly improve dynamic balance in both dominant and non-dominant legs compared to the control group.

Delimitations

The Biodex Balance System SD machine was chosen for testing balance because both static and dynamic balance could be easily assessed, it was easy to perform, and was a valid measure of balance.

Experienced college-aged resistance trained participants at SUNY Cortland will be recruited as a convenience sample.

Limitations

Due to Spring Break in the middle of the semester, the participants will use this week as a rest week in the training program.

Due to semester time constraints the intervention program had to be completed within a certain period of time.

The use of the International Fitness Scale, and International Physical Activity Questionnaires to assess fitness and physical activity may be skewed due to how the participants perceived their fitness and physical activity levels.

Although the participants were experienced, resistance-trained participants, they may not have followed the training protocol of lower-body training twice a week.

Results may have differed if other measured were used to measure static and dynamic balance.

Assumptions

It was assumed that all participants had similar fitness levels, but the everyday lifestyle choices of each participant were relatively unknown.

It was assumed that all participants answered the questionnaires truthfully, and to the best of their knowledge.

It was assumed that all participants had prior experience in resistance training.

It was assumed that all participants performed to the best of their abilities during each training session.

It was assumed that all participants performed every training session throughout the course of the study.

Definition of Terms

Balance	An even distribution of weight enabling someone or something to remain upright and steady
Bilateral Deficit	The reduction in the performance of force and strength during a bilateral contraction when compared to the sum of forces produced by two unilateral contractions.
Bilateral Leg Training	A movement in which both legs produce force in a closed or open kinetic chain
Biodex Balance System SD	A machine that assesses closed chain, multi-plane tests by measuring the participants ability to maintain dynamic unilateral or bilateral postural stability on either a static or unstable surface
Concentric Contraction	A type of muscle activation that increases tension on a muscle as it shortens
Eccentric Contraction	A type of muscle activation that increases tension on a muscle as it lengthens
Dynamic Balance	The ability to maintain one's balance at equilibrium during motion or switching between positions
Resistance Training	Exercises moving your limbs against resistance provided by your own bodyweight, gravity, bands, weighted bars, and dumbbells
Static Balance	The ability to maintain one's balance at equilibrium when stationary
Unilateral Leg Training	A movement in which one leg produces force while the opposite leg maintains stability or assists in minor force production.

Significance of the Study

The goal of this study was to investigate whether a short-term, unilateral training program improved static and dynamic balance in an experienced college-aged resistance-trained group when compared to a control group.

CHAPTER 2

Review of Literature

Introduction

Athletes, coaches, and fitness enthusiasts routinely seek out methods to more effectively and efficiently improve performance. Creating client-specific programs and implementing exercises are important contributors to static and dynamic balance, which are important performance characteristics in everyday activities and sport-specific movements. Habitual resistance training in general creates numerous muscular, skeletal, and neural adaptations in the body, which are directly linked to performance increases. Traditionally, bilateral exercises are incorporated into a resistance training program to develop fundamental movement patterns. Bilateral leg training is defined as a movement in which both legs produce force while fixed on the ground (Boyle, 2004; Howe, Goodwin, & Blagrove, 2014). However, in recent years, unilateral lower-body exercises have increased in popularity from an accessory exercise to a primary exercise (Boyle, 2005; Howe et al., 2014). Unilateral leg training is defined as a movement in which one leg produces force while the opposite leg maintains stability or assists in minor force production (Howe et al., 2014). Many locomotive skills are performed either entirely or predominately unilaterally. For example, during the mid-stance phase of the human walking gait cycle, the body is completely supported on one leg (Bartlett, 2007). Routine daily activities such as walking up and down stairs, walking, jogging, running, and sport-related skills such as bounding, jumping, landing, and changing direction are all performed unilaterally (McCurdy, Langford, Doscher, Wiley, & Mallard, 2005; Gonzalo-Skok et al., 2016; Nijem, 2016). One issue with training exclusively bilateral is that it may increase unknown asymmetries, imbalances, and could lead to injuries. Often, a phenomenon known as bilateral deficit can occur during training. Bilateral deficit is defined as the reduction in the performance of force and strength during a bilateral contraction when compared to the sum of forces produced by two unilateral contractions (Howe et. al, 2014; Costa, Moreira, Cavalcanti, Krinski, & Aoki, 2015; Beurskens, Gollhofer, Muehlbauer, Cardinale, & Granacher, 2015; Jakobi & Chilibeck, 2001). In other words, the sum of the two unilateral contractions when performing an exercise will almost certainly be greater than one single maximal bilateral contraction exercise (Howe et al., 2014; Costa et al., 2015; Beurskens et al., 2015; Jakobi & Chilibeck 2001). According to Howe et al. (2014), unilateral training increases the recruitment of muscle fibers in stabilizer muscles, decreases compressive loads on the spine, fixes imbalances, and is beneficial in injury prevention when compared to bilateral training. Other benefits of unilateral training are increases in strength and power of both legs with less compressive loads on the spine and increased trunk stability. Although bilateral training has produced improvements in performance for years, unilateral training can produce safer increases in performance with half the weight, while increasing neural drive, and decreasing bilateral deficit (Howe et al., 2014). It is hypothesized that performing exclusively unilateral exercises in a training program could increase balance in college-aged resistance trained participants.

Static and Dynamic Balance

Balance is one of the most important but overlooked factors in the implementation of most movements involved in daily living (Winter, Patla, & Frank, 1990; Bell, Guskiewicz, Clark, & Padua, 2011). Balance is defined as one's ability to maintain equilibrium by maintaining a base of support (Blackburn, Guskiewicz, Petschauer, & Prentice, 2000; Haff & Triplett, 2016; Daneshjoo, Mokhtar, Rahnama, & Yusof, 2012; Bell et al., 2011). Two types of balance exist: static and dynamic (Winter et al., 1990). Static balance is defined as the ability to maintain a firm base of support in a motionless position on one or two feet, and dynamic balance is defined as one's ability to maintain a base of support on one leg while moving (Winter et al., 1990; Daneshjoo et al., 2012; Blackburn, et al., 2000; Ricotti, 2011). The complexity of balance relies heavily on multiple systems including the vestibular system, visual system, proprioceptive system, central nervous system, and the musculoskeletal system (Blackburn et al., 2000; Winter et al., 1990; Ricotti, 2011). To achieve balance, the body uses sensory input from the vestibular system (Winter et al., 1990; Ricotti, 2011; Blackburn et al., 2000). The vestibular system relies on the inner ear to provide the central nervous system with information to contribute in spatial orientation and sense of balance (Winter et al., 1990). The visual system uses the eyes to provide the central nervous system with visual details about the environment and movement of the body (Winter et al., 1990). Proprioception refers to changes in equilibrium, recognition of kinesthesia or joint movement, and information regarding the environment such as sense of position, pressure, temperature, and pain (Winter et al., 1990, Blackburn et al., 2000; Cox, Lephart, & Irrgang, 1993). The proprioceptive system collects sensory information from receptors in the joints, skin, tendons, muscles, ligaments, and cutaneous receptors in the central nervous system (Winter et al., 1990, Blackburn et al., 2000; Cox et al., 1993). These specialized proprioceptors such as Golgi-tendon organs and muscle spindles relay information to the central nervous system regarding muscle tension and length (Cox et al., 1993; Blackburn et al., 2000; Winter et al., 1990; Haff & Triplett, 2016). Neuromuscular control via proprioceptors and muscular strength are vital in controlling balance of everyday life (Blackburn et al., 2000)

Adaptations to Resistance Training

Habitual resistance training has been directly linked to adaptations to the muscular, skeletal, and neural systems (Carrol et al., 2011; Enoka, 1988; Haff & Triplett, 2016). The amount of force a muscle can exert is influenced by numerous biomechanical factors, including neural control, muscle cross-sectional area, arrangement of muscle fibers, muscle length, muscle contraction velocity, and joint angular velocity (Carrol et al., 2001; Enoka, 1988; Haff & Triplett, 2016; Schoenfeld, 2016).

Neural control contributes to the maximal force produced by a muscle by regulating which and how many motor units are included in recruitment, and the frequency at which motor units are activated (Carrol et al., 2011; Enoka, 1988; Haff & Triplett, 2016; Schoenfeld, 2016). The stress of reoccurring resistance training results in increases in muscle synchronization (Carrol et al., 2011). Muscle fibers are organized into several types including radiate, longitudinal, fusiform, multi-pennate, bi-pennate, and uni-pennate (Haff & Triplett, 2016). The different types of muscle, the arrangement of muscle fibers, and the area across the muscle are directly related to how much force one can produce when the muscle shortens because of the number of sarcomeres in parallel (Enoka, 1988; Haff & Triplett, 2016). Inside a sarcomere, there are contractile muscle proteins (actin and myosin) that create a shortening of the muscle to produce force (Haff & Triplett, 2016; Schoenfeld, 2016). Muscles can create a greater amount of force when at resting length due to the amount of potential cross bridge areas (Haff & Triplett, 2016). Depending on the range of motion of the joint, muscle length torques or forces can be produced when needed (Haff & Triplett, 2016). The speed at which a muscle is contracted and the type of muscle contraction is related to the amount of force produced (Haff & Triplett, 2016, Carrol et al., 2011). There are three types of muscle contractions that can produce force (Haff & Triplett, 2016). The concentric muscle contraction occurs when the muscle is shortened because the contractile force is greater than the resistive force (Haff & Triplett, 2016). The eccentric muscle contraction is the movement of an active muscle while it is lengthening under tension (Haff & Triplett, 2016). Isometric contractions occur when the muscle length does not change because the forces are equal (Haff & Triplett, 2016).

The neural and muscular adaptations brought on by anaerobic resistance training increase the neural drive by enhancing strength, balance, and power to improve performance (Haff & Triplett, 2016; Enoka, 1988). Adaptations in the central nervous and musculoskeletal systems increase muscle recruitment, firing rate, and synchronization of motor units in the higher brain centers (Haff & Triplett, 2016; Schoenfeld, 2016; Carrol et al., 2011). When learning to perform a new movement, the primary motor cortex, which is associated with motor learning, is activated in the brain (Carrol et al., 2011; Haff & Triplett, 2016; Schoenfeld, 2016). The specific pattern in which motor units are recruited is related to the size principle (Kraemer, & Newton 2000), which is defined as the relationship between the recruitment of motor units or twitch force and the recruitment threshold (Kraemer, & Newton, 2000; Haff & Triplett, 2016; Schoenfeld, 2016). Recruitment threshold is determined by the type of muscle fibers being stimulated and how much force needs to be produced (Kraemer, & Newton, 2000; Haff & Triplett, 2016; Schoenfeld, 2016).

Most muscles are composed of two types of muscle fibers, Type 1 fibers and Type 2 fibers, each of which have subtypes (Kraemer & Newton, 2000; Haff & Triplett, 2016; Schoenfeld, 2016). The recruitment of muscle fibers depends on increasing demands of activity, where low threshold Type 1 muscle fibers are recruited first, followed by the higher threshold Type 2 muscle fibers (Kraemer & Newton, 2000; Haff & Triplett, 2016; Schoenfeld, 2016). Through repetitive resistance training muscle fibers increase in size and become easier to re-recruit (Kraemer & Newton, 2000; Haff & Triplett, 2016; Schoenfeld, 2016). The exception to the size principle is selective recruitment, which is defined as the ability to inhibit Type 1 low threshold muscle fibers to activate the Type 2 higher threshold muscle fibers to produce force at faster speeds (Kraemer, & Newton, 2000; Haff & Triplett, 2016; Schoenfeld, 2016).

The neural, skeletal muscle, and bone adaptations from resistance training occur because of the increase in metabolic stress, mechanical tension, and muscle damage (Haff & Triplett, 2016; Schoenfeld, 2016). Resistance training elicits changes in muscular strength, power, and endurance through changes in muscle fiber size, fiber type transition, and biomechanical markers in muscle (Haff & Triplett, 2016; Schoenfeld, 2016). The increase in the contractile proteins actin and myosin, newly created myofilaments, and the increase in muscle fiber cross sectional area following training is called muscular hypertrophy (Haff & Triplett, 2016; Schoenfeld, 2016). Muscle hypertrophy is associated with the type of contraction and amount of tension on the muscle, the build-up of lactic acid from exercise-induced stress, and tears in the sarcolemma from muscle damage when resistance training (Haff & Triplett, 2016; Schoenfeld, 2016). Muscular strength and hypertrophy are strongly related (Haff & Triplett, 2016; Schoenfeld, 2016). Mechanical loading from resistance training causes stressful forces on bones and muscles (Haff & Triplett, 2016; Schoenfeld, 2016). Forces from resistance training such as bending, compression, and torsion of bone stimulates osteoblasts to increase bone strength by adding new bone to the stressed area (Haff & Triplett, 2016; Schoenfeld, 2016).

Resistance training program design is the most important factor in adaptations to the skeletal and the neuromuscular system (Haff & Triplett, 2016; Schoenfeld, 2016). The volume, frequency, load, exercise selection, type of muscle action, rest period, repetition duration, exercise order, and intensity all elicit adaptations in the body (Haff & Triplett, 2016; Schoenfeld, 2016). Volume load is defined as the amount of sets, repetitions, and load one performs during resistance training (Haff & Triplett, 2016; Schoenfeld, 2016). Frequency is defined as the number of training sessions performed in a period of time (Haff & Triplett, 2016; Schoenfeld, 2016). The number of repetitions relates to the intensity of the load lifted (Haff & Triplett, 2016; Schoenfeld, 2016). The type of exercise selected should incorporate all three planes of motion: sagittal, frontal, and transverse (Haff & Triplett, 2016; Schoenfeld, 2016). Incorporating machines as well as free weights and using the three planes of motion will alter the movement patterns activating different muscle fibers, which will cause stress to the different muscle fibers, ultimately increasing their size over time (Haff & Triplett, 2016; Schoenfeld, 2016). Concentric, eccentric, and isometric muscle contractions should all be incorporated into resistance training programs because they recruit muscle fibers in different orders, which leads to changes in muscle size (Haff & Triplett, 2016; Schoenfeld, 2016). The amount of time rested in between sets of exercise can be categorized as short (30 seconds of less), moderate (60 to 90 seconds of rest), or long (3 minutes of more) (Haff & Triplett, 2016; Schoenfeld, 2016). Repetition duration refers to the tempo of the type of contraction during exercise (Haff & Triplett, 2016; Schoenfeld, 2016). The order of exercises in a resistance training program should start with larger muscle exercises, and end with smaller muscle exercises due to fatigue rates (Haff & Triplett, 2016; Schoenfeld, 2016). The intensity at which one exercises (e.g., light, moderate, or vigorous) is associated with increase in muscle size (Haff & Triplett, 2016; Schoenfeld, 2016). Creating a program that incorporates all of these factors is necessary to elicit adaptations over time.

Gait

Gait is defined as a repetitive pattern of locomotion involving steps and strides (Bartlett, 2007). Walking, jogging, and running are all continuous cyclic activities of daily living that can be broken down into similar phases (Bartlett, 2007). Normal human gait has eight phases including initial contact, loading response, mid-stance, terminal stance, pre-swing, initial swing, mid swing and late swing (Bartlett, 2007). During the mid-stance phase of gait, the body is supported unilaterally on one leg (Bartlett, 2007). However, many skills are performed unilaterally including walking up and down stairs, bounding, landing, jumping, kicking, and change in direction (McCurdy et al., 2005; Gonzalo-Skok et al., 2016; Nijem, & Galphin, 2016).

Unilateral/Bilateral Benefits and Bilateral Deficit

Athletes and coaches alike should have an understanding of the importance of incorporating unilateral and bilateral exercises to develop lower-body strength (Boyle, 2004). Unilateral leg training is defined as a movement in which one leg produces force while the opposite leg maintains stability or assists in minor force production (Howe et al., 2014). Bilateral leg training is defined as a movement in which both legs produce force in a closed or open kinetic chain (Boyle, 2004; Howe et al., 2014). Unilateral exercise has been incorporated as accessory exercises in lower-body programs to increase force production (Howe et al. 2014; Jakobi, & Chilibeck, 2001; McCurdy et al., 2005).

In the 1960s researchers studied differences in maximal hand grip strength between the right and left hand of thirty 21-year-old males using a dynamometer. Two trials were conducted using the dynamometer, single-hand contraction, and simultaneous contraction of both hands. The results indicated a three percent loss of hand grip strength of the dominant hand during the simultaneous contraction and a significant difference in maximal force between one and two limb movements (Henry & Smith, 1961). This phenomenon is termed bilateral deficit and is defined as the reduction in the performance of force and strength during a bilateral contraction when compared to the sum of forces produced by two unilateral contractions (Howe et. al, 2014; Costa et al., 2015; Beurskens et al., 2015; Jakobi & Chilibeck, 2001). In other words, the sum of the two unilateral contractions when performing an exercise will almost certainly be greater than one single maximal bilateral contraction exercise (Howe et. al., 2014; Costa et al., 2015; Beurskens et al., 2015; Jakobi & Chilibeck, 2001). Bilateral deficit only occurs when homonymous limbs of the body move together simultaneously. The effect is not observed when non-homonymous limbs, such as the leg and the arm, contract simultaneously (Jakobi & Chilibeck, 2001; Janzen, Chilibeck, & Davison, 2006; Howe et al., 2014). Howard and Enoka (1991) investigated the neural mechanisms of bilateral deficit on three groups (untrained individuals, cyclists, and weight lifters). Each participant performed a maximal one or two limb isometric test where the two-limb combination was either both legs or the left arm and right leg. They found that the arm-leg combination was unaffected for all groups, when compared to the homogeneous limbs. This discovery paved the path for future studies explaining that bilateral deficit only occurs when homonymous limbs simultaneously contract.

Neural drive is the most scientific plausible cause of the bilateral deficit. This neural activity differs between the unilateral and bilateral movements and the difference is large enough to significantly reduce performance during bilateral activates (Nijem, & Galphin, 2014). Vandervoort, Sale and Moroz (1984) investigated which type of motor unit is not utilized in voluntary bilateral maximal contractions and monitored electromyography (EMG) activity during unilateral and bilateral leg extension. Nine young (mean age = 22) resistance trained males were tested for strength-velocity relation and fatigability. Isokinetic equipment was used to assess voluntary strength via an isometric contraction, and the leg press was used to assess strength via concentric contractions. The EMG monitored the vastus medialis, vastus lateralis, and rectus femoris during each leg movement. Results revealed that the strength of the bilateral maximal voluntary contraction in leg extension was less than the summed unilateral strength in both isometric and concentric contractions. The greater relative decline in strength at high velocities, and fatigability in bilateral conditions explains that there is a reduced activation of fast twitched motor units in bilateral maximal voluntary contractions compared to unilateral. This indicated that the extent of motor unit activation appeared to be reduced in bilateral maximal voluntary contractions relative to unilateral maximal voluntary contractions. This reduction was due to a lesser utilization of fast twitch fatigable type of motor unit. The EMG findings concluded that the leg press showed significant decrease in motor unit activity of active muscles during bilateral maximal voluntary contraction compared with unilateral. Similar to the previous study, VanDieen, Ogita, and deHann (2003) researched whether bilateral deficit is a large enough factor to explain limitations in performance in bilateral exertions. Ten male participants were tested on voluntary force production and neural drive during unilateral and bilateral exertions in three conditions (unilateral maximal contraction, synchronous bilateral contractions, and asynchronous bilateral contractions) of finger and knee extensors. The results showed maximal voluntary force was significantly lower in bilateral knee extension, and the maximum rate of force development when compared to unilateral knee extension. The findings show that bilateral exertion neural drive can be reduced to such an extent that it will limit performance in maximum intensity activities. Since the discovery of the phenomenon there has been a surplus of studies (below) conducted on different intensities and different populations such as males and females, active and non-active, athletes, youth, adult, and the elderly (Howe et al., 2014; Nijem & Galphin, 2014; Janzen et al., 2006; Costa et al., 2015; Beurskens et al., 2015; Jakobi & Chilibeck, 2001; Bobbert, de Graaf, Jonk, & Casius, 2006; Weir, Housh, & Weir, 1997; Haff & Triplett, 2016).

Results from studies regarding how bilateral and unilateral training can influence bilateral deficit have been conflicting (Howe et al., 2014; Nijem, & Galphin, 2014; Janzen et al., 2006; Costa et al., 2015; Beurskens et al., 2015; Jakobi et al., 2001; Bobbert et al., 2006; Weir et al., 1997; Haff & Triplett, 2016). Understanding whether bilateral weight training or unilateral weight training is superior in eliciting lower limb benefits and correcting bilateral deficit is of great importance (Jakobi et al., 2001; Howe et al., 2014). Beurskens and colleagues (2015) investigated the effects of bilateral resistance training and unilateral training on maximal force production between a young and elderly population. Fifty-three elderly males and 14 young males were divided into three training groups (bilateral heavy resistance strength training, predominately unilateral balance training, and control group). The groups each trained every other day for 60 minutes where the training intensity and loads were individually assigned and adjusted accordingly based off of their initial force production. They found that both styles of training increased maximal force production and decreased bilateral deficit in younger males. In older adults there was a decreased level of both unilateral and bilateral muscular strength and increased unilateral deficit when compared to younger adults.

Similar to the previous article's research design, Gonzalo-Skok and colleagues (2016) conducted a study on bilateral deficit but in a highly trained population. The effects of unilateral versus bilateral lower-body training on single leg power output bilateral deficit, linear sprinting, jumping performance and between limb imbalances in male basketball players was investigated. Twenty-two highly skilled young male basketball players were divided into either an exclusive unilateral or bilateral strength training group. The participants completed a 25m running sprint test, a countermovement jump test, a V-cut test, a 15m sprint test, and a squat load test before starting the six-week strength training program. After completion of the training program both groups exhibited improvements in power output, sprinting, and jumping performance. The main findings of the study indicated that the unilateral group significantly improved in the single-leg maximum power output, reduced between-limb asymmetries and bilateral deficit in back-squat maximum power output compared to the bilateral group.

McCurdy and Langford (2005) studied the effects of a short-term unilateral versus bilateral resistance training program on thirty-eight young untrained individuals to investigate if strength and power would increase significantly in either group. Participants were tested on their vertical jump height, and their five-repetition maximum of single leg squat or bilateral squat. Over the course of eight-weeks the two groups of participants (unilateral and bilateral) followed a custom free weight program. The results revealed that there was a significant increase in strength in which both groups yielded similar results, yet the unilateral group improved more in jump height and relative power compared to the bilateral group.

Bilateral deficit may be caused by neurological factors such as neural activity, which differs between unilateral and bilateral movements, and can reduce performance during bilateral activities (Van Dieen et al., 2003; Vandervoort et al., 1984). McCurdy and colleagues (2010) measured the lower extremity EMG activity of eleven Division One female athletes. The female athletes participated in two sessions comprised of three repetition maximum testing for two-legged squat and a modified single leg squat (MSLS). EMG pads were placed on the gluteus medius, rectus femoris, and biceps femoris while performing three-repetition maximum at 85% of max force. EMG activity was significantly higher in the gluteus medius and hamstring in the MSLS, whereas quadriceps muscle activity was significantly higher in the two-legged squat. The findings of the study revealed that during unilateral exercises (e.g., MSLS) there is an increased activation of supporting stabilizer muscles and hamstring activation compared to bilateral exercises (e.g., two-legged squat).

Anderson and Behm (2005a) conducted a similar study examining differences in EMG activity in various muscles during a stable and unstable squat. EMG pads were attached on the soleus, vastus lateralis, biceps femoris, abdominal stabilizers, upper lumbar erector spinae, and lumbo-sacral erector spinae muscles of fourteen male participants. In a single testing session each participant was subjected to three types of squat variations (e.g., squatting on balance discs, regular squat, and Smith's bar squat). The participants were told to complete two slow repetitions at a randomized intensity of body weight (e.g., 29.5kg and 60% of body mass). They found that EMG activity for the abdominals, upper, and lower erector spinae muscles was significantly increased during an unstable squat when compared to the Smith bar squat, and regular squat. It appears that the instability of an unstable squat contributes to the development of trunk stabilizer muscles, ultimately increasing balance and coordination.

Similarly, DeForest, Cantrell and Schilling, (2014) examined muscle activity, vertical displacement, and unilateral ground reaction forces between a rear elevated single leg squat, split squat and a back squat in nine resistance-trained men. EMG pads were attached on the gluteus maximus, biceps femoris, semitendinous, rectus femoris, vastus lateralis, vastus medialis, tibialis anterior, and the gastrocnemius while performing a single session of a back squat at 85% of one repetition maximum, or at 50% of bilateral squat load for rear elevated split squat. The results showed similar muscle activity in the three squat variations, yet the rear elevated split squat showed similar lower-body muscle activity using half the load when compared to the back squat. The unilateral squat variations proved to be a safer effective exercise by stimulating lower-body muscle activity while, potentially preventing less injuries from occurring.

A meta-analysis concerning the effects of bilateral and unilateral training on bilateral deficit, axial loading, asymmetry correction, and muscle activation was conducted by Howe and colleagues (2014). The meta-analysis revealed that both training modalities generated similar results regarding increases in strength, but only unilateral training has been linked to increasing the recruitment of muscle fibers in stabilizer muscles, decreasing compressive loads on the spine, fixing imbalances, and is beneficial in injury prevention when compared to bilateral training.

The Relationship between Strength and Balance

The musculoskeletal system plays an important sensorial role through the use of proprioceptors to assist in maintaining balance (Celenk, Marangoz, Aktug, Top, & Akul, 2015). Unilateral resistance training has been linked to increasing muscular strength in both legs and the recruitment of muscle fibers in stabilizer muscles over time (Howe et. al, 2014).

The advantage of unilateral training causes an unfamiliar, unstable environment, which forces the body to adapt to a new training stimulus (Behm & Anderson, 2006). The new stimuli in the early stages of a resistance training program will cause an increase in muscle cross-sectional area and put a greater stress on the neuromuscular system, thus increasing neuromuscular stability and coordination (Behm & Anderson, 2006; Kibele & Behm, 2009). Balancing on one leg during unilateral training increases the sensitivity of feedback pathways and sense of position in the active muscles, contributing to the maintenance of body balance (Behm & Anderson, 2006). Ibis (2017), investigated the relationship between strength, leg volume, anthropometric features, and balance in a team of young female wrestlers. Sixteen young women (18.43 +/- 2.25 years) used the Biodex Balance System to assess static and dynamic balance in a double leg stance for three trials for thirty seconds. The participants' height, weight, BMI, leg and foot volume were measured as well as leg strength by use of a dynamometer. The results showed a positive relationship between static and dynamic balance and leg strength and leg volume. The results determined that wrestlers with better dynamic balance with high leg strength and volume also had greater muscular strength due to improvements in intra/inter muscular coordination. The size of the muscles in the leg have a large impact on balance. Celenk and colleagues (2015) investigated whether quadriceps femoris and hamstring muscular force of elite athletes affects static and dynamic balance performance (Celenk et. al., 2015). Sixteen elite level athletes tested quadriceps femoris and hamstring muscular force using the Pressure Air Biofeedback Test, which measured average, maximum, relative and total work. The Biodex Balance System was used to assess static and dynamic balance in the double leg position for three trials of thirty seconds each. The results showed that the quadriceps femoris muscular force of the athletes affected their static and dynamic balance performance. As the balance difficulty levels increased, the quadriceps femoris muscular force became more important, whereas the hamstring muscular force did not seem to affect balance performance. The importance of muscular strength, force and volume in the legs (especially the quadriceps) shows superior balance performance measures.

Because leg strength and balance are related, they should be developed simultaneously over time through resistance training programs. Mohammadi and colleagues (2011) examined the effects of a six-week strength training program on static and dynamic balance in young male athletes. Thirty young male athletes (16 +/- 1.2 years) were divided into either a strength training group or a control group. Both groups were assessed using the Romberg adjusted balance test for static balance and the Star Excursion Balance Test for dynamic balance. The strength training group partook in a six-week program consisting of three thirty-minute sessions per week performing squats, lunges, leg extensions, calf raises, and curl ups. Following the training program, the strength training group showed significant improvements in both static and dynamic balance compared to the control group. Similar to the previous article, Eylen and colleagues (2017) examined the effects of different strength training programs on static and dynamic balance in twenty young male volleyball players (21 +/- 3 years). The subjects were randomly divided into two groups, the experimental and control group. The experimental group was given different strength training programs varying the repetition range three days a week for eight-weeks during their regular season. Leg strength was assessed with the Takei Leg Dynamometer and balance was assessed by the Biodex Balance SD Isokinetic Balance test. The results showed significant increases in both static and dynamic balance in the experimental group after the eight-week program compared to the control group. The possible reason for the increase in static and dynamic balance over a few short weeks can be linked to the adaptations in the central nervous and musculoskeletal systems increase sensitivity enhancement of muscle spindles, muscle recruitment, firing rate, coordination, and synchronization of motor units in the higher brain centers (Haff & Triplett, 2016; Schoenfeld, 2016; Carrol et al., 2011; Mohammadi et al., 2017).

Conclusion

Over the past 40 years, the research regarding bilateral and unilateral training has generated conflicting results, particularly regarding which training style is superior in improving performance measures. There have been a few studies regarding resistance training and the effects on balance in trained populations, but no studies specifically examining the effects of a unilateral lower-body program. The objective of the current study is to determine whether specific unilateral lower-body training will significantly increase static and dynamic balance in both legs of college-aged experienced lifters.

CHAPTER 3

RESEARCH BRIEF

Methods

Participants and group selection. Following approval from the SUNY Cortland Institutional Review Board [Appendix A], male and female students were recruited for the study via word of mouth and email. Recruited participants were given an informed consent form [Appendix B] that thoroughly explained the study and procedures. The individuals who gave consent to participate were given the International Fitness Scale Questionnaire [Appendix C] and the International Physical Activity Short Form Questionnaire [Appendix D] to determine if the experienced lifter criteria were met (Lee, Macfarlane, Lam, & Stewart, 2001; Merellano-Navarro, Collado-Meteo, Garcia-Rubio, Gusi, & Olivaries, 2017).

In order to participate in the study, the following inclusion criteria were required: No lower-body injuries within the past 6 months, a minimum score of 16 on the International Fitness Scale, reported physical activity of five or more days per week, and reported five or more hours of physical activity a week on the International Physical Activity Questionnaire. If all criteria were met the participant was chosen to continue with the study. The participants were informed via word of mouth, text message, or email that they were chosen to participant in the study. Using the randomized ABBA method, participants were placed into either the Unilateral Training Group (UTG) or the Control Group (CG).

Measures. Before pre-testing, participants were given guidelines to balance testing, [Appendix F] and a Sociodemographic Questionnaire [Appendix E]. The sociodemographic questionnaire asked participants to self-report their height, weight, sex, past medical history, injuries, medicines, regular exercise routine, and dominant leg (the leg with which they kick).

Static balance. The Biodex Balance System SD (Biodex Medical Systems Inc., 950-440, Shirley, NY) machine assesses closed chain, multi-plane tests by measuring participants' ability to maintain dynamic unilateral or bilateral postural stability on either a static or unstable surface. The Biodex Balance System SD is composed of a digital display screen, support hand rails, a circular foot platform, and a printer. The Biodex Balance System SD was used to assess unilateral static balance for each participants' right and left legs.

The first test performed on the Biodex Balance System SD was the Postural Stability test. Each participant was briefed on how the machine worked prior to the start of the test. The participants' name, age, and height were entered into the digital display screen. Based on the selected height an appropriate static measure scale was applied automatically. The circular foot platform has a grid showing angles from 0 to 45 degrees in 5 degree increments as well as a horizontal and vertical overlapping grid labeled with numbers and letters. The grid let the participant know where to stand during each test. The display screen showed a digital model of the foot platform with an outline of the foot within three circles and a cross hair. Each participant was given a practice trial for each leg, followed by performing the testing trials three times on each leg. Each trial took 20 seconds. In between each trial was a 10 second countdown before the onset of the next trial. The participant stood on the circular foot platform while holding on to the handrails, which were about waist level. The circular foot platform was locked in a motionless position throughout the trials. Participants were told that they were to balance on one leg without touching the handrails, and without the non-balancing leg touching the balancing leg. During the testing trials participants were told to let go of the handrails (but they were allowed to hover their hands over the rails without touching them) until the trial was over. Participants were told to look at the display screen during the trials, and that the goal of the test was to stay in the inner most circle closest to the middle of the cross hairs. A small black dot appeared on the display screen, which moved depending on the participants' movement of the foot position and provided a green tracing line to show where it moved during the trials. The dominant leg was assessed first followed by the non-dominant leg. After completion of the testing trials the digital screen displayed the participants' results. The screen displayed the results by overall stability index, anterior/posterior index, and medial/lateral index with a balance score and a standard deviation. The actual score numbers provided were a distance measure of postural sway; therefore, a smaller number was indicative of better static balance (e.g., less sway and more control). The dominant and non-dominant leg overall stability index scores were summed and divided by two for one overall static balance score. Results were recorded and kept in a locked drawer on campus. Refer to Appendix G for pictures of testing positions on the Biodex Balance System SD.

Dynamic balance. The second test performed on the Biodex Balance System SD (Biodex Medical Systems Inc., 950-440, Shirley, NY) was the Athlete Single Leg Stability test. Each participant was briefed on how the machine worked prior to the start of the test. The participant's name, age, and height were entered into the digital display screen. Based on the selected height an appropriate static measure scale was applied automatically. On the circular foot platform there was a grid showing angles from 0 to 45 degrees in 5 degree increments as well as a horizontal and vertical over lapping grid labeled with numbers and letters. This grid let the participant know where to stand during each test. The display screen showed a digital model of the foot platform with an outline of the foot within three circles and a cross hair. Each participant was given a practice trial for each leg, followed by three testing trials per leg. Each trial took 20 seconds with a 10 second countdown between trials. Participants stood on the circular foot platform while holding on to the handrails, which were about waist level. During the testing trials the circular foot platform could move in any direction. Participants were told to balance on one leg without touching the handrails, and without the non-balancing leg touching the balancing leg. Participants were told to look at the display screen during the trials, and that the goal of the test was to stay in the inner most circle closest to the middle of the cross hairs. A small black dot appeared on the display screen, which moved depending on the participants' movement of the foot position and provided a green tracing line to show where it moved during the trials. The dominant leg was assessed first followed by the non-dominant leg. After completion of the testing trials the digital screen displayed the participants' results. The screen displayed the results by overall stability index, anterior/posterior index, and medial lateral index with an actual score and a standard deviation. The actual score numbers provided were a distance measure of postural sway; therefore, a smaller number was indicative of better static balance (e.g., less sway and more control). The dominant and non-dominant leg overall stability index scores were summed and divided by two for an overall dynamic balance score. Results were recorded and kept in a locked drawer on campus. Refer to Appendix G for pictures of testing positions on the Biodex Balance System SD.

Procedures. Prior to beginning the training protocol, all participants reported to the SUNY Cortland biomechanics laboratory for preliminary testing at a preassigned time. During the initial meeting, all participants read the testing guidelines and were briefed on the testing equipment. Each participant performed the Postural Stability and Athlete Single Leg Stability Test on the Biodex Balance System SD machine. Participants were first tested on unilateral static balance on their dominant leg followed by their non-dominant leg. The participants were given a five-minute break in between tests. After the rest period, participants performed the unilateral dynamic balance test on their dominant leg followed by their non-dominant leg. After all preliminary testing was complete participants were contacted via word of mouth, text message, or email to let them know which training group they were randomly placed in and what protocol they were to follow over the course of the study. The participants in the UTG were given a unilateral lower-body resistance training program consisting of ten exercises, while the CG continued their regular bilateral program. After the completion of the six-week intervention all participants completed post-testing on the Biodex Balance System.

Training protocol. Participants in the unilateral training group (UTG) were given a lower-body unilateral resistance training program to perform twice a week over the course of the 6-week study. The week of Spring Break, which fell after the third week of the training program, was used as a rest week. The UTG was instructed to continue their regular upper body exercise routine during the study. The UTG was given an exercise diary to record the number of sessions, days, times, exercises, sets, repetitions, and weights used. The number of sessions, exercises, sets, and repetitions were controlled for the UTG. Each training session began with a warm up consisting of a 5-minute jog and dynamic stretches of their choice. Following the American College of Sports Medicine resistance training guidelines (American College of Sports Medicine, 2017), participants were instructed to perform three sets of 10 repetitions for each exercise (listed below) during each training session in the order presented. Participants were instructed to start each set by performing the first ten repetitions on the dominant limb followed by the non-dominant limb. For visual explanation of each exercise refer to Appendix H.

1.) Laying single leg adduction
2.) Laying single leg abduction

3.) Single leg glute bridges
4.) Modified unilateral squat
5.) Frontal plyometric-box step-ups
6.) Lateral plyometric-box step-ups
7.) Unilateral swiss ball hamstring roll-ins
8.) Single leg RDLs
9.) TRX pistol squats
10.) Reverse lunges

The control group (CG) continued their regular bilateral lower-body and upper-body exercise routine throughout the course of the study. The CG was told not partake in any unilateral lower-body exercises during the intervention. The control group was also given an exercise diary to record the number of sessions, days, times, exercises, sets, repetitions, and weights used.

Statistical analysis. An *a priori* power analysis was conducted to determine sample size. Approximately 22 participants (11 control, 11 experimental) were necessary to have 95% power for detecting a moderate effect ($f^2(V) = 0.2$) when employing $a = 0.05$ criterion of significance. Descriptive statistics for participant characteristics and dependent variables were calculated. The independent variables were assigned training group (UTG or CG) and time (pre and post). Overall static and dynamic balance were the two dependent variables. A series of two-way mixed methods ANOVAs were used to assess a group by time interaction on static and dynamic balance. Independent and dependent samples *t*-tests were used to determine post-hoc simple main effects. Data were analyzed using IBM SPSS version 25 with an established alpha level of 0.05.

Results

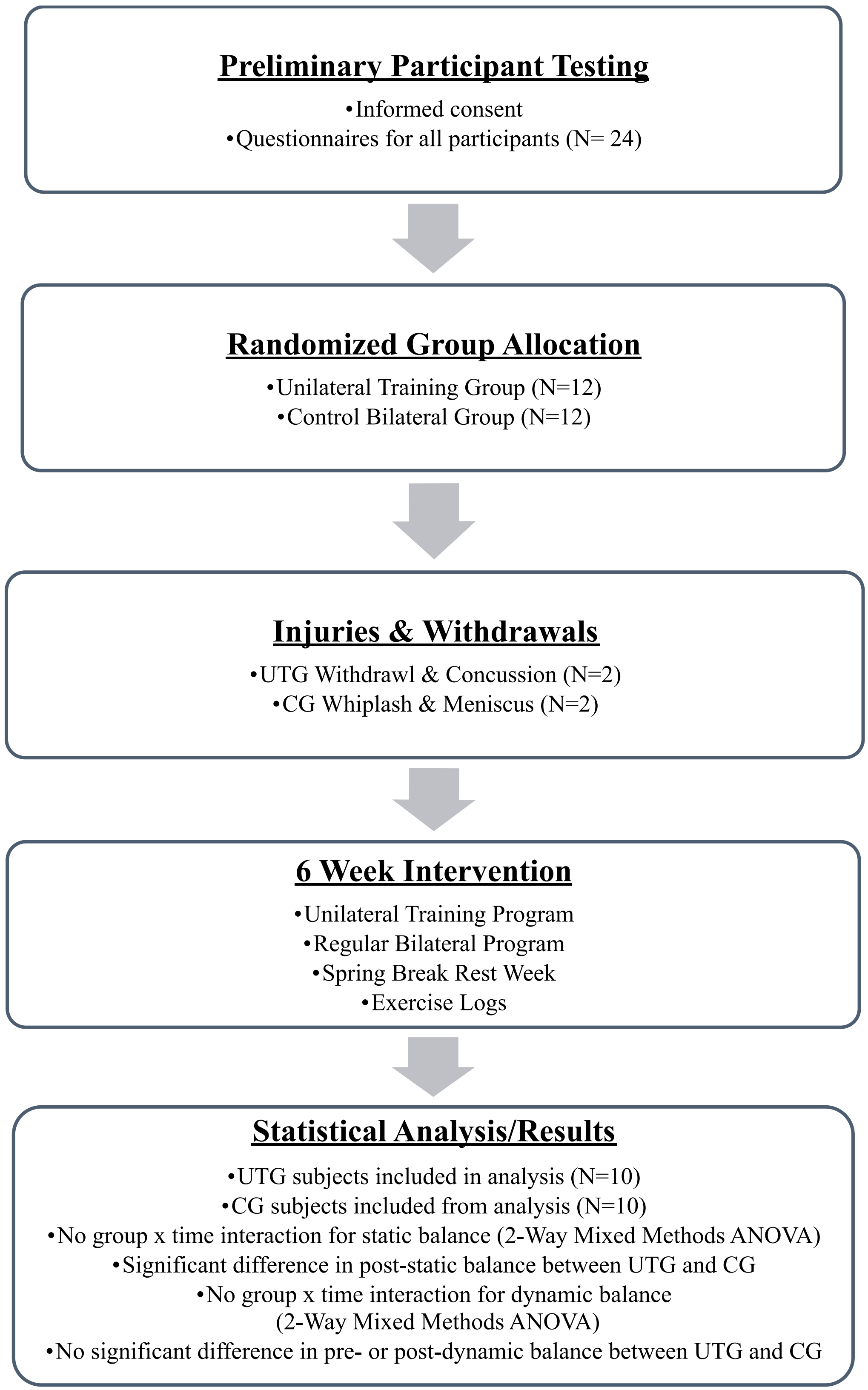
The overview of the study protocol and findings are presented in Figure 1. Table 1 displays the means and standard deviations of physical characteristics by group (control, experimental) and for total sample. A total of 24 participants signed the informed content, filled out the series of questionnaires and were randomly assigned into two groups; UTG (*n* = 12), and CG (*n* = 12). Two participants did not make it to pre-testing due to injury, so the total number of participants that were pretested was 22. An additional two participants withdrew because of mid-study injuries (unrelated to the intervention), dropping the total number of participants to 20, with an even split between the Unilateral Training Group (*n* = 10) and the Control Group (*n* = 10).

Table 1

Means and Standard Deviations of Physical Characteristics by Group and for Total Sample

	Control (*n* = 10)	Experimental (*n* =10)	Total (*n* = 20)
Age (yr)	21.54 ± .82	21.81 ± 2.63	21.68 ± 1.91
Height (in)	68.18 ± 3.28	69.09 ± 2.73	68.63 ± 2.98
Weight (lb)	171.81 ± 25.73	185.00 ± 20.51	178.40 ± 23.68

Figure 1. Study Overview



Static Balance. Means and standard deviations of pre- and post- static balance are presented in Table 2. Group differences in static balance were analyzed using the general linear model with a two-way mixed methods ANOVA to assess a group (control, intervention) by time (pre- and post-testing) interaction. There was no statistically significant interaction between the training groups and time on static balance, $F(1,18) = 3.294$, $p = 0.05$, partial $\eta^2 = .155$. A post-hoc analysis of independent samples *t*-tests was conducted to determine significant differences in pre-static balance between the control and experimental groups and post-static balance between control and experimental groups. There was no significant difference in mean pre-static balance between the control and experimental group, $t(18) = .177$, $p =.861$, Cohen's $d = 0.09$. There was a statistically significant difference in mean post-static balance between the control and experimental groups, $t(18) = 2.220$, $p = .040$, Cohen's $d = 1.01$. The experimental group had a significantly better post-static balance (m = 1.0050 versus m = 1.3850, respectively) as displayed in Table 2. An additional post-hoc analysis of dependent samples *t*-tests was conducted to determine significant differences in pre- and post-static balance separately for the UTG and CG. For the CG, there was no significant difference in mean static balance between the pre- and post-test, $t(9) = .555$, $p = .593$, Cohen's $d = .17$. For the UTG, there was a significant difference in mean static balance between the pre- and post-test, $t(9)$, = 3.144, $p = .012$, Cohen's $d = 1.20$; static balance was significantly better in the post-test (m = 1.00) compared to the pre-test (m = 1.43).

Dynamic Balance. Means and standard deviations of pre- and post- dynamic balance are presented in Table 2. Group differences in dynamic balance were analyzed using the general linear model with a two-way mixed methods ANOVA to assess a group (control, intervention) by time (pre- and post-testing) interaction. There was no statistically significant interaction between the training groups and time on dynamic balance, $F(1,18) = .368$, $p = 0.05$, partial $\eta^2 = .020$. A post-hoc analysis of independent samples *t*-tests was conducted to determine significant differences in pre-dynamic balance between the control and experimental groups and post-dynamic balance between control and experimental groups. There was no significant difference in mean pre-dynamic balance between the control and experimental group, $t(18) = 1.383$, $p = .184$. There was no significant difference in mean post-dynamic balance between the control and experimental group, $t(18) = 1.518$, $p = .146$, Cohen's $d = 0.67$. An additional post-hoc analysis of dependent samples *t*-tests was conducted to determine significant differences in pre- and post-dynamic balance separately for the UTG and CG. For the CG, there was no significant difference in mean dynamic balance between the pre- and post-test, $t(9) = 1.057$, $p = .318$, Cohen's $d = 0.16$. For the UTG, there was a significant difference in mean dynamic balance between the pre- and post-test, $t(9)$, = 2.268, $p = .05$, Cohen's $d = 0.68$; dynamic balance was significantly better in the post-test (m = 1.56) compared to the pre-test (m = 1.76).

Table 2

Means and Standard Deviations of Balance Tests

	N	Control	Experimental	Total
Pre-Static Balance	20	1.46 ± .41	1.42 ± .46	1.44 ± .43
Post-Static Balance*	20	1.38 ± .50	1.00 ± .18	1.19 ± 42
Pre-Dynamic Balance	20	2.09 ± .67	1.76 ± .32	1.92 ± .54
Post-Dynamic Balance	20	1.97 ± .82	1.56 ± .26	1.76 ± .63

Notes:
* = statistically significant difference between control and experimental conditions; $p < .05$

Discussion

The purpose of the study was to investigate whether a short-term, exclusively unilateral, lower-body resistance training program would significantly improve static and dynamic balance in experienced college-aged resistance-trained participants when compared to a control group's regular, bilateral, lower-body resistance training program. Results indicated no significant group x time interaction on static or dynamic balance, but post-hoc analyses indicated a significant difference in post-training static balance between the UTG and CG. The analysis also indicated that the UTG group significantly improved static and dynamic balance from pre- to post-testing, while the CG did not.

Results indicated that there was no significant group x time interaction on either static or dynamic balance. There are a few plausible explanations for the lack of significant interaction. The *a priori* power analysis that was completed indicated a sample size of 22 participants (11 control, 11 experimental) to achieve 95% power and a moderate effect size ($f^2(V) = 0.2$). As is typical in training studies, four participants withdrew over the course of the study, which could have impacted the overall power of the study. Additionally, two participants in the UTG missed two training sessions during the second week due to illness. Missing sessions during the relatively short training intervention may have hindered the time necessary to elicit adaptations to the musculoskeletal and central nervous system, which may have raised (e.g., hindered) the overall group data score. An anecdotal observation of the quantitative pre- and post-data sheets from the Biodex Balance System SD indicated that certain participants in the UTG improved vastly while others improved marginally. The lack of a significant group x time interaction could also be attributed to the length of the program. While, due to time constraints, the training protocol was limited to 6 weeks with a one-week rest period (Spring Break), a longer training period could have elicited greater changes in static and dynamic balance, and a significant group x time interaction may have been elicited. The unilateral/bilateral training literature presents conflicting results regarding training program length and frequency of exercise to elicit changings in balance (Eylen, Daglioglu, & Gucenmez. 2017; Mohammadi et al. 2012; McGuire et al., 2016). Eylen and colleagues (2017) randomly divided participants into groups to perform a lower-body strength training program with a varied repetition range three times weekly for eight-weeks. There were significant differences in the right and left leg static balance in the experimental group, but no significant differences in the control group after the eight-week study. In a shorter study by Mohammadi and colleagues (2011), thirty young male athletes were divided into two groups (exercise, control) and the exercise group performed lower-body exercises three times a week for six-weeks to improve static and dynamic balance. The six-week training program elicited significant, positive changes in post-static balance in the exercise group, but not in the control group after the six-week strength training program. McGuire and colleagues (2016) investigated static balance in female collegiate athletes using a three-week single-leg balance program. Pre- and post-static balance was tested using the Biodex Balance System SD. The training protocol during the three-week program required the experimental group to perform five exercises (3x/week) in a stationary position for the purpose of targeting key stabilizing muscles. Similar to the present study, at the conclusion of the study, there was no significant group x time interaction on static balance, but there was a decrease in balance scores from pre- to post-protocol. The literature indicates mixed success in eliciting changes in balance depending on the training length of the program; however, there is a trend towards longer-duration, higher-frequency programs being more successful in eliciting changes in balance (Eylen et al., 2017; Mohammadi et al., 2012; McGuire et al., 2016).

For the follow-up analyses, a series of independent samples *t*-tests were conducted to determine significant differences in pre-static balance between the control and experimental groups, post-static balance between control and experimental groups, pre-dynamic balance between the control and experimental groups, and post-dynamic balance between the control and experimental groups. Of these four analyses, the only combination that elicited a significant difference was post-static balance between the CG and UTG, which favored the UTG. In other words, focusing specifically on unilateral lower-body exercises over a certain period of time will elicit faster adaptations in static balance when compared to doing bilateral lower-body exercises. One explanation for the significant difference in post-static balance (but not post-dynamic balance) between the UTG and the CG could be because the participants in the UTG were challenged with new exercises, but the CG was not. The addition of new unilateral exercises in addition to their pre-established workout routine likely created an unfamiliar, new stress on the body, which created an adaptation in static balance. Even though the participants recruited were experienced, resistance-trained participants, starting a new exercise program with exercises never performed before could have attributed to the improvement in static balance. When novices begin to exercise they experience most of their improvements in performance measures within the first few weeks to months and eventually plateau. This could be related to the UTG starting a new program and seeing fast improvements over the six weeks regardless of their experience. Furthermore, because the participants were already experienced the possible margin to improve balance measures could have been limited. Another explanation for the lack of improvement in dynamic balance is because of how dynamic balance was measured on the Biodex Balance System SD, compared to other ways of measuring dynamic balance. Additionally, the exercises performed by the UTG were performed in a stationary position; that is, most of the exercises that the UTG performed (single leg glute bridge, modified unilateral squat, single leg stiff leg deadlifts, and TRX pistol squats) required foot placement in a unilateral static position for the duration of the exercise, unlike the exercises that we infer the CG was doing. Considering that the control group continued to perform their usual bilateral exercises, there was no new stress to the vestibular system to promote adaptations in static balance. Even though the participants were moving during the exercises the placement of the foot never moved (i.e., it remained in a static position). Dynamic balance is one's ability to maintain balance at equilibrium in motion or switching positions. Since there was no switching of positions while performing each exercise there was a possible a lack of dynamic challenge. The lack of dynamic challenge in the UTG may have contributed to the differences in UTG versus CG in static balance but not dynamic balance. A study by Gonzalez and colleagues (2013) investigated the effects of a six-week full-body resistance training program on balance performance in untrained older adults. Similar to our study, participants performed two full-body training sessions twice a week for six weeks, and improvements in static balance, but not dynamic balance, in the untrained older adults were elicited. Findings from the Gonzalez study support our findings because the exercises performed in both studies were all from a stationary position.

Changes in static and dynamic balance over time (e.g., pre to post) were considered separately for the CG and UTG. Results indicated significant, positive changes in static and dynamic balance from pre- to post-testing in the UTG, while the CG experienced no such changes in either static or dynamic balance. These findings suggest that the UTG's training protocol positively influenced static and dynamic balance over the course of the study. The results of the current study disagree with findings from Manini et al. (2007), Mahieu, Witvrouw, VandeVoorde, Michilsens, and VanderBroeche (2006), and Schlicht, Camaione, and Owen (2001). Mahieu et al. (2006) investigated the effects of whole-body vibration training and lower-body resistance training on strength and static balance in young skiers. Participants trained three times weekly for six weeks and while there were increases in lower-body strength, there were no significant changes in static balance. Manini et al. (2007) investigated the efficacy of a twice weekly, ten-week functional resistance training program on thirty-two older adults. Similar to Mahieu et al. (2006), participants' strength improved, but there were no significant differences from pre- to post-testing in static balance in the single leg and double leg position. Schlicht et al. (2001) also examined an older adult population over an eight-week, three time per week strength training program to improve risk of falling, strength, sit-to-stand, and one-legged balance. Again, participants' strength improved along with sit-to-stand performance, but no changes in one-leg balance were elicited from the intervention. Possible explanations as to why these studies found improvements in strength and not balance could simply be because of the differences in the training protocol, frequency, length, sample size, and populations used.

While many studies did not find pre- to post-testing changes in balance (either static or dynamic), especially when compared to changes in strength, there are studies with findings that agree with ours. Eylen and colleagues (2017) randomly divided participants into a control group (no training) and experimental group, who participated in a lower-body strength training program with a varied repetition range three times weekly for eight weeks. At the completion of the eight-week intervention, significant pre- to post-testing differences in right and left leg static balance were found in the experimental group, but not the control group. Similar to the present study, Eylen and colleagues (2017) also found no between-group differences in balance. The results of both studies suggest that the intervention may not have been long enough to elicit a group x time interaction, but still improved static and dynamic balance in the experimental group. Our study partially agrees with those of Mohammadi and colleagues (2011), who divided thirty young male athletes into an exercise and control group, and instructed the exercise group to perform lower-body exercises with the intention of improving static and dynamic balance. Like our study, they found significant differences between groups in post-static balance, but unlike our study they also found significant differences between groups in post-dynamic balance. The differing results in dynamic balance could be attributed to the frequency in training sessions, increases in intensity level per week, and different exercises performed. Regardless of the discrepancies between studies, we contend that balance can be improved over time and these changes can be attributed to increasing lower-body strength, muscle coordination, muscle fiber synchronization, and kinesthetic awareness following a six-week training protocol.

Furthermore, the population recruited for this study compared to other studies could have had an effect on the overall results. All of the participants recruited were categorized as "highly fit." Since the participants were already experienced resistance-trained participants, the potential for overall improvement may have been limited because of a ceiling effect that is associated with highly fit individuals. With a limited time schedule and a fit population the expectations for a huge room for improvements were low. However, the results indicated a 30% improvement in static balance in just five weeks. This relatively drastic change in static balance over a short period of time can be of great importance for the clinical setting, and especially for athletes, personal trainers, and strength and conditioning coaches. These results can provide insight on how to improve static balance in a highly trained population through the use of a unilateral lower-body resistance training program.

Conclusion

In conclusion, there was no group by time interaction for static or dynamic balance in either the experimental or control group over the course of the six-week study. The lack of an interaction effect could be attributed to intervention frequency, length, or lack of participation. Regardless of the group by time interaction, significant differences were found in post-static balance between the UTG and CG, but not post-dynamic balance between groups. These differences could be attributed to the new exercises being introduced to the UTG, exercise selection in the program, and the continuation of the CG regular program. Significant changes were found in static and dynamic balance over time when considered separately for the UTG and CG. Results indicated that the UTG experienced significant, positive changes in static and dynamic balance from pre- to post-testing, while the CG experienced no such changes in either static or dynamic balance. These findings suggest that the UTG's training protocol positively influenced static and dynamic balance over the course of the study.

The intervention was not without limitations. Throughout the study it was impossible to oversee and regulate each of the 20 participants' activities in and out of the gym. Individual-level differences could have had an effect on the results of the study. Because of the semester length and risk of participant dropout that would have inevitably occurred during the last two weeks of the semester and/or finals week, the time of the intervention was limited and potentially too short. The Biodex Balance System SD was used to test static and dynamic balance; other less objective measures may have elicited different results, particularly for dynamic balance. Additionally, the week off during spring break that was used as a rest week may have occurred too early in the program, ultimately influencing the development of balance adaptations in the body. Strengths of the study included use of an objective measure of two types of balance, and recruitment of a highly fit sample. Overall, the main findings agreed with the extant literature that indicates changes in static and dynamic balance can be elicited through an exclusively unilateral training program.

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Appendix A

IRB Approval Letter

MEMORANDUM

SUNY Cortland
Institutional Review Board

To:	Daniel Semprini Larissa True
From:	Thomas Frank, Reviewer *on behalf of* Institutional Review Board
Date:	2/12/2018
RE:	Institutional Review Board Approval

In accordance with SUNY Cortland's procedures for human research participant protections, the protocol referenced below has been approved for a period of one year:

Title of the study:	The Effects of a Short-Term, Unilateral, Lower-Body Resistance Training Program on Balance in College-Aged Resistance-Trained Participants		
Level of review:	**Expedited**	**Protocol number:**	171835
Project start date:	Upon IRB approval	**Approval expiration date*:**	2/11/2019

* **Note:** *Please include the protocol expiration date to the bottom of your consent form and recruitment materials.* For more information about continuation policies and procedures, visit www.cortland.edu/irb/Applications/continuations.html

The federal Office for Research Protections (OHRP) emphasizes that investigators play a crucial role in protecting the rights and welfare of human subjects and are responsible for carrying out sound ethical research consistent with research plans approved by an IRB. Along with meeting the specific requirements of a particular research study, investigators are responsible for ongoing requirements in the conduct of approved research that include, in summary:

- obtaining and documenting informed consent from the participants and/or from a legally authorized representative prior to the individuals' participation in the research, unless these requirements have been waived by the IRB;
- obtaining prior approval from the IRB for any modifications of (or additions to) the previously approved research; this includes modifications to advertisements and other recruitment materials, changes to the informed consent or child assent, the study design and procedures, addition of research staff or student assistants, etc. (except those alterations necessary to eliminate apparent immediate hazards to subjects, which are then to be reported by email to irb@cortland.edu within three days);
- providing to the IRB prompt reports of any unanticipated problems involving risks to subjects or others;
- following the principles outlined in the Belmont Report, OHRP Policies and Procedures (Title 45, Part 46, Protection of Human Subjects), the SUNY Cortland College Handbook, and SUNY Cortland's IRB Policies and Procedures Manual;
- notifying the IRB of continued research under the approved protocol to keep the records active; and,
- maintaining records as required by the HHS regulations and NYS State law, for at least three years after completion of the study.

Miller Building, Room 206 • P.O. Box 2000 • Cortland, NY 13045-0900
Phone: (607) 753-2511 • Fax: (607) 753-5995

Appendix B

Informed Consent Letter

Document of Informed Consent
Department of Kinesiology
State University College at Cortland

The research in which you have been asked to participate is being conducted by Daniel Semprini. I request your informed consent to be a participant in the study described below.

Title: The Effects of a Short-Term, Unilateral, Lower-Body Resistance Training Program on Balance in College-Aged Resistance-Trained Participants

Student Investigator: Daniel Semprini

Faculty Supervisor: Larissa True, PhD
Co-Investigators: Peter McGinnis, PhD
Co-Investigators: Mark Sutherlin, PhD

Purpose:
The purpose of this study is to investigate whether a short-term, exclusively unilateral, lower-body resistance training program will significantly increase static and dynamic balance in experienced college-aged resistance trained participants when compared to the control group's regular, bilateral program.

Procedures:
Signing this form does not guarantee you a place in this study. On completion of this form you will be given three questionnaires: The International Fitness Scale, The International Physical Activity Short Form, and a Sociodemographic Questionnaire. If you meet the required inclusion criteria (cannot have an injury to the lower-body within the last six months, cannot score lower than a 16 on the International Fitness Scale Questionnaire, and must report five or more hours of physical activity a week on the International Physical Activity Questionnaire) you will be selected to participate in the study.

If selected, you will be randomly placed into either the Unilateral Training Group (UTG) or the Control Group (CG). You will then be given a guideline form explaining the preliminary static and dynamic tests using the Biodex Balance System SD machine (e.g., Postural Stability Test, and the Athlete Single Leg Stability Test). As a participant, you will be requested to report to the Biomechanics Laboratory in the Professional Studies Building for preliminary testing. After preliminary testing, and depending on what group you are in, you will be given instructions on what to do. If you are in the UTG, you will be asked to perform 3 sets of 10 unilateral training exercises twice a week for 6 weeks, while continuing your regular upper body exercise routine. You will also be given an exercise diary to record a log of all days, times, sets, reps, weights and exercises performed through the study. If you are placed in CG, you will continue your regular bilateral exercise program. You will also be given an exercise diary to record a log of all days, times, sets, reps, weights and exercises performed through the study. After six-weeks, you will complete post-testing of the static and dynamic tests using the Biodex Balance System SD machine (e.g., Postural Stability Test, and the Athlete Single Leg Stability Test).

Risks Expected:
Proper precautions will be taken into consideration throughout the study to ensure your safety. Risks during this study are minimal but may happen. The primary risk associated with this study may be physical discomfort during testing, and throughout the exercise program.

Benefits Expected:
Participation in this study may indicate whether unilateral lower-body resistance training is a superior training method in increasing static and dynamic balance.

Confidentiality:
All data collected during the process of the study such as questionnaires, testing trials, experimental data, and results are to remain in full confidentiality. All data recorded including, paper copies and electronic data (USB stick) will be held in Dr. True's on campus office locked in a filing cabinet to ensure the privacy of your information. My Co-Investigators and I are the only people who have access to the data.

Freedom to Withdraw:
Participation in this study is completely voluntary, and you may withdraw from the study at any time, for any reason without penalty. You also have the right to stop any test, trial, or program at any time for any reason without penalty.

Contact Information:
For more information about this study please contact Daniel Semprini (631) 404-0336. For more information about research at SUNY Cortland or information about the rights of research participants, please contact the Institutional Review Board by email irb@cortland.edu, or by phone (607) 753-2511

I have read and understand the activities requested for my involvement in this project, and I consent to participate.

Name: ____________________________ Telephone#: ______________________

Signature: _____________________________ Date: ______________

Researcher's Signature: _____________________________ Date: ___________________

Appendix C

International Fitness Scale Questionnaire

IFiS

INTERNATIONAL FITNESS SCALE

It is important that you do this test by yourself without taking into account the answers or opinion from other persons. Your answer is only useful for the progress of science and medicine. Please answer all the questions and do not leave any blank. Mark only one answer per question, and more important: be sincere. Thank you for your cooperation.

NAME: ______________________________ **DATE (dd-mm-yy):** __________

Please, think about your current level of physical fitness (compared with your friends) and choose the most appropriate answer.

My general physical fitness is:

Very poor (1) □
Poor (2) □
Average (3) □
Good (4) □
Very good (5) □

My cardiorespiratory fitness (capacity to do exercise, for instance long running) **is:**

Very poor (1) □
Poor (2) □
Average (3) □
Good (4) □
Very good (5) □

My muscular strength is:

Very poor (1) □
Poor (2) □
Average (3) □
Good (4) □
Very good (5) □

My speed / agility is:

Very poor (1) □
Poor (2) □
Average (3) □
Good (4) □
Very good (5) □

My flexibility is:

Very poor (1) □
Poor (2) □
Average (3) □
Good (4) □
Very good (5) □

IFIS has been developed by the PROFITH research group, Granada, Spain. Versions of IFIS in different languages and for different age groups are available at: http://profith.ugr.es/IFIS IFIS was originally design and validated under the umbrella of the HELENA study, original reference: Ortega et al. The International Fitness Scale (IFIS): usefulness of self-reported fitness in youth. Int J Epidemiol 2011;40:701-1. IFIS has also been validated in adults: Ortega et al. Scand J Med Sci Sports, 2013;23:749-57; in children: Sanchez-Lopez et al. Scand J Med Sci Sports. 2015;25:543-51;and in women with fibromyalgia: Alvarez-Gallardo et al. Arch Phys Med Rehabil. 2016;97:395-404.

Appendix D

International Physical Activity Short Form Questionnaire

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE

We are interested in finding out about the kinds of physical activities that people do as part of their everyday lives. The questions will ask you about the time you spent being physically active in the **last 7 days**. Please answer each question even if you do not consider yourself to be an active person. Please think about the activities you do at work, as part of your house and yard work, to get from place to place, and in your spare time for recreation, exercise or sport.

Think about all the **vigorous** activities that you did in the **last 7 days**. **Vigorous** physical activities refer to activities that take hard physical effort and make you breathe much harder than normal. Think *only* about those physical activities that you did for at least 10 minutes at a time.

1. During the **last 7 days**, on how many days did you do **vigorous** physical activities like heavy lifting, digging, aerobics, or fast bicycling?

   _____ **days per week**

   ☐ No vigorous physical activities ➔ ***Skip to question 3***

2. How much time did you usually spend doing **vigorous** physical activities on one of those days?

   _____ **hours per day**

   _____ **minutes per day**

   ☐ Don't know/Not sure

Think about all the **moderate** activities that you did in the **last 7 days**. **Moderate** activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal. Think only about those physical activities that you did for at least 10 minutes at a time.

3. During the **last 7 days**, on how many days did you do **moderate** physical activities like carrying light loads, bicycling at a regular pace, or doubles tennis? Do not include walking.

   _____ **days per week**

   ☐ No moderate physical activities ➔ ***Skip to question 5***

SHORT LAST 7 DAYS SELF-ADMINISTERED version of the IPAQ. Revised August 2002.

4. How much time did you usually spend doing **moderate** physical activities on one of those days?

_____ **hours per day**

_____ **minutes per day**

☐ Don't know/Not sure

Think about the time you spent **walking** in the **last 7 days**. This includes at work and at home, walking to travel from place to place, and any other walking that you have done solely for recreation, sport, exercise, or leisure.

5. During the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time?

_____ **days per week**

☐ No walking → ***Skip to question 7***

6. How much time did you usually spend **walking** on one of those days?

_____ **hours per day**

_____ **minutes per day**

☐ Don't know/Not sure

The last question is about the time you spent **sitting** on weekdays during the **last 7 days**. Include time spent at work, at home, while doing course work and during leisure time. This may include time spent sitting at a desk, visiting friends, reading, or sitting or lying down to watch television.

7. During the **last 7 days**, how much time did you spend **sitting** on a **week day**?

_____ **hours per day**

_____ **minutes per day**

☐ Don't know/Not sure

This is the end of the questionnaire, thank you for participating.

Appendix E

Sociodemographic Questionnaire

Sociodemographic Questionnaire

Please answer the questions below truthfully. The following information will be kept confidential. This form will be locked away in a file once completed.

Name:

Sex:

Age:

Height:

Weight:

Class (e.g., Sophomore, Junior):

Dominant leg:

Questions:

Have you had any past lower-body injuries within the last six months?
Please circle: Yes or No
If you circled yes, please write what type of injury you had below:

Have you had surgery within the last six months to a year?
Please circle: Yes or No
If you circled yes, please write what type of surgery you had performed below:

Do you have any cardiovascular or pulmonary diseases?
Please circle: Yes or No
If you circled yes, please write what type of disease you have below:

____

Are you currently on an medications or prescriptions?
Please circle: Yes or No
If you circled yes, please write what type of medication or prescriptions you are currently taking below:

Please provide information about your regular, habitual exercise routine (e.g., how many days/week do you exercise? How often do you lift vs. cardio? How often do you lift upper body/lower-body? What kind of exercises do you normally perform?)

Do you understand that if you are placed into the Control Group that you will not participant in any lower-body unilateral leg training over the course of the next 6 weeks? If needed, I will provide more information on unilateral leg training. If you understand this, please circle yes below.

Please circle: Yes

Appendix F

Biodex Balance System SD Guidelines

The Biodex Balance System SD

Name:_____________________________

Age:________

Height (in inches):__________________

The Biodex Balance System SD machine assess closed chain, multi-plane tests by measuring the participants' ability to maintain dynamic unilateral or bilateral postural stability on either a static or unstable surface. The Postural Stability test will be the first test that you will perform. This test will assess unilateral static balance in both of your legs. The following test you will perform is the Athlete Single Leg Stability test. This test will assess your unilateral dynamic balance in both of your legs.

Directions/Procedures for the Postural Stability Test:

- The participant will be briefed on the parts that make up the Biodex Balance System SD machine
- Participants will step on the circular foot platform, hold the handrails, and look at the display screen
- The participants name, age, and height will be entered into the display screen
- The participant will be informed that for this test the foot platform will be in a locked position
- A practice trial will be performed to get the participant use the machine
- The participant will place the dominant foot in the correct position as displayed on the screen matched up with the grid on the foot platform
- A black dot will appear on the screen in a circle consisting of 3 circles and a cross hair
- Participants are instructed to try and stay within the most inner circle closest to the middle of the cross hair
- A series of 3, 20 second practice trials will take place
- The participant will be informed to lift up and bend the opposite leg backwards where it is not leaning against the opposite leg
- A count down of three seconds will begin and then the participant will release the hand rails and balance on the one leg
- After the twenty seconds the participant can relax for 10 seconds until the next trial
- Once the practice test is complete, the participant will complete the testing trial
- After completion of the dominant leg the same procedures are performed for the non-dominant leg
- Results are printed

Directions/Procedures for the Athlete Single Leg Stability Test:

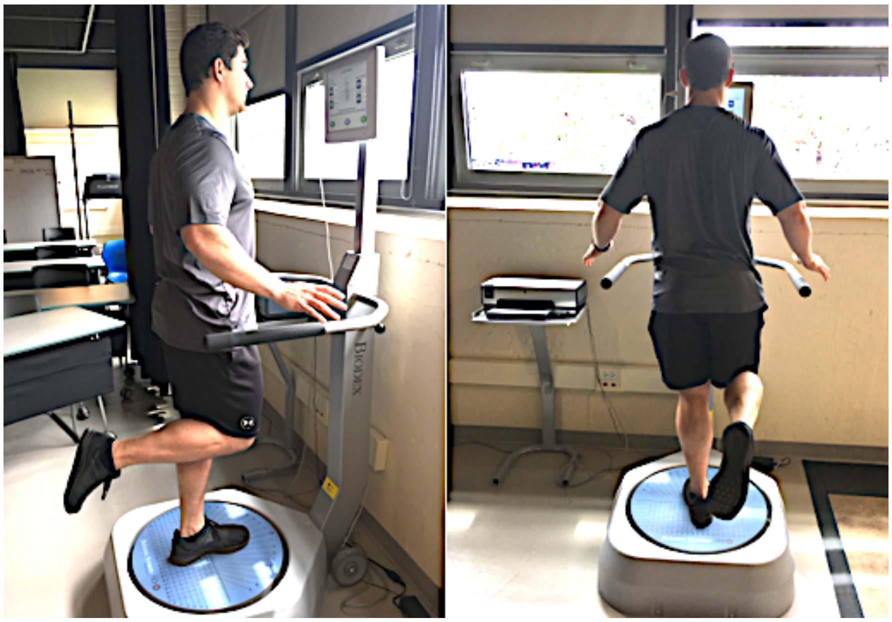
- The directions/procedures above are the same for the Athlete Single Leg Stability Test
- The only difference is that the circular foot platform can move in any direction

Appendix G

Pictures of Testing Positions on the Biodex Balance System SD

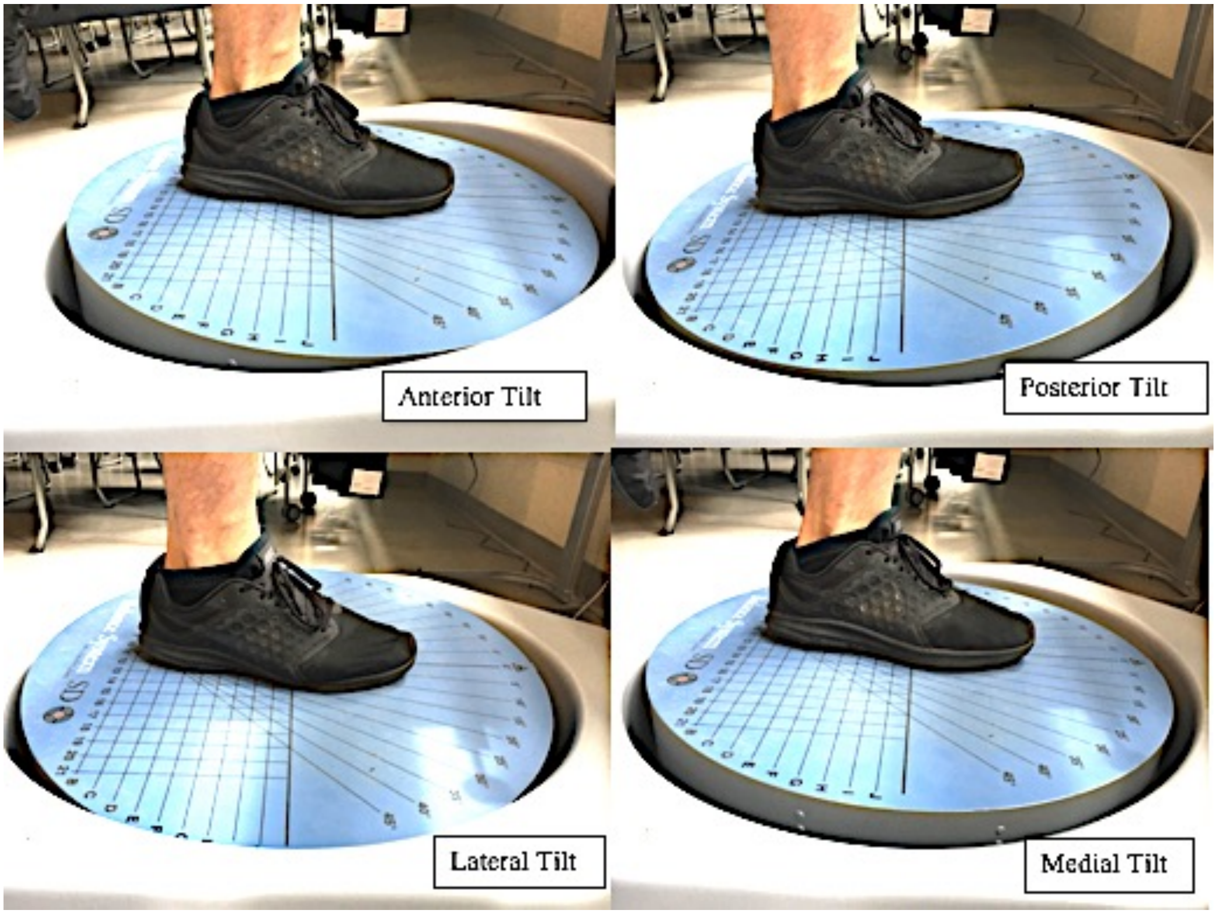
Postural Stability & Athlete Single Leg Stability Testing Positions

Left Leg Position



Right Leg Position

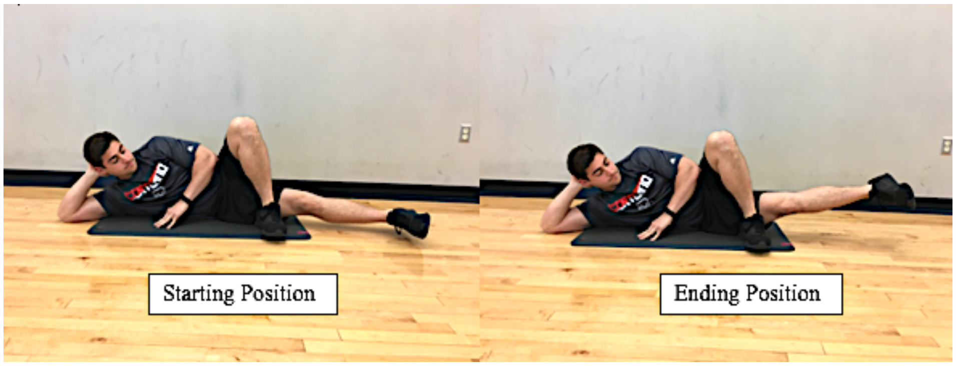
Athlete Single Leg Stability- Directions of Platform Tilt



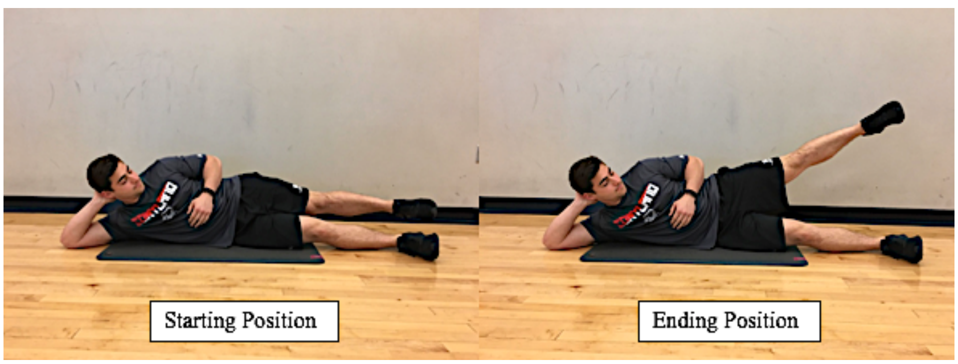
Appendix H

Pictures of Unilateral Training Group's Exercises

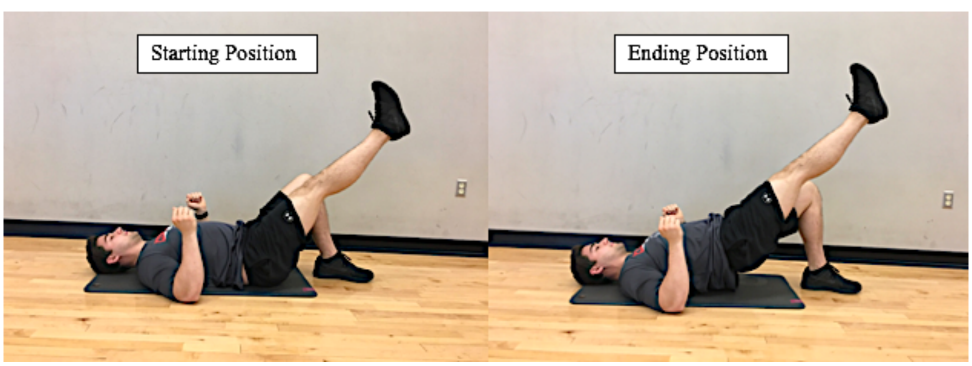
Exercise 1. Laying Single Leg Adduction.



Exercise 2. Laying Single Leg Abduction.



Exercise 3. Single Leg Glute Bridge.

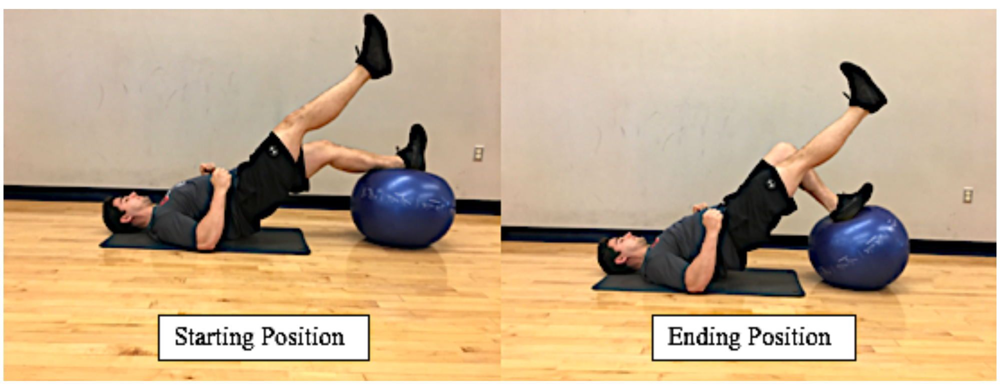


Exercise 4. Modified Unilateral Squat.

Exercise 5. Frontal Plyometric-box Step-Ups.

Exercise 6. Lateral Plyometric-box Step-Ups.

Exercise 7. Unilateral Swiss-ball Hamstring Roll-Ins.



Exercise 8. Single Leg RDLs

Exercise 9. TRX Pistol Squats.

Exercise 10. Reverse Lunges.