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Use of Isometric Mid-Thigh Pull to Determine Asymmetrical Strength Differences in NCAA D-I

Athletes

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A thesis

presented to

the faculty of the Department of Kinesiology, Leisure, and Sport Sciences

East Tennessee State University

In partial fulfillment

of the requirements for the degree

Master of Arts of Kinesiology & Sports Studies

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by

Ethan M. Owens

December 2011

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Michael W. Ramsey, Ph.D., Chair

Hugh S. Lamont, Ph.D., Committee Member

Kimitake Sato, Ph.D, Committee Member

Duane A. Williams, PT, DSc., Committee Member

Key Words: Isometric Mid-Thigh Pull, Sport Specific Joint Angles, Measuring Asymmetries

## ABSTRACT

Use of Isometric Mid-Thigh Pull to Determine Asymmetrical Strength Differences in NCAA D-I

Athletes

by

Ethan M. Owens

The purpose of this study is to investigate the use of isometric mid-thigh pulls to determine lower-limb asymmetrical strength differences in NCAA D-I athletes. Sixty-six subjects (40 males and 26 females) performed 2 maximal effort isometric pulls over two force plates sampling at 1000 Hz each. Peak force was scaled for body weight, and rate of force development was examined from 0-200ms. Results of the study show subjects' produced significantly greater scaled force with the left leg as compared to the right leg; however, no significant differences existed for rate of force development (RFD). Men exhibited significant differences between both scaled peak force and RFD, while women only showed significant differences in scaled peak force. Of the 66 subjects tested, 6 subjects (5 men and 1 woman) exhibited percent differences of 15% or greater asymmetry for scaled peak force. The results indicate that isometric mid-thigh pulls are a way to show the presence of asymmetries in D-I athletes.

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## DEDICATION

### *To Kelsey & Family –*

This thesis is dedicated to the people who mean the most to me in my life. Kelsey, my best friend and fiancé, your encouragement throughout the years and unwavering love have provided me an out when things get difficult. I love you!

To mom and dad, I wish I could have the words to express my gratitude. Thank you for providing me funding throughout life and showing me that there is no substitute for hard work. Cold Friday nights watching football, long days at wrestling tournaments, hefty grocery bills, and warm meals are just small examples of your love, support, and encouragement. Thank you for providing me with invaluable experiences and an education. I hope one day I can give back a portion of what you've provided for me. I love you both!

To my grandparents (Grandpa and Grandma Owens and Grandma Jean), who provided me with love and support throughout all these years, being able to escape the grind for a meal, a tank of gas, or whatever else I needed have helped me throughout my academic endeavors. I love you all and cannot thank you enough!

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CHAPTER 1  
INTRODUCTION

Problem Statement

Athletes are subject to many stimuli that determine their dominant lower limbs. This expression of dominance may lead to a development of asymmetry. However, much of the research conducted on asymmetries has been in rehabilitation settings, on devices with little application to athletes, or with little regards to the nature of the athletic environment. Therefore, the purpose of this study is to investigate the use of isometric mid-thigh pulls to determine asymmetrical strength differences in NCAA D-I athletes.

Operational Definitions

1. **Asymmetry:** A statistically significant strength discrepancy between lower limbs greater than 15%. Previous literature has shown (Knapik, Bauman, Jones, Harris, & Baughan, 1991) a strength difference of 15% or greater has been linked to decreased performance and an increased rate of injury. Asymmetries can be present between either left or right leg, or dominant and nondominant. Asymmetry comparisons between lower limbs were set at a statistical difference at  $p \geq 0.05$  between strength variables.
2. **Allometric Scaling:** A mathematical adjustment that allows comparison between subjects with different body masses. Vanderburgh (1999) displays the equation as  $y = x / (\text{body mass}^{0.67})$
3. **Bilateral Athletes:** Athletes who participate in bilateral sports such as track and field – sprinters.
4. **Bilateral Strength:** The amount of peak force from each leg exerted during an Isometric Mid-Thigh Pull.

5. **Isokinetic Devices:** Devices that measure force at a constant speed.
6. **Isometric Force Characteristics:** Measures of strength or RFD obtained during an isometric mid-thigh clean pull from analysis of the force-time curve.
7. **Isometric Peak Force (IPF):** The greatest positive value achieved during an isometric mid-thigh clean pull. Measured in Newtons.
8. **Isometric Rate of Force Development:** A measure of explosive strength during an isometric mid-thigh clean pull, e.g. the average rate of force production measured from 0 to 200 ms. Measured in Newtons x s<sup>-1</sup>.
9. **Isometric Mid-Thigh Clean Pull:** A method of measuring whole body strength. The subject stands on a force plate and grasps an immovable bar. The athlete's knee angle will be between 120°-130°, and the angle at the hip between 170°-180°. This position is often referred to as the "power position" and mirrors the start of the second pull in a clean. Isometric force is generated when an individual pushes vertically downward on the force plate and pulls up on the immovable bar.
10. **Maximum Strength:** The maximal voluntary force a muscle or group of muscles can generate under ideal conditions.
11. **Power:** The product of force and velocity. A rate of doing work.
12. **Rate of Force Development (RFD):** Ratio of force development to time. RFD is related to acceleration. RFD is measured in Newtons /second (N/s).
13. **Strength** – The ability of the neuromuscular system to produce force. Force is a vector quantity and has a magnitude and direction.
14. **Unilateral Athletes:** Athletes who participate in unilateral based sports such as baseball, tennis, soccer, volleyball, basketball, and track and field – jumpers and throwers.

## Review of the Literature

The review of literature encompasses theoretical origins of asymmetries; asymmetries in anthropometrics, strength, and vertical ground reaction forces; balance and posture; motor control; and methods of measuring asymmetries. By using methodology with specific application to sport, strength coaches and sport scientists alike can gain better of understanding of athletes' asymmetries.

### Theoretical Origins of Asymmetries

#### Neurodevelopmental

There are many theories of the origins of human asymmetries. While the literature is not consistent, it is however accepted that the primary motor cortex of each brain hemisphere controls the majority of the aspects of voluntary movement on the opposite side of the body, i.e. the left hemisphere controls the right and vice versa. Kinsbourne (1975) described this theory as functional brain asymmetry occurring at birth and lasting throughout one's lifespan. Gentry and Gabbard (1994) tested this theory by studying the foot preference behavior in age groups 4, 8, 11, 13, 16, and 20 years old (N=956). Their results contrasted that of Kinsbourne's in that foot preference behavior differ as a function of age or assorted factor that are not permanently set in vivo.

In 1991 Previc proposed a theory that asymmetries were traced to origins of asymmetry in uterus development of the ear and labyrinth as well as the fetus position during the final trimester. Previc hypothesized that in most humans (approximately two thirds) a left – otolithic advantage predisposes humans to the left side of the body for postural control and the right side for voluntary motor function. Pompeiano (1985) supported Previc's theory of asymmetry origins. The author showed that labyrinths exert bilateral control over antigravity reflexes;

however, their excitatory influence is greatest for the ipsilateral muscle group. Therefore, a left labyrinth stimulation yields left postural muscle excitation and produces greater extension of the left antigravity muscles and reduced right extension of the right antigravity muscles. Pompeiano suggested postural reflexes on the left side coming about before voluntary motor control of the right side. Their research also suggested that the left sided favoring reflected greater strength of the vestibulospinal reflexes as a result of early fetal maturation.

### Maturational

In a review by Corbaillis and Morgan (1978), the authors described the Maturational Hypothesis in which they suggested cerebral hemisphere development after birth is on a gradient from left to right after birth. Gentry and Gabbard (1994) tested the maturational hypothesis by examining foot preference in 956 participants. Results revealed foot preference behaviors are not innate but vary as a function of age among other factors. Lenneberg (1967) studied the maturational hypothesis as well. The results of the study showed maturational processes between infancy and adulthood and that the cerebral hemispheres of newborns are not specialized but progressively specialize with age.

Maturational processes as a means of developing asymmetries has been studied in the literature. Previc's Theory of Postural Control and Postural Origins Theory (1991) however insufficiently support maturational asymmetry development. Annett and Alexander (1978) described Annett's Right Shift Theory as a means of maturational asymmetry development. The theory was created by looking at a Gaussian (normal) distribution of cerebral asymmetry based on hand skill performance and its shift towards right-handedness during tasks tested in the study. It was suggested from the study that the normal distribution is due to chance and that the shift was genetically influenced for left cerebral advantage. The authors also considered social,

environmental, and technological influences, yet more thoroughly supported the idea of lateralization being genetic.

### Overload

The overload theory suggests that superior limb preference is based upon skill performance. Sainburg and Kalakanis (2000) tested two females and four males and their dominant and nondominant arm differences during reaching movements. The authors required the same elbow movement (20°) for all left and right-handed movements. While the elbow movements were the same, the shoulder movement was standardized at 5 °, 10 °, and 15 °. However, all subjects were right handed. This could have been a limitation because left-handed people might have differing reaching movements. While there was no significant differences in arm dynamics during arm reach initiation, differences were found for final limb position dynamics. As skills are repeated the CNS remembers movement patterns of the skills, and after time becomes instinctive because of skill mastery.

Asymmetries in the lower-limbs can be attributed to the overload principle. The Overload Principle suggests neuromuscular changes when a tissue experiences greater stress than the tissue is accustomed to overcoming. The rapidity with which overload increases the capacity for the muscle to handle heavier loads indicates that there is a dramatic increase in neurological activation of motor units during the initial phases of resistance training (Pearson, Faigenbaum, Conley, & Kramer, 2000). Through the overload principle, a unilateral athlete such as a jumper or baseball player generates unequal amounts of work than the other limb. This causes greater neuromuscular stress and greater neuromuscular changes in the limb generating the greatest amount of force on a repetitive basis. Kidgell, Stokes, Castricum, and Pearce (2010) investigated the neurophysiologic responses after short-term strength training. The authors investigated

motor evoked potentials in 23 individuals pre and post 4 weeks of progressive overload strength training at 80% of one-repetition maximum. Their results found significant differences (28% increases) in one-repetition maximum strength. Increases in one-repetition can be attributed alterations in neural transmission via the cortical spinal pathway projecting to the motoneurons controlling the biceps. While progressive overload was observed in Kidgell and colleagues study, they used isotonic muscle contractions of only the biceps brachii. In strength-power training, dynamic, periodized training should be used to achieve maximum genetic potential.

A sequential, periodized approach to developing the athlete's potential is necessary because it is not possible to maintain the athlete's physiological and psychological abilities at maximal capacity through the entire year of training (Bompa & Haff, 2009). McCurdy and Langford (2005) investigated short-term unilateral and bilateral resistance training on lower body strength and power in men and women. Training consisted of 2 days per week for 8 weeks of resistance training. Five of the 8 weeks also included lower body plyometrics. Training was progressively increased from 50% of predicted 1-RM to 87%. Volume and intensity were equalized for both groups. The unilateral training group increased greater than the bilateral group in the vertical jump and relative power. However, there were no significant differences between groups. The study revealed that progressive overload training either unilaterally or bilaterally can produce gains in leg strength and power.

With regards to asymmetry, perhaps it can be speculated that it is caused by a mixture of neurobiological, developmental, and overload and equipotent causes; furthermore, training and athletics may increase these asymmetries.



## Asymmetries

### Anthropometric

There are many variables that may contribute to the asymmetry of athletes; handedness, footedness, genetics, and sport specific demands are only some. Asymmetry has been noted in the literature in terms of anthropometry. However, whether asymmetry is caused or innate is greatly debated (Gentry & Gabbard, 1994; Kidgell et al., 2010; Sainburg & Kalakanis, 2000). Kearns, Isokawa, and Abe (2001) noted a difference in muscle thickness in the preferred leg of 26 junior soccer players. Their study used a B-mode ultrasound to measure muscle thickness bilaterally at a level of 30% from the proximal end of the lower leg segment measured from the lateral condyle of the tibia to the lateral malleolus of the fibula. Interestingly, the authors found significant correlations in muscle thickness and muscle fascicle length. Chibber and Singh (1969) investigated asymmetries in muscle and found a difference in weight between the dominant and nondominant leg, with the dominant leg weight average being heavier. Limbs were removed from cadavers for weighing. Tate, Williams, Barrance, and Buchanan (2006) used MRI analysis between the ankle mortise and the iliac crest in 10 athletes to determine muscle morphology. The authors looked at muscle volume, peak CSA, and length of 13 muscles of the lower limb. The results showed significant anthropometric differences in the dominant leg vastus medialis muscle volume compared to the nondominant vastus medialis. The authors also found several significant differences in muscle morphology between dominant and nondominant vastus lateralis, vastus medialis, rectus femoris, short head of the bicep femoris, semimembranosus, and the medial gastrocnemius.

Shultz and Nguyen (2007) studied bilateral asymmetries in lower-extremity anatomical characteristics. Using 50 males and 50 females, the authors measured 14 anatomic variables

using unspecified clinical measurements: pelvic angle, hip anterversion, standing quadriceps angle, supine quadriceps angle, tibiofemoral angle, anterior knee laxity, genu recurvatum, tibial torsion, femur length, tibia length, and navicular drop. All 14 variables were taken three times each side and averaged for reporting and making comparisons. Out of the 14 variables measured, 10 of them revealed asymmetries. Their results show that anatomic variables can differ from the left and right sides and that measurements taken on one side cannot necessarily account for the other. Their results are similar to that of Kearns et al. (2001) whose results showed fascicle lengths correlate to dominant and nondominant limb differences due to differences in muscle thickness of dominant and nondominant legs.

### Strength

Data on asymmetries suggests a strength discrepancy of 15% or greater may have negative effects on performance and higher occurrence of injuries (Elliot, 1978; Gleim, Nicholas & Webb, 1978; Kannus, 1994; Knapik et al., 1991). Knapik et al. (1991) investigated 138 female collegiate athletes during their preseason for strength asymmetries between the knee flexors and extensors. A Cybex II dynamometer at 30 and 180°/second measured isokinetic knee flexor to extensor ratios. Their study revealed a right knee flexor 15% stronger than the left knee flexor and a knee flexor: extensor ratio of less than 0.75 at 180°/second. They also investigated flexibility using a goniometer with the subject moving through a range of motion. Flexibility results showed a right hip extensor 15% more flexible than the left hip extensor. Interestingly, Knapik and colleagues showed that subjects who had knee flexor or knee extensor imbalances of 15% or more on either side had higher rates of injury during their 3-year study.

Asymmetry in strength and certain performance characteristics has also been noted in the literature. Paterno, Ford, Myer, Heyl, and Hewett (2007) showed side-to-side asymmetries in

vertical ground reaction forces during both landing and take-off phase of drop vertical jumps in 14 females; however, it is to be noted that these 14 females were 2 years or more removed from ACL reconstructive surgery. Vertical ground reaction force data were collected from the “drop” portion during a drop vertical jump; however, sampling frequency was not mentioned. Nonis and Parker (2005) found females ages 3 through 6 favored the preferred leg over the nonpreferred leg during in-step hopping. Cromie, Greenwood, and McCullagh (2007) investigated whether the rigidity of Irish-dance training intensified lower-limb asymmetries. The authors prefaced their work, describing the tasks of Irish dancing is to lead with the right leg. Therefore, the authors compared dancers to nondancers. Of the five variables measured in the study, four involved the lower-limbs; feet together and step-up onto a five-tread (step) stepladder, kick a ball three meters in front of them, feet together and on command hop on one foot, and with feet together begin walking on command. Of the four lower-limb tasks measured, 99 out of 100 Irish-dancers measured stepped up with their right foot, kicked the ball with their right foot, and 95 walked off with their right foot. Hopping yielded results similar to the three previous tasks, with 98 of the dancers using the left foot, the apparent weight-bearing foot of Irish-dance training. The authors reviewed Irish-dance history and noted that regardless of gender, Irish-dancers are taught to lead with their right foot, leaving the left foot for balance. This would explain why their results showed a lead of the right foot, and the hopping test showed a left-foot favored performance. While not an athletic population, the study lends itself to the questions of training and its effects on asymmetry. Does training with a bilateral deficit elicit bilateral asymmetries or further an asymmetry?

Costain and Williams (1984) measured asymmetries in their study using a Cybex II dynamometer. Tests were conducted at a fast speed (180°/second) and slow (30°/second) in 16

high school female soccer players. Dominant leg was determined by asking the subjects which leg they used to kick with; however, the authors did not state whether the players had a preference for using their right or left leg. Speeds were chosen based on previously cited work by the authors. Their result revealed the subjects had no significant asymmetries at both speeds for concentric flexion and extension between dominant and nondominant legs. Interestingly, the quadriceps: hamstring ratio was greater at the faster speed compared to the slow speed. Based on research cited by the authors, they conclude that the ratio became greater at a faster speed due to the increase in speed, which in turn peak torque is achieved later in the arc of the motion of knee flexion and extension. Agre and Baxter (1987) investigated musculoskeletal profiles in male collegiate soccer players for lower-limb flexibility and muscle strength. Similar to Costain and Williams, a Cybex II Dynamometer was used to measure concentric knee flexor to extensor ratios. Flexibility was measured by averaging two measurements via goniometer. The authors found no significant differences between the dominant and nondominant legs for isokinetic strength pre and post the soccer season. No significant flexibility asymmetries occurred throughout the soccer season also; furthermore, no hamstring or groin injuries occurred during the season. Everett, Strutton, and McGregor (2007) investigated trunk muscle flexors and extensors to see if different sporting tasks influenced asymmetry between them. They divided 35 subjects into three different groups: controls, bilateral sports (swimming, rugby, running), and unilateral sports (tennis, squash, hockey, and badminton) and measured concentric trunk strength using a Cybex TEF unit. A ratio of left and right EMG activity was calculated for each set of muscles to examine asymmetry as well. Results showed that unilateral athletes had significant asymmetric trunk flexor: extensor ratios compared to the bilateral group subjects at 30 and 90°/second, respectively. EMG activity however revealed no significant asymmetries.

While asymmetry has been noted in the literature, Parkin, Nowicky, Rutherford, and McGregor (2001) did not find significant asymmetries in tested subjects. The authors investigated whether oarsmen had greater frequency of asymmetric strength of the leg (including left and right hamstring: quadriceps ratio) and trunk musculature (flexor: extensor ratio and symmetry of muscle activity) than a control group. Using 39 males, 19 rowers and 20 controls, asymmetries were measured using a Kin-Com dynamometer and EMG. The investigation revealed no asymmetries between left and right legs for isokinetic and isometric strength of the hamstring and quadriceps, as well as the hamstring: quadriceps ratio in the rowing group. However, EMG data of the erector spinae showed significantly greater activity compared to the controls

Meylan, Nosaka, Green, and Cronin (2010) investigated 30 team sport athletes (soccer, basketball, field hockey, and rugby) for the magnitude of variability associated with certain eccentric variables during unilateral vertical, horizontal, and lateral countermovement jumps. Jump data were measured on a Kistler force plate sampling at 1,000 Hz. Their investigation showed no significant differences found between the lower limbs for eccentric peak velocity, displacement, and ground contact time.

Chavet, Lafortune, and Gray (1997) also studied asymmetries of the lower-limbs by investigating the cushioning response of the lower limbs to external impact loading of the body. The cushioning response was measured with a wall-mounted Kistler force plate sampling at 1,000 Hz to collect VGRFs. In order to quantify impact loading, the authors used a human pendulum to measure the shock wave that traveled through the locomotor system, with subjects seated against the force plate at a 20° knee angle. The investigation found no statistical difference between the dominant and nondominant limb VGRFs, but histogram representations of the

results showed 65% of the subjects responded asymmetrically. The authors could not link asymmetric leg strength to the external impact load. The study's high asymmetric response has many implications for postural and locomotion control. The lower limb's structural properties and muscle activation could perhaps overcome nonsignificant asymmetrical response, such as body weight loads during low impact locomotion and posture control. However, one has to wonder if this would hold true during athletic competitions? Chavet and colleagues were seated and pressed against a force plate at a 20° knee angle. While the authors chose this knee angle at an impact during running, many athletic activities take place at 120°-130°-knee angle.

### Vertical Ground Reaction Forces

Many authors have studied lower-limb asymmetries using vertical ground reaction forces. Asymmetries have been shown to occur in drop vertical jumps, as shown by Ball and Scurr (2009) and Ball, Stock, and Scurr (2010). Ball and Scurr (2009) investigated bilateral neuromuscular and force differences in 16 recreationally active men average age 25. The subjects not only performed drop vertical jumps onto a dual force plate but also mean peak EMG activity of the soleus and the medial and lateral gastrocnemius muscles. Force plate data investigated included peak ground reaction force, ground contact time, and duration of the drop jumps. Each jump was done bilaterally but measured unilaterally using a dual force plate. The authors' investigation revealed significant differences between left and right soleus EMG activity and the triceps surae.

Ball et al. (2010) again investigated bilateral contact ground reaction forces and contact times during plyometric drop jumps using dual force plates. This time the authors used ten recreationally active males and performed drop jumps at three different heights: 0.2, 0.4, and 0.6 meters, respectively. The authors again found significant bilateral differences in force and time

as drop jump height increased. The post hoc tests revealed that 0.2 and 0.4 meter heights revealed bilateral differences in time to peak force, average force, and impulse. The study concluded that in drop vertical jumps, 0.6 meters is the preferred height in which bilateral differences are no longer present. This study in conjunction with Ball and Scurr (2009) show significant bilateral ground reaction forces when performing plyometric drop vertical jumps at selected heights. For the strength and conditioning coach or sport scientist, this is important. If prior to training asymmetries are found, training plans can be adjusted so as to limit asymmetric activity.

Flanagan and Salem (2007) also found asymmetries in vertical ground reaction forces between the left and right limbs during the squat exercise. Ankle and knee joint torque data was also significantly larger on the left than right side. The authors' findings suggest that joint torques and VGRFS should not be assumed to be equal during the squat. Flanagan and Salem (2007) used nine men and nine women, unlike the studies conducted by Ball and Scurr, in which they used males in both studies. Furthermore, both Ball and Scurr studies used force plates sampling at 1,000 Hz, whereas Flanagan and Salem used a sampling rate of 2,400 Hz.

### Balance and Posture

Investigations have been conducted on asymmetries in terms of balance and posture. Having symmetrical ability for balance and posture is key for the athlete for both training and performance. Abnormal dynamic postures may increase the stress on the musculoskeletal system. This lead Latash (2008) to state that vertical posture is a miracle in and of itself. In fact, dynamic misalignment of the lower extremity has been associated with soft tissue injuries such as plantar fasciitis, iliotibial band syndrome, and patellofemoral pain syndrome (Zifchock, 2008). Due to the many joints along the human body's vertical axis, the center of mass must be within a

certain range in order to maintain balance and center of mass and reduce asymmetric activity. Various feedback systems such as the Golgi tendon organs, muscle spindles, the vestibular system, and mechanoreceptors provide kinesthetic and proprioceptive awareness that may allow for asymmetries to be present without significant performance decreases.

Asymmetries during static and dynamic postures commonly exist in humans (Christiansen & Stevens-Lapsley, 2010). Chung, Remelius, Van Emmerik, and Kent-Braugh (2008) investigated the magnitude and associations between bilateral strength and limb-loading asymmetries, postural control, and symptomatic fatigue in women with multiple sclerosis. The authors studied peak knee extensor and dorsi flexor isometric torque and isotonic power with a Biodex dynamometer. They also studied center of pressure movement in the anteroposterior (AP) and mediolateral (ML) directions during 20 s of quiet standing using dual force plates. Bilateral asymmetry scores were calculated as follows: strength asymmetry score =  $[1 - (\text{strength}_{\text{weaker}} / \text{strength}_{\text{stronger}})] * 100$  were calculated for power and torque. Normal and brisk walk times (25 ft) and symptomatic fatigue were measured via Visual Analog Fatigue Scale and Fatigue Severity Scale before strength and balance testing. Postural variability of the center of pressure was greater in the AP direction than in MS direction. Knee extensor power asymmetry was associated with fatigue and walk times. The authors contributed this association with the role strength asymmetries and its role in mediating fatigue, gait, and balance in people with MS. AP center of pressure variability was correlated with fatigue, walk times, and power asymmetries. Their results show that people with MS have asymmetric knee extension power outputs, which the authors concluded had negative results on postural stability.

Hoffman, Schrader, and Kocaja (1999) also investigated postural control; however, they used subjects with ACL graft reconstruction. To examine postural control the authors measured



sway path for the static position, dynamic-phase recovery time after perturbation, and peak torque of the quadriceps. Their results showed significant differences between the ACL and control groups for both dynamic phase duration and peak torque, and no significant differences for static sway. From these results, the authors concluded only the dynamic condition showed differences in postural control for ACL and control groups, and dynamic posture suggests a greater presence of independent control mechanisms. Thorpe and Ebersole (2008) also found independent control mechanisms not investigated by Hoffman and colleagues. The authors investigated maximal concentric test efforts at a velocity of  $90^{\circ}\cdot\text{s}^{-1}$  for supine ankle dorsiflexion (ADF) and plantarflexion (APF);  $60^{\circ}\cdot\text{s}^{-1}$  for seated leg extension (LE) and flexion (LF) and supine hip extension (HE) and flexion (HF) in NCAA D-I female soccer players. Isometric conditions were measured using a Humac Norm Isokinetic dynamometer. In addition, participants performed maximal Star Exclusion Balance Test (SEBT) reaches in the anterior, medial, and posterior directions. The authors showed SEBT tests for all three directions were similar for both groups; however, the soccer group reached significantly farther than the nonsoccer group, suggesting that the SEBT may be sensitive to training status and/or sport-related adaptations. The concentric strength resulted in the soccer group being significantly stronger than the nonsoccer subjects. Furthermore, concentric strength differences between the flexors and extensors were significant for all strength measures for both soccer and nonsoccer groups. Data from the study also showed that despite group differences in all strength tests, strength in general was not highly correlated to SEBT performance. This leads to further conclusions that neuromuscular factors beyond strength may have accounted for the group differences in SEBT performance.

Lin, Liu, Hiseh, and Lee (2009) compared unilateral ankle eversion to inversion strength ratio (E/I R) and static balance control in the dominant and nondominant limbs and determined the relationship between ankle E/I R and static balance control in the dominant and nondominant limbs. Using 28 untrained females the authors used a Biodex III isokinetic dynamometer at speeds of  $30^{\circ}\text{s}^{-1}$  and  $120^{\circ}\text{s}^{-1}$  to measure concentric ankle eversion and inversion. Static balance control was determined by the center of pressure excursion parameters on a force plate during the single-leg upright standing balance test. The authors found no significant differences in ankle E/I R and static balance control existed between the dominant and nondominant limbs. Ankle E/I R was greater at a speed of  $30^{\circ}\text{s}^{-1}$  than that at a speed of  $120^{\circ}\text{s}^{-1}$  in both the dominant and nondominant limbs. In addition, no significant correlation was identified between the unilateral ankle E/I R and static balance control. The authors concluded that both unilateral ankle E/I R and static balance control in the dominant and nondominant limbs were symmetric in young, healthy adult males and females.

#### Motor Control of Lower Limbs

While there are many theories that differ on the origins of asymmetries, it is a consensus that lower-limbs are controlled by the central nervous system (CNS). The central nervous system sends and receives information from the peripheral nervous system's motor division, which receives information from the CNS. The peripheral nervous system (PNS) has many apparatuses to aid in sending and receiving information to the CNS. Kinesthetic receptors are located in joint capsules and are sensitive to joint angles and rates of changes in those angles. Muscle spindles sense muscle length and the changes in those lengths, while Golgi tendon organs sense tensions applied by a muscle to the tendon. We can further break down its control to the frontal lobe where the primary motor cortex is housed. Within the primary motor cortex neurons known as

pyramidal cells allow conscious control of skeletal muscle movement (Wilmore, Costill, & Kenney, pg. 96, 2007).

CNS impulses that control movement of the limbs originate from the spinal cord, the lower regions of the brain, and the motor area of the cerebral cortex (Wilmore et al., pg. 93, 2007). Different patterns of manual timing have been researched to explain motor control asymmetries. In-phase, or symmetry, is known when the timing of contraction cycles occurs with 180° of error. However, both in-phase and out-phase patterns represent natural movements (Schmidt & Lee, 2005). Researchers such as Kalaycioğlu, Kara, and Nalcaci (2008) confirm these timing patterns through finger tapping. Fifty subjects were tested for foot and hand preference by finger and foot tapping, respectively. The average of three 10-second trials was calculated. Dominance score was calculated to show the difference in tapping speeds. The results revealed foot preference in skilled and unskilled movements was correlated with hand preference and foot and hand tapping speed. The authors concluded that asymmetrical lateral (corticospinal) pathway controls skilled movements while the medial pathways control unskilled movements. This asymmetrical corticospinal pathway may be a reason for asymmetrical biomotor patterns in skilled and unskilled movements. Anatomical and physiological research shows that the corticospinal system is asymmetric in the majority of people: the right half of the cord is usually found to be bigger than the left and this asymmetry is due to a difference in size of the corticospinal tract (Kalaycioğlu et al., 2008).

### Measuring Asymmetries

#### Isokinetics

There are several ways in which asymmetries have been measured in the literature. Isokinetics devices have been used to measure flexor: extensor ratios, speed of contraction, and

max velocity. Isokinetics have been shown to produce high levels of reliability, as shown by Li, Wu, Maffulli, Change, and Chane (1996). Using 18 males and 12 females the authors investigated peak torque, total work, and average power of both the knee flexors and extensors. Using continuous concentric and eccentric cycles at  $60\text{s}^{-1}$  and  $120\text{s}^{-1}$  the authors found the Cybex 6000 isokinetic dynamometer to produce high levels of interclass correlations. The interclass correlation coefficient for peak torque ranged from 0.82 – 0.91, 0.76 – 0.89 for total work, and 0.71 – 0.88 for average power, respectively. Interestingly, peak torque, total work, and average power were significantly greater for interclass correlation coefficients at  $120\text{s}^{-1}$  than at  $60\text{s}^{-1}$ . Therefore, isokinetics may not represent normal functional activities or athletics because they are not done at a constant velocity. Furthermore, the testing protocol used for the isometric mid-thigh pulls in the current study shows a knee angle between  $120^\circ$  and  $130^\circ$  is relevant to athletic events and yields high relationships with muscle contraction.

Hadzic, Sattle, Markovic, Veselko, and Dervisevic (2010) used 95 professional male volleyball players to evaluate the concentric and eccentric quadriceps and hamstrings muscle function and to investigate the differences in quadriceps and hamstrings strength ratios and bilateral strength asymmetry among age groups, playing positions, and playing levels. Using a TechnoGym REV 9000 isokinetic dynamometer, the subjects were seated in the dynamometer and performed five concentric quadriceps and hamstrings flexion at  $60^\circ/\text{second}$  for each leg. After a 60-second pause, five eccentric quadricep contractions were completed, followed by another 60-second pause and then five eccentric hamstring contractions. The authors revealed significant multivariate differences in quadriceps and hamstrings muscle function with respect to playing level. Also, the authors showed that quadriceps and hamstrings muscle function of professional male volleyball players was independent of their age and playing position. In their

introduction Hadzic and colleagues mention knee extensors being maximally active during landing and take-off phases of a jump; however, volleyball is an explosive game in which the lower-limbs flex and extend maximally multiple times a game. Perhaps asymmetric activity was witnessed due to the consistent velocity that occurred during their testing, thus not allowing maximal activation of the knee flexors and extensors. While dynamometers are reliable (Li et al., 1996), external validity may have been reduced by controlling the velocities of the study. Single-joint measurement lacks specificity to most sporting motions, which generally involve a coordinated movement of several joints and muscle groups (Cardinale, Newton, & Nosaka, 2011). Coaches may also find isometric testing data useless in determining the appropriate lifting load to be used in dynamic exercise (Cardinale et al., 2011). Furthermore, investigations of the strength and power variables are needed with respect to playing positions of the male volleyball players.

Siatras, Mameletzi, and Kellis (2004) investigated knee flexor to extensor isokinetic strength in nine gymnasts and 14 swimmers (all males under the age of 14). Using a Cybex Norm dynamometer, the authors measured concentric knee flexion at 60°, 120°, and 180°/second. Significant differences were found only in gymnasts' flexor to extensor ratios at 120° and 180°. The swimmer's ratios did not change at any of the velocities tested. Drid et al. (2009) investigated asymmetry among judoists, wrestlers, and untrained subjects (10 each) using an "Easy-Tech" dynamometer. Their results however yielded no asymmetry results in any of the subject groups for knee flexor to extensor ratios. Everett, Strutton, and McGregor (2007) investigated trunk muscle flexors and extensors and to see if different sporting tasks influenced asymmetry between them. They divided 35 subjects into three different groups: controls, bilateral sports (swimming, rugby, running), and unilateral sports (tennis squash, hockey, and

badminton), and measured trunk strength using a Cybex TEF unit. Results showed that unilateral athletes had significant asymmetric trunk flexor: extensor ratios compared to the bilateral group subjects in the EMG tests.

Similar to Hadzic et al. (2010), Brown and Whitehurst (2003) investigated the effects of short-term isokinetic training on rate of velocity development (RVD) and force. Using a KinCom dynamometer, the authors investigated pre and post knee extension RVD and force at 1.04 (slow groups) and 4.18 rad·s<sup>-1</sup> (fast groups) and in a control group (no training). The training of the slow and fast group consisted of 2 workouts, separated by 48-72 hours, that consisted of three sets of eight of maximal intensity repetitions at either 1.04 (slow) or 4.18 (fast) rad·s<sup>-1</sup>. After training was complete, all subjects in each training group were retested. The slow and fast groups completed 2 days of velocity-specific training (slow or fast), and the control group did not train. Results demonstrated significant decreases in RVD between pre- and posttests for the slow group at the slow velocity (RVD-1.25±0.04 vs. 1.08±0.03) and for the fast group at the fast velocity (RVD-14.24±0.33 vs. 13.59±0.29); furthermore, force exhibited no significant differences between testing days for any group. The results of this study demonstrate that short-term repeated isokinetic training yields velocity-specific RVD improvements. This study shows the importance to sport scientists and strength coaches alike that athlete testing should be conducted with sport scientific velocities.

Population and training specificity are also important aspects for the strength and conditioning specialist and sport scientist alike. Brown and Whitehurst (2003) used healthy college students training isokinetically. Athletes train using concentric, eccentric isotonic muscle actions with periodized schemes. Studies have shown training for strength can elicit more dramatic effects on power, rate of force development, and dynamic exercise (Cormie,

McGuigan, & Newton, 2010; Stone et al., 2003); furthermore, this shows that testing and training on isokinetic dynamometers would not reflect the true nature of the strength-power profile of the athletes tested in the current study.

Shiltz et al. (2009) investigated five professional basketball players, 10 junior basketball players, and 20 healthy men (controls) to determine lower limb explosive-strength asymmetries. The three groups performed an isokinetic test to evaluate the knee extensor and flexor concentric peak torque at  $60^{\circ}\text{s}^{-1}$  and  $240^{\circ}\text{s}^{-1}$  and eccentric peak torque at  $30^{\circ}\text{s}^{-1}$  and  $120^{\circ}\text{s}^{-1}$  using a Cybex Norm dynamometer. Evaluation also included countermovement jump with no arm swing, countermovement jump with arm swing, 10-m sprint, single-leg drop jump, and single-leg, 10-second continuous jumping. The two groups of basketball players showed a better isokinetic and functional performances than the control group. Interestingly, no differences in functional or isokinetic variables were demonstrated between professional and junior basketball players. Further research should be conducted to determine if asymmetry profiles are greater in athletes who are less advanced (high school and college) versus professional and elite athletes (professional, national and international level).

While isokinetic devices are very precise, highly reliable and work well in physical therapy settings, they do not necessarily predict athlete strength and power characteristics, and injury. Bennell et al. (1998) investigated isokinetic strength and hamstring injury in Australian Rules football players. They authors used an observational cohort study to research 102 Australian Rules footballers over a season of the sport. The footballers were tested at the beginning of the season on a Kin-Com dynamometer at velocity angles of 60 and 180 degrees /second, respectively. In order to diagnose injury rate the medical staff monitored the athletes

throughout the entire season. The authors concluded that a Kin-Com dynamometer was not able to directly predict Australian Rules football players risk for a hamstring injury.

Other research has been conducted to determine asymmetry other than isokinetics. Field tests or other practical testing methods may identify or predict performance, or identify potential for injury better. Impellizzeri, Rampinni, Maffiuletti, and Marcora (2007) found a vertical jump force testing to be a valid and reliable measure of bilateral strength. Also, Jones and Bampouras (2010) concluded that field tests such as seated unilateral leg press, horizontal hop, and single-leg vertical and drop jumps are valid means of detecting imbalances between lower limbs. Interestingly, they concluded that the ultimate choice of test used should depend on the specific strength quality that predominates in the sports. With that in mind, static and dynametric force measurements do not account for actual athletic movements and body segment positions undertaken during practices, games, or matches.

Although research has been conducted with dynamometers to examine lower limb asymmetries, measurement equipment and methodology are inconsistent (Brown, Whitehurst & Buchalter, 1994; Fousekis, Tspis, & Vagenas, 2010; Siatras et al., 2004). Drid et al. (2009) examined asymmetry in muscle strength in elite athletes. Their methods included judoists, wrestlers, and untrained subjects testing on an “Easy Tech” dynamometer at maximal voluntary contraction. This is dissimilar to Iwai et al. (2008), in which 14 collegiate wrestlers and 14 judokas were tested on a Biodex system at angular velocities of 60, 90, and 120°/second. Furthermore, Drid and colleagues examined lower limb strength, while Iwai examined trunks strength. Schiltz et al. (2009) examined explosive strength in the lower limbs using the 60, 90, and 120°/second protocol such as Iwai, but their study had basketball players as subjects and examined lower limb asymmetry instead of trunk strength. While dynamometers are a valuable



tool, comparing data can become cumbersome due to the lack of consistency among methodology.

Fousekis et al. (2010) researched lower limb asymmetries in soccer players. Using a Biodex II dynamometer, their results found significant differences between knee flexors and extensors at 60, 180, and 300 °/second. Jones and Bampouras (2010) found asymmetries in 13 male athletes when using a dynamometer at only one velocity (60°/second). Hadzic, Sattle, Markovic, Veselko, and Dervisevic (2010) found no significant differences in 95 elite male volleyball players using a dynamometer at only 60°/second. Agre and Baxter (1987) found results dissimilar to that of Fousekis et al. (2010). Agre and Baxter (1987) found no significant differences in knee flexor/extensor strength at 30°/second in 25 collegiate soccer players. From the review of literature, it becomes clear that isokinetic research methodology is somewhat convoluted due to the lack of standard velocities. It is important to have standardized methodology for future comparison and study replication.

### Force Plates

While isokinetics are reliable ways to measure lower-limb force production, research has also been done using force plates. With the ability to measure such variables as vertical ground reaction forces, rate of force development, peak force, and force at different time intervals, force plates are recognized as valuable tools to the sport scientists. Patterson, Raschner, and Platzer (2009) investigated power variables during loaded and unloaded jumps in high performance alpine skiers. The investigators had the participants (20 men and 17 women) perform unloaded and loaded (barbell loads equal to 25, 50, 75, and 100% body weight) squat jumps with free weights. The jumps took place on dual force plates sampling at 1,000 Hz. Ground reaction was recorded along with relative average power, relative average power in the first 100 ms of the

jump, relative average power in the first 200 ms of the jump, jump height, percentage of best jump height, and maximal force difference between dominant and nondominant leg. The authors found that no bilateral force imbalances were present in men and women alpine skiers while performing unweighted or weighted squats. Men produced more peak power than the women except when power was averaged over the first 100 ms. Women were less powerful than the men in the study; however, both men and women reached peak power at lighter loads quicker.

McGuigan, Winchester, and Erickson (2006) used force plates to investigate the importance of whole-body maximum isometric strength in D-III wrestlers using the isometric mid-thigh pull method. The isometric rack was placed over a Quattro Force plate that sampled at a rate of 500 Hz. The purpose of the study was to examine relationships between measures of peak force, rate of force development (measured on the force plate), and one-repetition maximum strength with other variables that might contribute to the successful performance in collegiate wrestlers. Pearson-product correlations revealed a correlation coefficient of 0.73-0.97 between peak force and 1-RM, strong correlations ( $r=0.97$ ) between 1-RM in the power clean and peak force, and squat 1-RM and peak force ( $r=0.96$ ). As mentioned by the authors in the study, isometric mid-thigh pulls provide quick and efficient methods for assessing isometric strength in athletes, and it also provides a strong indication of dynamic performance in wrestlers. We can further the authors conclusions in that isometric mid-thigh pulls provide strong indices of dynamic performance in strength-power athletes (Haff et al., 1997). Rate of force development and other variables investigated in the study did not produce high correlations amongst the wrestlers. This may be due to the unique demands of grappling or combat like sports. Other studies by Haff et al. (1997, 2005) and Stone et al. (2003) have investigated similar variables using force plates. Haff et al. (2005) used AMTI force plate sampling at 600 Hz to investigate

dynamic and isometric muscle actions in elite female weightlifters. Similar to McGuigan et al. (2006), strong correlations were found between isometric strength and dynamic strength performance. Stone et al. (2003) again found strong correlations between isometric mid-thigh pulls and dynamic peak force, peak power at 30 and 60% of IPF, the snatch, and distance in the shot put and weight throw in collegiate throwers. In comparison, McGuigan et al. (2006) used methods similar to this study. Stone et al. (2003) used an AMTI force plate, at 500 Hz instead of 600 Hz.

When investigating asymmetries, research methodology must take into account sport specific movements and practical testing methods. Jones and Bampouras (2010) compared isokinetic dynamometry (isoinertial strength testing) with functional field tests for assessing bilateral strength imbalances. The authors used 13 male subjects from various sports to study knee flexor and extensor strength at  $60^{\circ}\cdot\text{s}^{-1}$  for the isokinetic and dynamometry tests on a Concept II DYNO dynamometer. The field tests included involved seated unilateral leg press, horizontal hop, and single-leg vertical and drop jumps. When comparing the dominant and nondominant strength levels of the subjects, the authors found significant differences for all strength measures. However, no significant differences existed between the right and left limbs were found. No significant relationships between strength dominant: nondominant ratios of isokinetic variables and the field tests were evident. The authors concluded from their study that the ultimate choice of test used should depend on the specific strength quality that predominated in the sport. Newton et al. (2006) also studied dynamometry and field tests on lower limb asymmetries. The authors aim of the study was to determine whether a significant strength imbalance existed between the left and right or dominant and nondominant legs and to investigate possible correlations among various unilateral and bilateral closed kinetic chain tests

that included a field test, and a traditional isokinetic dynamometry test. Using 14 female D-I softball players, measures of average peak torque for isokinetic flexion and extension at  $60^{\circ}\cdot\text{s}^{-1}$  and  $240^{\circ}\cdot\text{s}^{-1}$  were used for the dynamometry test using a Cybex dynamometer. In addition, measures of peak and average force of each leg during parallel back squat, 2-legged vertical jump, and single-leg vertical jump and performance in a 5-hop test were examined. The authors found significant differences between 4.2% and 16.0% for all measures except average force during single-leg vertical jump when comparing the dominant and nondominant limbs. Similarly, the 5-hop test revealed significant differences between the dominant and nondominant limbs and showed a moderate correlation with the dynamometry tests.

Regardless of how force plates are used, it's important that isometric testing be used so maximal rates of force development and maximum strength can be achieved. Schmidtbleicher (2004) states that RFD is associated with the concept of explosive strength and is directly related to the ability to accelerate objects including body mass. Murphy, Wilson, Pryor, and Newton (1995) determined that changing joint angles from  $90^{\circ}$  to  $120^{\circ}$  significantly changed the variables tested in the study, specifically RFD and peak force during the bench press. They related these changes to recruitment patterns, joint mechanics (changing moment arm), and muscle mechanics (changing length-tension relationships). Murphy and Jones (1994) showed that maximal isometric RFD and peak force have significant correlations with performance tests. Furthermore, the authors suggest that isometric testing occur at an angle in which the desired variable(s) can be maximally achieved.

From the review of literature, we can conclude there are many speculations among the origins of asymmetries. Asymmetries have also been shown in anthropometrics, balance and posture, and strength and performance. However, much of the data found on asymmetries came

from methods not appropriate for an athletic population. Isokinetic dynamometry is very beneficial for rehabilitation but is not necessarily practical for athletic testing to predict performance. Jones and Bampouras (2010) concluded that testing for asymmetries must be sport specific, and Murphy and Jones (1995) concluded maximal isometric testing should take place at a joint angle optimal for maximal rates of force.

## CHAPTER 2

### USE OF ISOMETRIC MID-THIGH PULL TO DETERMINE ASYMMETRICAL STRENGTH DIFFERENCES IN NCAA D-I ATHLETES

**Ethan M. Owens<sup>1</sup>, K. Sato<sup>1</sup>, and Duane A. Williams<sup>2</sup>, and Michael W. Ramsey<sup>1</sup>**

<sup>1</sup>Center of Excellence for Sport Science and Coach Education  
Kinesiology, Leisure, and Sports Science  
East Tennessee State University  
Johnson City, Tennessee 37614

<sup>2</sup>College of Clinical and Rehabilitative Sciences  
East Tennessee State University  
Johnson City, TN 37614

Corresponding Author:

Michael W. Ramsey  
East Tennessee State University  
PO Box 70654  
Phone: (423) 439-4375  
Fax: (423) 439-5383  
Email: ramseym@etsu.edu

## **Abstract**

The current study investigates the use of isometric mid-thigh pulls and its ability to measure lower-limb strength asymmetries in NCAA D-I athletes. This is the first study to examine isometric mid-thigh pulls as a method of measuring asymmetries. Isometric mid-thigh pulls have previously been validated as a means of measuring strength populations. While many of the devices used to investigate asymmetries are valid ways to measure asymmetries, the majority of them were designed for use in rehabilitation settings, using nonsport specific joint angles, or with controlled velocities. **PURPOSE:** The purpose of this study is to investigate the use of isometric mid-thigh pulls to determine asymmetrical lower-limb strength differences in NCAA D-I athletes. **METHODS:** Sixty-six subjects (40 males, 26 females) performed isometric mid-thigh pulls over 2 force plates sampling at 1000 Hz each. Each subject performed 2 maximal isometric mid-thigh pulls, lasting approximately 4-5 seconds. Previous work (several hundred trials) with this system has consistently resulted in test-retest reliability for IPF of  $ICC\alpha \geq 0.99$  and RFD,  $ICC\alpha \geq 0.90$ . Student's t-test were used to examine differences between left and right scaled isometric peak force and left and right rate of force development from 0-200 ms for the subjects as a whole, the men, and the women. Percent differences were calculated as well to examine differences between lower limbs. **RESULTS:** As a whole, the subjects showed significant differences between left and right isometric scaled peak force. The men of the study showed significant differences between left and right isometric scaled force, and RFD 0-200 ms. Women showed significant differences only in scaled peak force. A percent difference between average maximum and minimum trials revealed the subjects as a whole had 6 subjects with asymmetries of 15% or greater. Five of the men subjects showed a 15% or greater asymmetry in IPFa, and a singular female revealed a IPFa asymmetry of 15% or greater. RFD 0-200 ms for all

the subjects revealed 25 had 15% or greater asymmetries. The men had 15 subjects (37.5%) with a 15% or greater RFD asymmetry, and the women had 10 subjects (38.5%) with an RFD asymmetry of 15% or greater, respectively. **CONCLUSION:** The results of this study indicate isometric mid-thigh pulls are a sport specific method in which asymmetries can be determined in athletes. Further research is needed to investigate asymmetries found from isometric mid-thigh pulls and whether athletes become more symmetric with increased strength. **PRACTICAL APPLICATION:** The present study shows that isometric mid-thigh pulls are a valid way to measure asymmetries in athletes. Furthermore, observing asymmetries early may assist in single athlete program design or decrease injury potential.

**Key Words:** Asymmetries, Isometric Mid-Thigh Pull, Sport Specific Joint Angles, Measuring Asymmetries



## **Introduction**

The use of isokinetic dynamometers have been the most common measurement instruments used in trying to quantify asymmetric strength differences in the lower-limbs. However, the joint position angles, body position, and constant velocities used do not cross match well with actual sports function. On the other hand, studies performed by Haff et al. (2005) and Stone et al. (2003, 2007) have validated the use of isometric mid-thigh pulls as a means to investigate strength and power characteristics of the lower-limbs. However, to date, no investigation has been done examining the use of the isometric mid-thigh pull to quantify and identify any potential asymmetries of strength in the lower-limbs. Furthermore, the majority of the research investigating asymmetries has originated from rehabilitation or injury prevention settings using isokinetic devices (Newton et al., 2006). Not using sport specific body positions and joint angles when testing for lower-limb strength asymmetries may inhibit maximal development of strength or decrease the rate at which force may be developed.

Studies have been done investigating asymmetries as a way to measure asymmetries. Li, Wu, Maffulli, Change, and Chane (1996) showed that isokinetics devices produced high levels of reliability in males and females. Interestingly, peak torque, total work, and average power were significantly greater for interclass correlation coefficients at 120s-1. McLean and Tumilty (1993) found leg extension differences between right and left limb at 60°s-1 and 240°s-1 in 12 elite Australian junior soccer players. Drid et al. (2009) used isokinetic strength training to test asymmetries in 10 subjects for each group of Judoists, wrestlers, and untrained subjects and found asymmetry measures were significant for each group. Markou and Vagenas (2006) found significant isokinetic differences between the left and right leg in their study in 24 male Greek elite volleyball players. Other researchers have used different means of measuring asymmetries

in their research. Patterson, Raschner, and Platzner (2009) used dual force plates to measure vertical ground reaction forces in high performance skiers. Their study revealed no significant asymmetries when averaging power for the first 100ms of a vertical jump. McGuigan, Winchester, and Erickson (2006) found strong positive correlations between variables measured using isometric mid-thigh pulls and a 1-RM test. These results are similar to previous done by Haff et al. (2005) and Stone et al. (2003, 2007), in which both authors reported strong correlations between isometric mid-thigh pull variables and dynamic mid-thigh pulls. Newton et al. (2006) found asymmetries using a field tests (parallel back squat, two-legged vertical jump, and single-leg vertical jump and performance in a 5-hop test) and a traditional isokinetic dynamometer. While field tests, dynamometers, or force plates are ways in which asymmetries can be measured, it is imperative to the sport scientist to use sport specific angles and velocities (Cardinale, Newton, & Nosaka, 2011). It's important that maximal isometric testing be used so maximal rates of force development and maximum strength can be measured. Murphy and Jones (1995) determined that changing joint angles from 90° to 120° in the bench press significantly changed the variables tested in the study, specifically RFD and peak force. They related these changes to recruitment patterns and muscle mechanics such as length-tension relationships. Murphy and Jones (1994) showed that isometric RFD and peak force have significant positive correlations with performance tests. Furthermore, the authors suggest that isometric testing occur at an angle in which the desired variable(s) can be maximally achieved. The current investigations uses a knee angle associated with the mid-thigh position of a clean or snatch. Comfort, Allen, and Smith (2011) found significantly greater peak forces and instantaneous RFD during the mid-thigh power clean (PF =2,801.7 N; RFD = 14,655.8 N/s) and mid-thigh clean pull

(PF = 2880.2 N; RFD = 15,320.6 N/s) compared to both the power clean (PF = 2,306.24 N; RFD = 8,839.7 N/s) and hang power clean (PF = 2,442.9 N; RFD = 9,768.9) in 11 elite rugby players.

While dynamometers appear effective in measuring asymmetries, perhaps the ultimate choice of test used should depend on the specific strength quality that predominates in the sport (Jones & Bampouras, 2010). Therefore, the purpose of this study was to investigate the use of isometric mid-thigh pulls to determine asymmetrical strength differences in NCAA D-I athletes

## **Methods**

All testing session took place in the Exercise and Sport Science Laboratory on East Tennessee State University's campus. Also, all testing was in accordance with the East Tennessee State University Institutional Review Board (IRB).

## SUBJECTS

Sixty-six subjects (40 men, 26 women) completed the testing protocol of the current study. Subjects ranged in collegiate experience in their respective sport from 1<sup>st</sup> year freshmen to 5<sup>th</sup> year senior. As a whole, the subjects were  $20.2 \pm 1.3$  years old. Men were  $20.3 \pm 1.2$  years old, and the women were  $20.0 \pm 1.5$  years. The subjects signed the long-term athlete monitoring IRB forms in accordance with the university and sport science laboratory policies.

## ANTHROPOMETRIC MEASURES

Before maximal strength tests occurred, physical anthropometrics were measured in the lab, which included height (cm), body mass (kg), and percent fat. . Height was measured to the nearest 10<sup>th</sup> of a centimetre using a stadiometer (Cardinal Scale Manufacturing Co., Webb City,

MO). Body mass and percent body fat was measured through air displacement plethysmography using a Bod Pod (Life Measurement, Inc., Concord, CA). Athletes followed specific protocols published by Bod Pod prior to and during body composition testing. Specific population equations (Heyward, 2005) were used for each individual and thoracic lung volume was predicted.

### ISOMETRIC MID-THIGH PULL

Subject's maximum strength was measured using an isometric mid-thigh pull, performed over two 45.5cm x 90cm force plates (Rice Lake, WI) sampling at 1,000 Hz in an immovable custom designed force rack. The apparatus and standard joint angles were established based on research done previously by Haff and colleagues (1997). Immovable bar heights were set to previously measured distances specific to the individual, with a knee angle of  $125^{\circ} \pm 10^{\circ}$ . Athletes' hands were attached to the bar using weightlifting straps and athletic tape to prevent hand movement and to ensure maximum efforts could be given for each pull without the limitation of hand grip (Haff et al., 1997).

A warm up of 30 jump-jacks, one set of five of dynamic pulls from mid-thigh position with 20 kg, and two sets of five at 60 kg were completed before maximal isometric mid-tigh pull tests. Once athletes were warmed up and in proper position, practice trials at submaximal intensities were performed (one at 50%, one at 75%). Each practice pull lasted between 3 to 4 seconds, and 2 minutes rest was given before the second practice pull. Two maximal effort test trials were completed, with 2 minute of rest between trials. During each maximal trial, subjects were instructed to "pull as hard and as fast as possible." If the second pull was not within 250 Newtons of the first pulls, a third attempt was given. Customized Labview 8.6 Software

(National Instruments Co., Austin, TX) was used to analyze the two maximal trials. Data analysis consisted of peak force (PF), allometrically scaled peak force (IPFa), and rate of force development (RFD 0-200 ms) from 0-200 milliseconds. The variables from each trial were averaged to better indicate the athlete's typical performance level (Henry, 1967). Previous testing in our lab ( $n > 200$ ) has consistently produced a test-retest reliability of: PF,  $ICC\alpha \geq 0.98$ , and RFD,  $ICC\alpha \geq 0.95$ .

## STATISTICAL ANALYSIS

Student's paired t-test was used to analyze if differences existed between left and right IPFa and RFD 0-200 ms. Furthermore, IPFa and RFD 0-200ms were compared between maximum and minimum value regardless of side. Percent differences were also calculated to examine if asymmetries  $> 15\%$  were present in the whole subject population, men and women. This was calculated by averaging subjects' maximum and minimum values, and then calculating percent differences using the following equation:  $(\text{Maximum} - \text{Minimum}/\text{Maximum}) * 100$ . Alpha levels were set to  $p \leq 0.05$ . Effect size was calculated to determine the magnitude of the difference between the means. Coefficient of variation was calculated to determine disbursement of the data. Statistics were performed with Microsoft Excel 2010 (Redmond, WA).

## **Results**

### ANTHROPOMETRIC MEASURES

Anthropometric data were taken once for each subject, which were collected throughout the fall of 2010. Table 2.1 displays group, men, and women anthropometric data expressed as mean  $\pm$  S.D. Sixty-six subjects, 40 men and 26 women, completed the study. Data were collected throughout the fall of 2010. As a whole, the subjects were  $20.2 \pm 1.3$  years old,  $177.4$

$\pm 9.7$  cm, weighed  $77.7 \pm 16.1$  kg, and had a percent fat of  $17.0 \pm 7.3$ . Men were  $20.3 \pm 1.2$  years old,  $182.7 \pm 8.1$  cm, weighed  $83.4 \pm 14.2$  kg, and had a percent fat of  $13.4 \pm 5.4$ . The women were  $20.0 \pm 1.5$  years,  $169.3 \pm 5.4$  cm, weighed  $68.9 \pm 15.1$  kg, and  $22.6 \pm 6.2$  percent fat..

**Table 2.1: Subject anthropometrics**

Subjects	Age (years)	Height (cm)	Weight (kg)	% Fat
Whole (n=66)	$20.2 \pm 1.3$	$177.4 \pm 9.7$	$77.7 \pm 16.1$	$17.0 \pm 7.3$
Men (n=40)	$20.3 \pm 1.2$	$182.7 \pm 8.1$	$83.4 \pm 14.2$	$13.4 \pm 5.4$
Women (n=26)	$20.0 \pm 1.5$	$169.3 \pm 5.4$	$68.9 \pm 15.1$	$22.6 \pm 6.2$

#### ISOMETRIC MID-THIGH PULL

Values expressed for IPFa are in  $\text{N/kg}^{2/3}$  and RFD 0-200ms N/s, respectively. As a whole, there were significant differences between the left and right leg in IPFa ( $t(1,65) = -3.353$ ,  $p = 0.001$ ,  $p < 0.05$ ). IPFa effect size for the subjects as a whole was 0.147. No significant difference was observed for the subjects as whole for RFD ( $t(1,65) = -1.619$ ,  $p = 0.110$ ,  $p > 0.05$ ). RFD effect size for all the subjects was 0.039.

The men in this study showed significant differences in both IPFa ( $t(1,39) = -2.200$ ,  $p = 0.034$ ,  $p < 0.05$ ) and RFD 0-200 milliseconds ( $t(1,39) = -2.081$ ,  $p = 0.044$ ,  $p < 0.05$ ) between the left and right legs. IPFa and RFD effect size was 0.110 and 0.100, respectively.

Women in the study showed significant differences existed between left and right IPFa values ( $t(1,25) = -2.345$ ,  $p = 0.03$ ,  $p < 0.05$ ). IPFa effect size in the women was 0.181. No

significant difference existed between left and right RFD values in the women ( $t(1,25) = -0.019$ ,  $p = 0.96$ ,  $p > 0.05$ ). Effect size for RFD in the women was 0.000. Table 2.2 summarizes the results of the subject's IPFa and RFD 0-200ms data.

**Table 2.2: Strength Characteristics**

Subjects	Left IPFa (N/kg <sup>2/3</sup> )	Right IPFa (N/kg <sup>2/3</sup> )	Left RFD 0-200 ms (N/s)	Right RFD 0-200ms (N/s)
Whole (n=66)	149 ± 34*	155 ± 36	3388 ± 1695	3501 ± 1659
Men (n=40)	161 ± 33*	167 ± 34	3670 ± 1824*	3856 ± 1754
Women (n=26)	130 ± 25*	136 ± 26	2887 ± 1219	2889 ± 1162

**\* Denotes significant difference between left and right values ( $p < 0.05$ )**

Maximum and minimum IPFa values were compared, regardless of side. The subjects as a whole showed a significant difference between maximum and minimum IPFa values ( $t(1,65) = -8.959$ ,  $p = 0.0001$ ,  $p < 0.0001$ ). Percent difference was calculated as followed:  $[(\text{Mean Max. IPFa} - \text{Mean Min. IPFa}) / \text{Mean Max. IPFa}] * 100$ . The subjects' mean percent difference was  $7.2 \pm 5.9$ , respectively. Of the 66 subjects, 6 of the 66 (9.0%) had IPFa differences greater than 15%.

The men of the study showed significant differences between maximum and minimum IPFa values ( $t(1,39) = 6.634$ ,  $p = 0.0001$ ,  $p < 0.001$ ). The mean percent difference between maximum and minimum IPFa of the men was  $7.3 \pm 6.6$ . Of the 40 men tested in the study, five showed IPFa asymmetries greater than 15%.

Women in the study showed a significant difference between maximum and minimum IPFa values ( $t(1,25) = 6.747, p = 0.0001, p < 0.0001$ ). Women had a mean percent difference of  $7.0 \pm 4.8$ . Only one woman of the 26 tested in the study had an asymmetry greater than 15%. Table 2.3 summarizes the results of IPFa data analyzed using percent difference.

**Table 2.3: IPFa & Percent Differences**

Subjects	Maximum IPFa (N/kg <sup>2/3</sup> )	Minimum IPFa (N/kg <sup>2/3</sup> )	IPFa % Difference
Whole (n=66)	156 ± 34*	145 ± 33	7.2 ± 5.9
Men (n=40)	170 ± 33*	157 ± 33	7.3 ± 6.6
Women (n=26)	136 ± 26*	126 ± 23	7.0 ± 4.8

Data expressed as mean ± standard deviation

\* Denotes significant difference between left and right values ( $p < 0.0001$ )

RFD 0-200ms values were compared between maximum and minimum value, with no regards to side. The subjects as a whole showed significantly different maximum and minimum RFD values ( $t(1,65) = -9.352, p = 0.0001, p < 0.0001$ ). The mean percent difference, calculated as:  $[(\text{Mean Max. IPFa} - \text{Mean Min. IPFa}) / \text{Mean Max. IPFa}] * 100$ , was  $12.1 \pm 9.5$ . Twenty-five of the 66 subjects (37.8%) showed a percent difference in RFD greater than 15%.

Men of the study exhibited a significant difference between maximum and minimum RFD values ( $t(1,39) = -7.708, p = 0.0001, p < 0.0001$ ). The RFD 0-200 ms mean percent difference for the men was  $12.0 \pm 9.8$ . Of the 40 men who tested in the study, 15 (37.5%) of them exhibited a percent difference of greater than 15%.



The women in this study reported significant differences between maximum and minimum RFD ( $t(1,26) = -5.287, p = 0.0001, p < 0.0001$ ). The mean RFD 0-200 ms percent difference of the men was  $12.4 \pm 9.2$  N/s, respectively. Ten of the 26 women (38.4%) in the study exhibited a RFD 0-200 ms asymmetry greater than 15%. Table 2.4 provides RFD 0-200ms when data are analyzed using percent difference.

**Table 2.4: RFD & Percent Differences**

Subjects	Maximum RFD 0-200ms (N/s)	Mean RFD 0-200ms (N/s)	RFD 0-200ms % Difference
Whole (n=66)	$3593 \pm 1679^*$	$3165 \pm 1577$	$12.1 \pm 9.5$
Men (n=40)	$3992 \pm 1733^*$	$3535 \pm 1733$	$12.0 \pm 9.8$
Women (n=26)	$2980 \pm 1232^*$	$2596 \pm 1106$	$12.4 \pm 9.2$

Data expressed as mean  $\pm$  standard deviation

**\* Denotes significant difference between left and right values ( $p < 0.0001$ )**

Coefficient of variation was calculated to examine the disbursement of the data. Table 2.5 and Table 2.6 represent CV data.

**Table 2.5: Left and Right Coefficient of Variation Values**

Subjects	Left IPFa	Right IPFa	Left RFD	Right RFD
Whole	23%	23%	50%	47%
Men	20%	50%	20%	45%
Women	19%	42%	19%	40%

**Table 2.6: Maximum and Minimum Coefficient of Variation Values**

Subjects	Maximum IPFa	Minimum IPFa	Maximum RFD	Minimum RFD
Whole	22%	23%	47%	50%
Men	32%	33%	46%	49%
Women	26%	23%	41%	43%

## **Discussion**

The purpose of this study was to determine the use of isometric mid-thigh pull as a means of determining lower-limb asymmetrical strength differences in NCAA D-I athletes. In the current study when data were compared as a whole group, significant differences were seen between left and right IPFa values. When subjects were separated by sex, men had significant asymmetries between left and right leg IPFa values, and RFD 0-200ms, women showed only significant differences in left and right IPFa, respectively. While no previous study has investigated isometric mid-thigh pulls as a method of examining asymmetries, lower limb asymmetries have been shown through other methods to a similar extent (Chin, So, Yuan, Li, & Wong, 1994; Kellis, Gerodimos, Kells, & Manou, 2001; Knapik, Bauman, Jones, Harris, & Baughan, 1991). Strength deficits between the two limbs (strength asymmetries) or between agonist-antagonist muscle groups (reciprocal strength ratio imbalances) have been reported in sports with asymmetric kinetic patterns like soccer (Arnason et al., 2004; Dauty, Potiron-Josse, & Rochcongar, 2003) and volleyball (Markou & Vagenas, 2006) as well as in sports with symmetric motor patterns like running (Vagenas & Hoshizaki, 1991, 1992) and cycling (Smak, Neptune, & Hull, 1999). Kellis et al. (2001) showed a significant main effect suggesting greater knee strength in the preferred leg than the nonpreferred leg of soccer players. The preferred leg in the study was the kicking leg as opposed to the stabilizing leg. Similarly, Chin et al. (1994) found significant asymmetries in the legs of soccer players. They reported stronger knee flexors

in the dominant leg compared to the nondominant leg when testing on a Cybex II isokinetic dynamometer at 60° and 240 °/second.

When conducting research using joint specific angles is important so that desired variable(s) can be maximally achieved (Wilson & Murphy, 1996). Joint specific tests, therefore, provide both a means to assess changes in strength over time and standards or normative values against which comparisons can be made (Kramer, Leger, & Morrow, 1991). Furthermore, gains in isometric strength are progressively small as measurement moves away from the training angle (Cardinale et al., 2011). However, whether data gathered using these tests are used most appropriately only to make comparisons within the confines of the specific test protocol or whether joint- specific tests provide information about activity-specific performances is unclear (Kramer et al., 1991). Due to greater ranges in knee velocities, subject populations, and joint angles nonspecific to athletic, it is rather difficult to compare the current study to previous asymmetry research. Further review of the literature reveals the majority of research that has been conducted with isometric mid-thigh pulls has been done in laboratory settings investigating strength and power measures. One of the advantages of isometric testing is that measures of RFD can be obtained (Häkkinen, Alen, & Komi, 1985) to accurately represent the athletes' ability to rapidly and forcefully contract their muscles, an important aspect of power production (Cardinale et al., 2011). Furthermore, isometric testing that has been well performed can provide information on the maximal voluntary muscle force an athlete can produce and can help the coach in determining the complete force-velocity and power-velocity relationships in specific muscle groups in order to properly assess the status of the athlete and/or effectiveness of a training program (Cardinale et al., 2011).

For explosive movement such as sprints, throws, and jumps, in which force production times range from 100 – 300 ms, the rate at which force is developed has been suggested to be the most important physical capacity (Wilson, Lyttle, Ostrowski, & Murphy, 1995). The current study examined unilateral rate of force development in a bilateral task. To date no research has examined the possible asymmetric values of rate of force development. However, rate of force development has been studied previously. Stone et al. (2004) examined the force-time curve from an isometric mid-thigh pull to obtain RFD measures, similar to the current study. Stone et al. (2003) found strong positive correlations between RFD, static and countermovement jump height and Wingate power in 30 male sprint cyclists. McLellan, Lovell, and Gass (2011) found RFD to be a primary contributor to vertical jump in physically active men. Indeed, rate of force development may be a contributor to superior performance. The majority of athletics have an acceleration component; therefore, large rates of force development are important for success. In most sporting activities both the rate of force development and maximum force produced are strongly related to performance (Wilson et al., 1995).

While the current study used isometric mid-thigh pulls as a means of reporting lower limb asymmetries, most investigations reporting lower limb asymmetries have used isokinetic devices as a means of asymmetry measurement. While this makes data from the current study difficult to compare with previous investigations, methodology of previous studies are somewhat similar. Markou and Vagenas (2006) found significant differences between the left and right legs of male volleyball players tested with a Cybex II isokinetic device at 60°/second. In Markou and Vagenas (2006) their volleyball players were all male and participated on national teams for Greece. The current study used volleyball players; however, they were all female. Furthermore, the males in the current study were younger than male subjects in Markou and

Vagenas (2006). Newton et al. (2006) found significant differences in female softball players tested on a Cybex norm dynamometer. Significant differences existed in the female softball players for isometric flexion and extension at 60° and 240°/second. Newton and colleagues' (2006) conclusion, similar to the present study, was significant strength imbalances exist even in collegiate level athletes, and future research should be conducted to determine how detrimental these imbalances could be in terms of peak performance for athletes as well as the implications for injury risk.

Drid et al. (2009) found asymmetry in elite athletes also. Examining concentric quadriceps and hamstring strength at 60°/second, asymmetry was found in wrestlers, judoists, and untrained subjects. While the current study did not include wrestlers and judoists, it may be assumed that regardless of methodology, asymmetries may be present in athletes. Everett, Strutton, and McGregor's (2007) subjects represent a population similar to the current study. The authors divided 35 subjects into three different groups from different sports controls, bilateral sports (swimming, rugby, running), and unilateral sports (tennis squash, hockey, and badminton), and measured trunk strength using a Cybex TEF unit. Results showed that unilateral athletes had significant asymmetric trunk flexor: extensor ratios compared to the bilateral group subjects in the EMG tests. The current study did not attempt to divide the subjects based on participation in their respective sport; however, asymmetries were shown in male and female subjects. In the current study male and female subjects participated in sports similar to Everett et al.'s (2007) – tennis, running (sprinters). The current study along with previous research shows that regardless of measurement, asymmetries are present in athletes.

Isokinetic device methodology is somewhat convoluted. Research using dynamometers has used a range of knee velocities. Velocities range from 30°-240°, respectively (Capranica,

Cama, Tessitor, & Figura, 1992; Costain & Williams, 1984; McLean & Tumilty, 1993). Drid et al. (2009) found asymmetries in wrestlers using an Easy-Tech isokinetic dynamometer; however, they tested only at 60°/second. However, Hadzic et al. (2010) found no asymmetries in volleyball players at 60°/second. Siatras, Mameletzi, and Kellis (2004) used three different knee velocities – 60°, 120°, and 180° /second, to investigate asymmetries in gymnasts and swimmers. Their results found significant knee flexor: extensor ratios at 60 and 120°/second in gymnasts. No significant asymmetries were observed in swimmers at all three angular velocities. Furthermore, typical sporting activities require acceleration and deceleration and not constant velocities. So, as a whole, mid-thigh pulls are somewhat more representative of strength requirements in sport than the artificially controlled constant velocity measurements.

Results of this study showed that six subjects (9.0%) showed asymmetries  $\geq 15\%$  for IPFa. These results are similar to Knapik et al.'s (1991) findings. The authors found knee flexor differences between the right and left leg  $\geq 15\%$  at 180°/second as measured by a Cybex II dynamometer. Furthermore, the authors concluded that athletes with asymmetries  $\geq 15\%$  between left and right knee flexors, extensors, or flexor: extensor ratio was associated with a higher incidence rate of injury. This conclusion by Knapik could lead to further investigation of using isometric mid-thigh pulls and the  $\geq 15\%$  theory. If athletes showed a  $\geq 15\%$  asymmetry between IPFa or RFD 0-200ms on an isometric mid-thigh pull, would they be more susceptible to or have a higher incidence of injury? This question however is beyond the scope of this study and can be studied in the future.

Similar to the present study, percent differences have been used to determine lower limb asymmetries. McCurdy and Langford (2005) used both t-tests and percent differences to examine asymmetries in male and female unilateral squat strength. No significant differences

were found in the men between dominant and nondominant unilateral squat strength. However, when the authors compared the stronger and weaker leg of the men they found a mean difference of 2.8% between the dominant and nondominant leg. The current study revealed an IPFa difference of 7.3%, showing greater asymmetries than the subjects in McCurdy and Langford's study. The females in the McCurdy and Langford study revealed no significant asymmetries between the dominant and nondominant legs, with a mean difference of 5.0% between the dominant and nondominant. The current study revealed an average strength difference between the females in the study of 7.0%. Perhaps the differences in subject populations could explain the greater amounts of asymmetries in the present study. McCurdy and Langford used healthy males and females, while the present study used D-I collegiate athletes. Perhaps asymmetries were greater in the current study due to the nature of the sporting tasks such as consistent unilateral overload through sport or training.

Some research investigating asymmetries has shown no significant asymmetries in the lower limbs (Costain & Williams, 1984; Kramer et al., 1991). Costain and Williams (1984) measured quadriceps and hamstring torque speeds at 30° and 180°, respectively. The authors chose the two speeds based on previously cited research by Johnson and Siegel (1978) dealing with Cybex II reliability. Their results also revealed no asymmetry between the lower limbs. Kramer et al. (1991) investigated knee extensor strength of oarside and nonoarside rowers. Their research used a KinCom at velocities of 160 and 200°/second. Joint angles were chosen by the authors of the study based on typical knee extension velocities in rowing and within the velocity limitation of the KinCom. Their study showed no significant at an asymmetry of 200°/second. As stated previously, Hadzic et al. (2010) revealed no significant differences in volleyball players at 60° /second. Greenberger and Paterno (1995) found no significant asymmetries

between dominant and nondominant in male and female community college students at a speed of 240°/second. This speed was chosen by the authors for its functional nature to activities such as walking, jogging, running, and hopping.

This study reveals isometric mid-thigh pulls are advantageous to the sport scientist and strength coach because its ability to measure forces in two key joints involved in triple extension movements. Triple extension movements such as running and jumping are key elements in many sports.

### **Practical Applications**

Identifying asymmetries can assist the strength and conditioning coach or sport scientist in program design. Both identifying potential risks for injury and identify biomechanical imbalances such as strength in order to correct or improve performance. Allowing program changes may decrease the incidence of injury in athletes who present asymmetries. However, due to the small effect sizes observed in the study, it may be more beneficial for the athlete to train for maximal strength gains. Cross-sectional comparisons have revealed that individuals with higher strength levels have markedly superior power production capabilities than those with a low level of strength level (Cormie et al., 2010). Also, isometric mid-thigh pulls may be a means of tracking recovery progress in athletes rehabilitating from unilateral injuries. Also, due to mid-thigh pulls efficiency in measuring strength, RFD, and asymmetry, practitioners may want to consider this as a method of testing rather than previous testing devices such as dynamometers and other isokinetic devices (McGuigan et al., 2004). Mid-thigh pulls measurement of knee and hip strength are a more valid means of measurement due to those joints being involved in triple extension movements.



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## CHAPTER 3

### DISCUSSION

#### Results

The purpose of this study was to use isometric mid-thigh pull as a way to determine asymmetrical lower-limb strength difference, if any, were present in NCAA D-I athletes. Strength deficits between the two limbs (strength asymmetries) or between agonist-antagonist muscle groups (reciprocal strength ratio imbalances) have been reported in sports with asymmetric kinetic patterns like soccer (Arnason et al., 2004; Dauty, Potiron-Josse, & Rochcongar, 2003) and volleyball (Markou & Vagenas, 2006) as well as in sports with symmetric motor patterns like running (Vagenas & Hoshizaki, 1991, 1992) and cycling (Smak, Neptune, & Hull, 1999). In the current study when data were compared as a whole group, significant differences were seen between left and right and maximum and minimum IPFa values. When subjects were separated by sex, men had significant asymmetries between left and right leg IPFa values, and RFD 0-200ms, women showed only significant differences in left and right IPFa, respectively. However, both men and women were significantly different for both maximum and minimum IPFa and RFD values. While no study has investigated isometric mid-thigh pulls as a method of examining asymmetries, research has found lower limb asymmetries. Kellis, Gerodimos, Kellis, and Manou (2001) showed a significant main effect suggesting greater knee strength in the preferred (kicking) leg than the nonpreferred leg of soccer players. Similarly, Chin, So, Yuan, Li, and Wong (1994) found significantly asymmetries in the legs of soccer players. They reported stronger knee flexors in the dominant leg compared to the nondominant leg when testing on a Cybex II isokinetic dynamometer at 60 and 240 °/second.

Results of the current study showed that six subjects (9.0%) showed asymmetries  $\geq 15\%$  for IPFa. These results are similar to Knapik, Bauman, Jones, Harris, and Baughan's (1991) findings. The authors found knee flexor differences between the right and left leg  $\geq 15\%$  at  $180^\circ/\text{second}$  as measured by a Cybex II dynamometer. Furthermore, the authors concluded that athletes with asymmetries  $\geq 15\%$  between left and right knee flexors, extensors, or flexor: extensor ratio was associated with a higher incidence rate of injury. This conclusion by Knapik could lead to further investigation of using isometric mid-thigh pulls and the  $\geq 15\%$  theory. If athletes showed a  $\geq 15\%$  asymmetry between IPFa or RFD 0-200ms on a isometric mid-thigh pull, would they be more susceptible to or have a higher incidence of injury during their respective sport season?

Similar to the present study, research has used percent differences to examine lower limb asymmetries. McCurdy and Langford (2005) used both t-tests and percent differences to examine asymmetries in male and female unilateral squat strength. No significant differences were found in the men between dominant and nondominant unilateral squat strength. However, when the authors compared the stronger and weaker leg of the men they found a mean side-to-side difference of 2.8%. The current study revealed an IPFa difference of 7.3%, showing greater asymmetries than the subjects in McCurdy and Langford's (2005) study. The females in the McCurdy and Langford (2005) study revealed no significant asymmetries between the dominant and nondominant legs, with a mean side-to-side difference of 5.0%. The current study revealed an average strength difference between the females in the study of 7.0%. Perhaps the differences in subject populations could explain the greater amounts of asymmetries in the present study. McCurdy and Langford used healthy untrained males and females (mean body mass  $78.3 \pm 21.47$  kg; age  $20.74 \pm 2.6$  years) while the present study used D-I collegiate athletes that were lighter in

body mass (mean body mass  $77.7 \pm 16.1$  kg; age  $20.2 \pm 1.3$  years). Perhaps asymmetries were greater in the current study due to the nature of the sporting tasks.

The current study used isometric mid-thigh pulls as a means of reporting lower limb asymmetries. However, most investigations reporting lower limb asymmetries have used isokinetic devices as a means of asymmetry measurement. Kramer, Leger, and Morrow (1991) investigated knee extensor strength of oarside and nonoarside rowers. Using a KinCom dynamometer at velocities of 160 and 200°/second, the authors found that oarside leg produced significantly greater torques than the nonoarside leg only during the concentric portion of the 160°/second test. Similar to Kramer et al. (1991), Siatras, Mameletzi, and Kellis (2004) found asymmetries in athletes using a dynamometer. Unlike Kramer and colleagues (2004), Siatras et al. used a Cybex Norm dynamometer in which knee flexor and extensor ratios were measured at 60, 120, and 180°/second, respectively. Gymnasts knee flexor: extensor ratio were significantly asymmetric at angular velocities of 60 and 120°/second. Swimmers showed no asymmetries at any given angular velocity.

While the present study found asymmetries present in NCAA D-I athletes, some investigations have not found symmetry between the lower limbs. Capranica, Cama, Tessitor, and Figura (1992) examined concentric knee extensor strength using a KinCom dynamometer at 240°/second. Both male and female subjects ( $n=20$ ) reported no significant differences between dominant and nondominant leg. Costain and Williams (1984), similar to Capranica et al. (1992), examined knee flexor extensor strength. Their results also revealed symmetry between the lower limbs; however, they used a Cybex II at 30 and 180°/second, respectively. Parkin, Nowicky, Rutherford, and McGregor (2001) examined bilateral strength differences in male oarsmen and nonathletic subjects. Knee flexion and extension both concentrically and eccentrically was



examined at 3.5 and 1.75 radians /second. Results showed no significant differences between right and left legs. Lake, Lauder, and Smith (2011) investigated side dominance affects on the end kinematics of a barbell during lower body resistance exercise. To investigate the end kinematics, ground reaction forces and three high-speed cameras were placed around the subject executing the back squat. Of the 10 healthy male subjects tested, the authors concluded asymmetry in ground kinetics had no influence on the symmetry of the bar end kinetics.

Many studies such as the present study have examined asymmetries in athletic populations. An extensive review of the literature found that many studies have used athletic populations tested on dynamometers to examine asymmetries; none have used isometric mid-thigh pulls. Of these studies using athletic populations, many have used soccer players as subjects (Chin et al., 1994; Dörge, Bullandersen, Sørensen, & Simonsen, 2002; McLean & Tumilty, 1993). Chin et al. (1994) found asymmetries between the knee flexors of the dominant leg compared to the nondominant leg at 60 and 240°/second. McLean and Tumilty (1993) reported strength differences in the right knee extensor compared to the left at 60, 180, and 240°/second, respectively. These results are similar to the present study in which asymmetry was found between left and right strength measures for both males and females. Hadzic, Sattle, Markovic, Veselko, and Dervisevic (2010) investigated knee flexor and extensor strength in elite volleyball players, using a TechnoGYM 9000 dynamometer at 60°/second. However, their results differ from the present study in that there were no significant differences reported. Drid et al. (2009) also reported asymmetries in wrestlers and judoists between the knee flexor and extensors. They measured knee flexor and extensor strength with a Easy-Tech dynamometer at 60°/second.

Many of the results of the current study are difficult to compare with previous research. Further review of the literature reveals the majority of research that has been conducted with isometric mid-thigh pulls has been done in laboratory settings investigating strength and power measures. To date no research has been done using mid-thigh pulls as a means of investigating asymmetries. Almost all asymmetry research has been conducted using isokinetic dynamometers as the main method of assessing strength and power.

### Methods

The methods used in this study were well implemented; however, improvements could be implemented. One limitation of the study could have been the disproportion of males and females. With almost twice as many male subjects, this increase in subject number may have contributed to the male's having greater occurrence of asymmetries compared to the females. Another limitation to the study could have been the training age variance between subjects. While it was not assumed, both the sport scientist and strength and conditioning coach hoped for stronger upper classmen than lower classmen. This wide range of training age, both in the sport and in terms of strength, could have been a limitation in the study. Perhaps conducting research with just the upper or lower classmen may have been more beneficial, or separating upper and lower classmen. Also, it was not known if athletes in the study had previous significant asymmetries or injury to one of the lower limbs.

Large discrepancies in the data may also be a limitation to the current study. Coefficient of variation calculations was determined to examine the disbursement of data. Subjects as a whole showed coefficient of variations no more than 50%. Of the variables measured, CV values that were 50% were left RFD and minimum RFD, respectively. These large CVs may be due to the heterogeneous mixture of both men and women comprising the subjects as a whole.

The differences in strength between sexes may account for some of the variance. Men in the study revealed a 50% CV value for right IPFa, 49% for minimum RFD. However, it must be noted that maximum RFD showed a 46% CV value, while maximum and minimum IPFa values were 32% and 33%, respectively. Furthermore, left and right IPFa and RFD values differed greatly (Left IPFa 20% vs. 50% Right IPFa; Left RFD 20% vs. Right RFD 45%). Perhaps this large discrepancy between sides was due to the large range of training age within the males. Training status in the men ranged from little to no experience training to 5<sup>th</sup> year seniors with 5 years training with a collegiate strength coach. Similar to the men, women in the study showed large variation between left and right IPFa and RFD coefficient of variation values. This could also be due to large differences within the women's training status. In addition to the large differences in training status of the subjects, it should be noted that of the 66 subjects tested, only 3 were left side dominant. While side dominance was not used in the analysis of data, it may be speculated that men and women right RFD coefficient of variation values were greater on the right side than the left. Perhaps the expression of side dominance has a greater effect on rate of force development than scaled peak force.

Isometric mid-thigh pulls are a total body test of strength. Therefore, it requires some strength of the upper body, although its emphasis is on lower body strength. Perhaps an important and possibly large limitation of the study was not addressing upper body strength. The body as a whole is connected, and not identifying upper body asymmetries may have perhaps transferred down the torso and lower limbs and through the feet and revealed greater asymmetries. Without knowledge of upper body strength, it is difficult to know the effect of upper body strength and asymmetry on the mid-thigh pull.

## Future Research

The current study used isometric mid-thigh pulls as a method of assessing asymmetries, which showed it was able to do so. However, this is the first study of its kind using mid-thigh pulls as a means of investigating asymmetries. Therefore, it's somewhat difficult to compare previous investigations due to different methodology. Murphy and Jones (1995) concluded isometric testing should take place at a joint angle optimal for maximal and maximal rates of force. More research should be conducted using mid-thigh pulls and asymmetry data. Furthermore, McGuigan, Winchester, and Erickson (2004) pointed out mid-thigh pulls use as an efficient way to gain maximum strength measures. Using this as a method to measure strength asymmetries may be more time efficient than isokinetic dynamometers and possibly more externally valid to sport. Perhaps this study could be repeated using EMG on the muscles being tested in addition to simultaneously measuring forces on dual force plates.

Further investigation involving athlete classification according to sport should be conducted. Miyaguchi and Demura (2008) classified athletes in their respective study; however, no reason was stated why subjects were classified as unilateral or bilateral. Unilateral sports are those that favor greater use of one side of the body as compared to the other, for example tennis, throwers, and baseball. Bilateral athletes are those that during their sporting task do not favor one side of the body, such as running, weightlifting, and swimming. Further investigation as to how to classify athletes as unilateral or bilateral and their subsequent asymmetry measures should be done. Furthermore, training status and asymmetries should be researched. To date no research has been conducted on upper class and lower class comparisons in terms of asymmetry data. A periodized program in which bilateral, dynamic movements are implemented may allow athletes to become stronger and possibly less asymmetric. Similarly,

greater research should be given to training programs implementing greater volume load to the weaker limb of significantly asymmetric athletes. Do athletes who attempt to correct asymmetries become less susceptible to injuries? The subject of asymmetries in athletes has been studied; however, using isometric mid-thigh pulls may allow both the strength coach and sport scientist to achieve more efficient and applicable results.

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# APPENDICES

## Appendix A: IRB Approval



East Tennessee State University  
Office for the Protection of Human Research Subjects • Box 70565 • Johnson City, Tennessee 37614-1707  
Phone: (423) 439-6053 Fax: (423) 439-6060

### IRB APPROVAL – Continuing Expedited Review

August 16, 2011

Dr. Michael Stone  
KLSS  
Box 70654

Re: Long Term Athlete Monitoring  
IRB#: c06-033s

The following items were reviewed and approved by an expedited process:

- Form 107 (no conflict identified); Previously approved Narrative; Informed Consent Document for Athletes Ages 18 Years of Age and Older (ver. 08/20/08 stamped approved 08/15/11); Assent Document for Athletes Ages Under 18 Years of Age (ver. 10/27/08 stamped approved 08/15/11); Video Recording Release consent Form (ver. 01/25/10 stamped approved 08/15/11); Parental Permission Form (ver. 10/24/07 stamped approved 08/15/11); Previous child determinations; Minor modifications approved during continuing review period

On **August 15, 2011**, a final approval was granted for a period not to exceed 12 months and will expire on **August 14, 2012**. The expedited approval of the study will be reported to the convened board on the next agenda.

The following **enclosed stamped, approved ICD** has been stamped with the approval and expiration date and this document must be copied and provided to each participant prior to participant enrollment:

- Informed Consent Document for Athletes Ages 18 Years of Age and Older (ver. 08/20/08 stamped approved 08/15/11)
- Assent Document for Athletes Ages Under 18 Years of Age (ver. 10/27/08 stamped approved 08/15/11)
- Video Recording Release consent Form (ver. 01/25/10 stamped approved 08/15/11)
- Parental Permission Form (ver. 10/24/07 stamped approved 08/15/11)

Federal regulations require that the original copy of the participant's consent be maintained in the principal investigator's files and that a copy is given to the subject at the time of consent.



Accredited Since December 2005



The Vice-Chair concurred with the previous child determinations: (1) the research is not greater than minimal risk to children because permission from parent and assent from children will be obtained. The IRB determined that the permission of one parent is sufficient in the event that only one parent is available. Permission will be obtained and documented appropriately. If permission is to be obtained from a guardian, the guardian will be an individual who is authorized under applicable State and local law to consent on behalf of the child to general medical care. The IRB determined that assent is required for each child who is capable of providing assent based on age, maturity, and psychological state. All are considered capable of providing assent as they are ETSU students participating in intercollegiate sports. The IRB determined that assent must be documented by child signature on assent form.

Unanticipated Problems Involving Risks to Subjects or Others must be reported to the IRB (and VA R&D if applicable) within 10 working days.

Proposed changes in approved research cannot be initiated without IRB review and approval. The only exception to this rule is that a change can be made prior to IRB approval when necessary to eliminate apparent immediate hazards to the research subjects [21 CFR 56.108 (a)(4)]. In such a case, the IRB must be promptly informed of the change following its implementation (within 10 working days) on Form 109 ([www.etsu.edu/irb](http://www.etsu.edu/irb)). The IRB will review the change to determine that it is consistent with ensuring the subject's continued welfare.

Sincerely,  
Dale Schmitt, Ph.D., Vice-Chair  
ETSU Campus IRB

## Appendix B: Informed Consent



East Tennessee State University  
Office for the Protection of Human Research Subjects • Box 70565 • Johnson City, Tennessee 37614-1707  
Phone: (423) 439-6053 Fax: (423) 439-6060

### IRB APPROVAL – Continuing Expedited Review

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Dr. Michael Stone  
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Federal regulations require that the original copy of the participant's consent be maintained in the principal investigator's files and that a copy is given to the subject at the time of consent.



Accredited Since December 2005

**Principle Investigator:** Michael H. Stone

**Title of Project:** Long-term Athlete Monitoring

**Procedures con't:**

- 7. measures of aerobic capacity and low-intensity exercise endurance (treadmill and cycle tests, beep test etc.)
- 8. HR, blood pressure measures
- 9. when appropriate - measures of specific blood borne parameters (e.g. testosterone, cortisol etc.) - carried out with appropriate medical supervision
- 10. when appropriate - questionnaires will be administered dealing with recovery from training such as RestQ, profile of modes state (POMS) (fatigue management), recovery from trauma (e.g. concussion).

**Alternative Procedures**

There are no alternative procedures except not to participate

**POSSIBLE RISKS/DISCOMFORTS:**

The only risk to the athletes in regards to this study is a loss of confidentiality. The risks are explained to the athletes prior to the initiation of the monitoring procedures. The procedures are already performed as part of an athlete monitoring process and the potential for injury is small - all participants will be performing exercises regularly executed in training. For example: There is a potential for a sprain (such as the ankle) upon landing from the vertical jump (it should be noted that the injury potential of the vertical jump is quite low compared to the inherent injury potential of most training routines) - there are no anticipated injuries as result of using these protocols If blood is drawn during the test period - there is a slight potential for bruising or infection.

**POSSIBLE BENEFITS:**

Superior sports performance depends upon the process of recovery-adaptation, (i.e. the training stimulus results in an adaptation during the recovery phase). Thus adequate monitoring of the recovery -adaptation process can enhance the potential for superior performance. Monitoring allows the sports enhancement team (e.g. coaches, sports physiologists and biomechanics, sports medical personnel and sports psychologists) to appropriately adjust the training load.

**Financial Costs**

Ver. 08/20/08

APPROVED  
By the ETSU IRB

SEP 10 2010

By:   
Chair IRB Coordinator

Page 2 of 4

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DOCUMENT VERSION EXPIRES

SEP 09 2011

ETSU IRB Subject Initials \_\_\_\_\_

There are no financial costs to you.

**Principle Investigator:** Michael H. Stone

**Title of Project:** Long-term Monitoring of Athletes

**Compensation in Form of payment to Research Participants**

There is no compensation for your participation in this research

**VOLUNTARY PARTICIPATION:**

Participation in the research portion of this program is voluntary. You may refuse to participate or withdraw from the study at any time. If you refuse or quit, the benefits or treatments to which you may be entitled to will not be affected. You can withdraw by calling Dr. Michael H. Stone whose phone number is 423-439-5796, or Dr. Michael Ramsey, 423-439-4375.

**CONTACT FOR QUESTIONS:**

If you have any questions, problems or research-related problems at any time, you may call Michael Stone at 423-439-5796 or Michael Ramsey at 423-439-4375. You may call the chairman of the Institutional Review Board at 423-439-6054 for any questions you have about your rights as a research subject. If you have any questions or concerns about the research and want to talk to someone independent of the research team or you can't reach the study staff, you may call an IRB coordinator at 423-439-6055 or 423-439-6002.

APPROVED  
By the ETSU IRB

SEP 10 2010

By   
Chair/IRB Coordinator

Ver. 08/20/08

DOCUMENT VERSION EXPIRES

SEP 09 2011

Page 3 of 4  
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ETSU IRB Subject Initials \_\_\_\_\_

**Principle Investigator:** Michael H. Stone

**Title of Project:** Long-term Monitoring of Athletes

**CONFIDENTIALITY:**

Every attempt will be made to see that your study results are kept confidential. A copy of the records from this study will be stored in the Exercise and Sports Science Laboratory for at least 10 years after the end of the research. The results of this on-going study will be published and/or presented at meetings without naming you as an athlete involved in this study. Although your rights and privacy will be maintained, the secretary of the Department of Health and Human Services, the ETSU IRB and the staff involved in the research have access to the study records. Since videotaping is being performed there is a possible loss of confidentiality.

After a testing period, a summary of the study results with group averages and your individual scores will be returned to you and your coach after as soon as possible after analyses of the data are finished.


By signing below, you confirm that you have read this document or had it read to you. You will be given a signed copy of this informed consent document.

---

Signature of Participant	Date
Signature of Investigator	Date

Ver. 10/27/08

**APPROVED**  
By the ETSU IRB

**SEP 10 2010**  
By   
Chair IRB Coordinator

**DOCUMENT VERSION EXPIRES**  
**SEP 09 2011**

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(IC template version 12/05/05)

ETSU IRB

Subject Initials \_\_\_\_\_

Video Recording Release Consent Form

Instructions: Video or photographic recordings may be made of you while participating in aspects of this research project (e.g. training, competition, laboratory). The informed consent document describes how the information from this project and the video images will be used for this specific study as well as who will have access to the image and where the records will be maintained. The investigator would like your permission to use your video image for purposes outside of the study. Please use this form to indicate whether you are willing to allow the use of your image for the purposes described below. Your name will not be associated with the image in any case. You may request to stop the photography or video-taping or erase any portion of the tape at any time.

- |  | Yes                      | No                       |
|--|--------------------------|--------------------------|
| 1. The video-tapes/photo can be shown to other athletes participating in similar projects. | <input type="checkbox"/> | <input type="checkbox"/> |
| 2. The video-tapes/photo can be used for scientific publications and/or presentations.     | <input type="checkbox"/> | <input type="checkbox"/> |
| 3. The video-tapes/photo can be shown in non-scientific publications and/or presentations. | <input type="checkbox"/> | <input type="checkbox"/> |
| 4. The video-tapes/photo can be shown in classrooms to students.                           | <input type="checkbox"/> | <input type="checkbox"/> |

Your Signature indicates that you have read the information and made a decision about how your video image may be used.

Signature: \_\_\_\_\_

Print: \_\_\_\_\_

Date: \_\_\_\_\_

Project: Long-term non-ETSU Athlete Monitoring

APPROVED  
By the ETSU IRB

SEP 10 2010

By   
Chair/IRB Coordinator

DOCUMENT VERSION EXPIRES

SEP 09 2011

ETSU IRB

Ver. 01/25/10

## VITA

### ETHAN M. OWENS

- Education: M.A. Exercise Physiology & Performance, Research  
East Tennessee State University, Johnson City, TN, 2011  
B.S. Education & Allied Professions, K-12 Physical Education  
University of Dayton, Dayton, OH, 2007  
New Lebanon Local Schools, New Lebanon, OH 2005
- Professional Experience: Graduate Research Assistant  
East Tennessee State University, 2010-2011  
Graduate Strength & Conditioning Coach,  
East Tennessee State University, 2010-2011  
Student Strength & Conditioning Coach,  
University of Dayton, 2008-2009  
Wellness Counselor, Dayton YMCA, 2008-2011  
Personal Trainer  
Personally Fit, Dayton, OH 2006 - 2009
- Professional Certifications: NSCA Certified Strength and Conditioning Specialist (CSCS), 2011  
USA Weightlifting Level I Coach (USAW Level I), 2011  
Licensed K-12 Physical Educator in OH, TN, 2009  
American Heart Association CPR/AED, 2007  
American Red Cross First Aid, 2007
- Professional Memberships: National Strength and Conditioning Association  
USA Weightlifting
- Abstracts: **Owens, E.M.**, Lamont, H.S., Sato, K., Williams, D.A., Ramsey, M.W. "Use of isometric mid-thigh pull to determine asymmetrical strength differences in NCAA D-I athletes." East Tennessee State Center of Excellence in Sports Science and Coach Education Conference, Johnson City, Tennessee, October, 2011.
- MacDonald, C.J., Lamont, H.S., Garner, J.C., Jackson, K., Kavanaugh, A.A., Carter, C.R., **Owens, E.M.** "Relationship between measures of jump performance and strength following three different methods of resistance training", 39<sup>th</sup> Annual 2011 SEACSM Conference, Greenville, South Carolina.

Carter, C.R., **Owens, E.M.**, Serrano, A.J., Hornsby, W.G., Lamont, H.S., Stone, M.H. “Relationship of Strength and Power Characteristics and Performance in Collegiate Weightlifters”, East Tennessee State Center of Excellence in Sports Science and Coach Education Conference, Johnson City, Tennessee, December, 2010.

**Owens E**, Serrano A, Mizuguchi S, Stone M, Ramsey M, Johnston B. “Comparing Lower-Limb Asymmetries in NCAA D-I Male and Female Athletes”, NSCA National Conference, Orlando, Florida, June, 2010.

Gallo G., DeMarco, Jr. G., Parr B., Lohmeyer B., Triola M., **Owens E.**, Hord D., Doyle A., Millio J., Inendino A., Greaney C., “Getting Children Motivated to Move Part III: A Focus on Fitness with Skill Themes”, 81st Annual Ohio Alliance for Health, Physical Education, Recreation, and Dance Convention, Columbus, Ohio, December 2009.

Gallo G., De Marco, Jr. G., Parr B, Watson P., Lohmeyer K., Triola M., Zink K., **Owens E.**, Waintraub D., Goff N., Horcher, S., Hord D., Gates C., Frye B., “Getting Children Motivated to Move Part II: An Interdisciplinary Approach to Skill Themes”, 80th Annual Ohio Alliance for Health, Physical Education, Recreation, and Dance, Convention, Columbus, Ohio, December 2008.

Honors and Awards: University of Dayton Dean’s List for Academic Achievement, 2006 – 2009

Professional Conferences Attended:

ETSU Coaches and Sport Science College, December 2010, 2011  
NSCA National Conference, July 2010  
OAHPERD State Conference, December 2008, 2009

Courses Taught: PHED1135 General Conditioning, ETSU, 2010-11