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The Effect of Core Activation on Lower Extremity Kinematics and Kinetics

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THE EFFECT OF CORE ACTIVATION ON LOWER EXTREMITY KINEMATICS AND KINETICS

BY

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Abstract

Core activation is an essential component of movement, especially in athletics, as it allows the body to easily distribute forces and control distal extremity movement. The purpose of this study was to identify the effects of core activation on hip and knee flexion, as well as vGRF. Results indicated no significant difference in hip and knee flexion or vGRF ($p > .05$) between non-intentional and intentional core activation conditions. With individual variability present in the results, the need to further examine the effect of core stability on distal extremity movement is warranted.

Key Words: Core Stability, Neuromuscular Control, Biomechanics, Kinetic Chain

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Chapter 1 – Introduction

Core stability has been a popular topic of interest since the later part of the 1990's, but research dates back to the early 1980's (Hibbs, Thompson, French, Wrigley, & Spears, 2008; Lederman, 2010). There are numerous assumptions about core stability that have led to the popularity of this topic. One assumption is that certain trunk muscles are more important than other muscles in regards to stabilization of the spine, such as the transverse abdominis. The transverse abdominis has received a high amount of attention in research and it was believed that this muscle was the primarily anterior stabilizer of the trunk. However, it has been accepted that numerous trunk muscles contribute to stability, including the rectus abdominis. Additional assumptions regarding core stability include that weak abdominal muscles lead to back pain, strengthening of abdominal muscles can reduce back pain, improving the timing of core muscle contractions can reduce back pain, and that there is a relationship between stability and back pain. As is evident in these assumptions, the literature on core stability has primarily focused on the relationship between core stability and the incidence of back injury, however, there is limited research on core stability and lower extremity injury. These assumptions are disproved in the following chapter in a general sense, but these assumptions regarding core stability have led to the development of programs that focus on injury prevention (Lederman, 2010). One of these programs is the Functional Movement Screen, which is elaborated on below.

Since its development in 2001, the Functional Movement Screen (FMS) has become a popular evaluation tool for a variety of clinicians to assess an individual's movement patterns (Butler, Plisky, Southers, Scoma, & Kiesel, 2010; Chorba, Chorba, Bouillon, Overmyer, & Landis, 2010; Cook, 2010; O'Connor, Deuster, Davis, Pappas, &

Knapik, 2011; Shirey, Hurlbutt, Johansen, King, Wilkinson, & Hoover, 2012). The FMS stems from the concept that the body is one kinetic chain, where proximal segments will impact distal segments of the body (Cook, Burton, Hoogenboom, & Voight, 2014; Shirey et al., 2012). However, while the effect of distal extremity movement on proximal structures has been extensively studied, the influence of proximal stability on lower extremity mobility is not as heavily researched (Leetun, 2006). This concept is imperative to clinical practice because it is relevant to recognize that all structures in the body are connected in various ways, both anatomically and biomechanically (Lederman, 2010). Majority of the current research focuses on the relationship between utilizing the FMS in conjunction with injury prevention and predictions of performance (Chorba et al., 2010; O'Connor et al., 2011; Parchmann & McBride, 2011; Peate, Bates, Lunda, Francis, & Bellamy, 2007). While this literature has assisted with bridging FMS scores with injury risk and athletic performance, research focused on the effect of core functioning on lower extremity movement is limited. A common corrective exercise for a poorly performed overhead squat is to implement core activation exercise. While the popularity of core functioning has increased, the influence that the core has on the lower extremity segments is not well understood. An athlete is only as strong as their weakest link (Bliss & Teeple, 2005). If the weakest link is in the core, this deficit potentially has negative implications on the extremities.

Statement of the Problem

While core stability has become popular in the health care profession, there is a gap in the literature regarding core stability and its effect on lower extremity kinematics and kinetics. The squat is of particular interest in regards to core stability since the performance of a squat requires functional stability and mobility in order to properly position the body, while effectively transferring forces (Bliven & Anderson, 2013; Cook et al., 2014; Frost, Beach, Callaghan, & McGill, 2012; Warren, Baker, Nasypany, & Seegmiller, 2014; Wilkerson, Giles, & Seibel, 2012). Muscle activation anteriorly, laterally and posteriorly is required to stabilize the spine, but the rectus abdominis plays a critical role in stabilizing the body during a squat in order for extremity movement to occur (Bressel, Willardson, Thompson, & Fontana, 2009; Comerford & Mottram, 2006; Lehman, 2006). The squat is a common athletic maneuver and research into the effect of core stability on lower extremity kinematics and kinetics can provide a functional connection to the athletic population (Butler et al., 2010; Cook, 2010; Cook et al., 2014; Schoenfeld, 2010).

Purpose

The purpose of this research study is to compare hip and knee kinematics, as well as vertical ground reaction forces (vGRF) of the lower extremity during the performance of a squat without intentional core activation and a squat with intentional core activation.

Hypotheses

There are three hypothesis for this research. These include:

1. The core activation squat trials will experience higher degrees of peak knee flexion angles compared to the non-intentional core activation squat trials.
2. The core activation squat trials will have smaller degrees of peak hip flexion angles compared to the non-intentional core activation squat trials.
3. The core activation condition will have less variability and lower peak vGRF compared to the non-intentional core activation condition.

Rationales and Significance of the Study

The results of this study will enhance the current literature on corrective exercise by identifying the relationship between intentional core activation and its influence on lower extremity kinematics and kinetics during the performance of a squat. It is essential and necessary for athletic trainers to have an organized plan for assessing and treating individuals with motor control dysfunction or stability deficits (Warren et al., 2014). The results of this study will demonstrate if the use of core activation causes alterations in lower extremity kinematics and kinetics, which can be of benefit to clinicians when developing rehabilitation protocols and individualized exercises. Understanding movement patterns and muscle activation levels during exercise performance will allow for clinicians to more appropriately design rehabilitation protocols based on the physical demands of each individual patient (Dwyer, Boudreau, Mattacola, Uhl, & Lattermann, 2010). Additionally, the incorporation of motor control and stability exercises into these protocols has the ability to positively impact patient care across numerous health care settings and patient populations (Warren et al., 2014). Finally, there are no studies that have examined the influence of core involvement on a double leg squat, which is a common rehabilitation exercise and a high power generation position in athletics (Lehman, 2006). The use of a squat in core activation analysis will provide insight into how the rectus abdominis functions in an athletic, closed-chain position (Leetun et al., 2004). The use of a popular rehabilitation exercise will provide clinicians with a better understanding of the exercise under various techniques, as well as allow for easy application and transfer to real-world activity.

Assumptions

It is assumed that the participants in this research study performed each squat trial to the best of their ability. This assumption includes assuming that the participants were contracting the rectus abdominis at full effort during the intentional core activation condition. Additionally, it is assumed that each participant performed the intentional core activation squat only after they reached the indicated threshold on the MyoTrac Infiniti. Finally, it is assumed that all participants truthfully divulged any current or previous lower extremity injury that may affect the results of the study.

Delimitations

Male participants from the Barry University NCAA Division II collegiate athletic programs were recruited for participation in this study. Research has predominantly examined the influence of core strength and activation in a female population (Evans, Refshauge, & Adams, 2007; Leetun et al., 2004; McGill, 2010; Stickler, Finley, & Gulgin, 2015; Willson, Ireland, & Davis, 2006). Few studies have compared males and females in the same research in regards to core functioning (Dwyer et al., 2010; Evans et al., 2007; Hodges & Richardson, 1997; Kulas, Schmitz, Shultz, Henning, & Perrin, 2006; Leetun et al., 2004; Nakagawa, Maciel, & Serrao, 2015; Willson et al., 2006). At the present time of this study, no research that exclusively evaluated core activation and the effect on the lower extremity in males during a functional activity has been identified. Stickler et al. (2015) indicated the need to examine research between males and females separately in order to account for potential differences in kinematics and strength. Therefore, research exclusively on males is warranted. Additionally, the use of current collegiate athletes were utilized in order to evaluate the influence of core activation on lower extremity kinematics and kinetics in an active population.

Criteria for exclusion included: individuals under the age of 18, current lower extremity injury, which included injury to the spine or abdomen, previous lower extremity injury that the participant is still currently rehabilitating, lower extremity surgery (<12 months post-operation), and inability to perform any portion of the testing protocols.

Limitations

One limitation of this study is that some participants are in-season during the time of data collection. Therefore, in-season training was not a variable that was controlled for in this study. In-season practices and training sessions can have an effect on an individual's mobility and soreness level, which would affect the performance of a squat.

A second limitation is that the consistency of the core contraction was not assessed for once the activation level was met. In other words, once the participant reached the desired core activation level, the maintenance of the core contraction was not identified. While it was assumed that participants contracted the rectus abdominis during all trials of the intentional core activation squat, it is understood that this may not have been the case. The participants may have initially reached the desired core activation level, but then discontinued the activation level while actually performing the squatting task.

A third limitation to this study is that the speed of the squat for both the intentional and the non-intentional core activation condition was not controlled for. During both conditions, the participants were instructed to squat how they normally would on their own. The speed of the movement pattern could have an effect on the amount of force distribution through the lower extremity.

A final limitation is that the actual numerical firing activity level was not assessed. The rectus abdominis was only assessed to identify if muscle activity was occurring. It may be relevant to identify if various electromyographic activation levels of the rectus abdominis have an effect on core stability, lower extremity kinematics, or lower extremity kinetics.

Operational Definition of Terms

Abdominal Bracing: Maximally activating the abdominals without drawing the navel toward the spine (Maeo, Takahashi, Takai, & Kanehisa, 2013; Vera-Garcia, Elvira, Brown, & McGill, 2007).

Core Activation: A general term used to describe engagement of the core musculature (Shirey et al., 2012).

Core Stability: The ability of the body to control the entire range of motion of a joint, including trunk position and motion over the pelvis, in order to allow for the production, transfer, and control of forces that are incorporated into activities involving the entire kinetic chain (Faries & Greenwood, 2007; Kibler, Press, & Sciascia, 2006; Wilkerson et al., 2012).

Core Strength: The ability of a core muscle to exert or withstand force (Faries & Greenwood, 2007).

Intentional-core activation: Performance that requires engagement of the abdominal muscles through an abdominal bracing technique (Maeo et al., 2013; Shirey et al., 2012; Vera-Garcia et al., 2007).

Motor Control: The generation and monitoring of movement patterns by the central nervous system (Warren et al., 2014).

Muscular Capacity: The ability of muscles to generate and maintain force. Muscular capacity involves muscular endurance and muscular strength in order to perform movement of the body (Warren et al., 2014).

Perturbation(s): Outside influences created by forces of activity, such as squatting, that generate offsets of balance (Kibler et al., 2006).

Chapter 2 – Literature Review

Core strength is a common area of fitness that athletes attempt to improve frequently. Core strength can be defined as the ability of a muscle to exert or withstand force (Faries & Greenwood, 2007). While it is important to have appropriate muscle strength during performance of sport-specific tasks, it has been suggested that the ability of trunk musculature to maintain appropriate muscle activation levels for an extended period of time may be more relevant towards enhancing performance (Evans et al., 2007). Spinal stability is achieved when there is sufficient trunk muscular endurance in order to prevent rapid fatigue of the core (Evans et al., 2007; Wilkerson et al., 2012). Trunk muscular endurance is an essential characteristic in order to maintain proper core stability, while performing complex and demanding tasks of athletics, and may be more important than the strength capabilities of the core musculature (Evans et al., 2007; Lehman, 2006; Wilkerson et al., 2012). Currently, research is examining the connection between core stability and injury frequency, as well as the effect of prevention methods to reduce injury (Willson, Dougherty, Ireland, & Davis, 2005). Injury-prevention efforts primarily focus on identifying and reducing risk factors, but current literature does not focus on developing individualized neuromuscular adaptations (Wilkerson et al., 2012). The concept of core stability training has become more popular in the athletic population, however, there is limited research that indicates that these training programs lead to improved performance (Araujo, Cohen, & Hayes, 2015). One method that is attempting to bridge the gap between core stability, injury risk, pre-participation exams, and performance is that of the Functional Movement Screen.

Functional Movement Screen

In 2001, Gray Cook developed the Functional Movement Screen (FMS) to assist with identifying areas of discrepancy in the body and provide solutions for correcting faulty movement patterns (Butler et al., 2010; Chorba et al., 2010; Cook, 2010; O’Connor et al., 2011). The FMS is a full body screening tool that assess both right and left sides of the body, identifying compensatory movements during performance (Cook et al. 2014). The premise behind the FMS is to expose an individual’s weakness through a movement pattern analysis (Butler et al., 2010; Cook et al., 2014; Frost et al., 2012; O’Connor et al., 2011). The FMS consists of seven exercises that challenge an individual’s mobility, stability, and neuromuscular control (Butler et al., 2010; Cook et al., 2014; Frost et al., 2012; Parchmann & McBride, 2011; Peate et al., 2007). One exercise that has become increasingly popular since FMS began being utilized is the deep squat. The deep squat places the human body in a vulnerable position where functional stability and mobility must occur in order to keep proper positioning and alignment of the body (Cook et al., 2014; Frost et al., 2012). The body is forced to work together as a kinetic chain by providing a stable base through core stability in order to transfer loads appropriately (Bliven & Anderson, 2013; Cook et al., 2014; Warren et al., 2014; Wilkerson et al., 2012). This creation of the stable base allows for one specific, fluid action that is evaluated in terms of function, neuromuscular control, proprioception, joint stability, mobility, strength, and balance (Bliven & Anderson, 2013; Cook et al., 2014). Additionally this positioning also allows for the extremities to move more accurately and with more force. The appropriate transfer of loads occurs as a result of co-activation of trunk muscles to provide stiffness, stability and compression of the spine (Bressel et al., 2009). The contraction of the rectus abdominis is critical during the performance of a squat since this muscle assists with stabilizing the trunk in order to increase the amount of tension in the core, while also increasing the intra-abdominal pressure (Comerford & Mottram, 2006). If the body is loaded with improper technique or under poor biomechanics, an individual is placed at a higher risk of sustaining injury (Bliss & Teeple, 2005). This creation of the stable base allows for one specific, fluid action that is evaluated in terms of function, neuromuscular control, proprioception, joint stability, mobility, strength, and balance (Bliven & Anderson, 2013; Cook et al., 2014).

Grading of the FMS.

There are four different point totals that are utilized to grade each exercise in the FMS. The scores range from zero to three (Butler et al., 2010; Cook et al., 2014; O'Connor et al., 2011; Parchmann & McBride, 2011). Each point value is awarded based on the fluidity and performance of the movement. A point value of three, which is the top score that can be received in a FMS analysis, is awarded if the performer can partake in the exercise without compensation, while meeting all standardized movement expectations for the exercise (Cook et al., 2014; O'Connor et al., 2011; Parchmann & McBride, 2011). In order to receive a three on the deep squat exercise, which is the prime position for the exercise, the performers trunk must be parallel to the tibia or near vertical, the femur must be below horizontal, and the knees must be aligned over the feet (Cook et al., 2014). This is opposed to a score of one on the deep squat exercise. An individual receives a score of one when the upper torso and tibia are not parallel, the femur is not below horizontal, and the knees are not aligned over the feet (Cook et al., 2014). The inter and intra-rater reliability of the scoring of the FMS has recently been researched (Butler et al., 2010; Frost et al., 2012). Among athletic trainers who are familiar with the FMS, Gribble et al. (2013) identified that intrarater reliability was excellent (ICC (2, 1): 0.946; 95% CI: 0.684 – 0.991). Additionally, Minick et al. (2010) found that for expert raters of the FMS, the interrater reliability was 86.7%.

Deep Squat Analysis

The deep squat is a common athletic maneuver that is associated with high power generation, as well as pelvic and core stability. Since the squat requires muscle activation of the anterior, lateral, and posterior musculature to stabilize the spine, the squat has been identified as a core stability exercise (Lehman, 2006). Furthermore, the deep squat assesses neuromuscular control and full body mechanics, including mobility of the hips and knees (Butler et al., 2010; Cook, 2010; Cook et al., 2014, Schoenfeld, 2010). In order to perform a squat appropriately, an individual stands upright with the knees and hips fully extended. The downward phase of the squat occurs by flexing the hips, knees, and ankles. After achieving the desired squat depth, the direction of the squat is directed upwards towards returning to hip and knee extension (Schoenfeld, 2010). The FMS takes a deep squat a step farther by assessing shoulder and thoracic spine mobility by having the individual squat with a dowel pressed overhead (Butler et al., 2010; Cook, 2010; Cook et al., 2014). However, for the purposes of this study, this portion of the FMS deep squat will be removed. Additionally, specific to the variables that will be studied in this research, it is necessary for an athlete to have proper hip flexion and knee flexion during the performance of the deep squat (Butler et al., 2010; Cook et al., 2014). If an individual has difficulty performing the deep squat test, the faulty result can be attributed to inadequate mobility in the hip or knee joint, as well as limited core activation (Butler et al., 2010; Cook et al., 2014).

In regards to the deep squat, there is only one study present in the literature regarding kinematic biomechanical differences during the performance of this movement pattern under the FMS guidelines. Butler et al. (2010) examined the differences in hip flexion and extension between FMS scores of one, two, and three, in a general population. During the performance of this study, 28 participants (9 males and 19 females) were divided into one of three different groups based on the individual's performance of the deep squat (Butler et al., 2010). Three-dimensional kinematic data was gathered for all individuals. Butler et al. (2010) identified that individuals with a score of three on the deep squat, on average, had higher amounts of peak hip flexion (121.1 ± 2.0°) compared to those with a score of two (117.5 ± 4.0°) and one (88.8 ± 5.1°). Additionally, in regards to knee biomechanics, individuals with a deep squat score of three also had the highest peak knee flexion (130.7 ± 3.8°) (Butler et al., 2010). This is compared to those with a score of two (111.0 ± 4.9°) and one (84.7 ± 4.3°). The results from Butler et al. (2010) display that individuals who score higher on the deep squat are capable of more joint motion compared to lower groupings. However, the reasoning behind the higher amounts of joint motion is not well understood, as the structure of the joints in college aged individuals would not be expected to have limited joint mobility, especially in the hips (Butler et al., 2010). While Butler et al. (2010) identified differences in hip flexion and knee flexion measurements between the various FMS scores, these differences were found in a general population. Since the FMS is typically utilized to screen active individuals, research assessing joint motions in an athletic population is indicated. Additionally, research that examines alterations in joint motion when altering mobility and stability of the deep squat is required (Butler et al., 2010). Increasing core stability is one method that can be implemented towards achieving these goals and identifying its effect on hip and knee kinematics.

Core Anatomy

Core stability is compromised of the lumbopelvic hip complex (Araujo et al., 2015; Wilkerson et al., 2012; Willson et al., 2005). This complex is the bridge between the upper and lower extremities of the human body (Bliss & Teeple, 2005). The lumbopelvic hip complex consists of the lumbar vertebrae, the pelvis, and the hip, as well as active and passive structures of the neural system that cross these locations and are responsible for creating or restricting movement (Araujo et al., 2015; Kibler et al., 2006; Lederman, 2010; Panjabi, 1992a; Panjabi, 1992b; Sharma, 2012; Vera-Garcia et al., 2007; Warren et al., 2014; Wilkerson et al., 2012; Willson et al., 2005). In addition to active and passive structures, there is also a neural system that assists with core stabilization (Bliven & Anderson, 2013; Panjabi, 1992a; Panjabi, 1992b; Vera-Garcia et al., 2007; Sharma, 2012). The passive structures of the core are static tissues and includes the bones, such as the vertebrae and pelvis, as well as intervertebral discs, ligaments, and joints capsules (Bliven & Anderson, 2013; Lederman, 2010; Panjabi, 1992a; Panjabi, 1992b; Sharma, 2012; Warren et al., 2014; Zazulak, Hewett, Reeves, Goldberg, & Cholewicki, 2007). These structures have a relatively small role in regards to core stability, but the passive structures are responsible for handling the mechanical load imposed on the body, as well as the compliance of soft tissues (Panjabi, 1992b; Willson et al., 2005). The active structures of the core includes the core and trunk musculature, as well as the muscle tendons (Bliven & Anderson, 2013; Lederman, 2010; Panjabi, 1992a; Panjabi, 1992b; Warren et al., 2014; Willson et al., 2005; Zazulak et al., 2007). This musculature provides dynamic stabilization to the skeleton, while providing movement information for the neural system (Bliven & Anderson, 2013; Panjabi, 1992a; Panjabi, 1992b; Sharma, 2012). This dynamic stabilization consists of the ability to utilize strength and endurance, functionally, in all three planes of motion, and is an imperative component of core stability (Bliss & Teeple, 2005; Wilkerson et al., 2012). Compared to passive structures, the muscles of the core provide majority of the dynamic stabilization and force generation that is required in core stability (Panjabi, 1992a; Willson et al., 2005). The muscles of the trunk create stability of the core through three mechanisms (Kibler et al., 2006; Willson et al., 2005). These mechanisms include intra-abdominal pressure, spinal compressive forces, and hip and trunk muscle stiffness (Kibler et al., 2006; Kulas et al., 2006; Willson et al., 2005). Intra-abdominal pressure is considered to result from abdominal muscle activity, since the muscle activation acts as a stabilizer for the lumbopelvic hip complex (Kulas et al., 2006; Willson et al., 2005). Finally, the neural system is the receiving center of incoming and outgoing signals from the active structures and assists with determining the needed core stability at all times during movement. In order to maintain core stability, these three systems of active, passive, and neural structures must have continuous interaction (Bliven & Anderson, 2013; Panjabi, 1992a; Panjabi, 1992b).

The core musculature is comprised of muscles surrounding the trunk and pelvis that assist with maintaining stability, while transferring forces from large, central body segments to the smaller, extremity body segments (Kibler et al., 2006; Warren et al., 2014). There are a variety of muscles that assist with the performance of these three mechanisms. When examining the core musculature, anterior, posterior, lateral, and inferior structures all need to be considered. The superior muscle boundary of the core is at the diaphragm and the inferior muscle boundary of the core is the pelvic floor and hip girdle (Bliss & Teeple, 2005; Bliven & Anderson, 2013; Kibler et al., 2006). Anteriorly and laterally, the abdominal complex, hip abductors and rotators, and oblique muscles are the core boundaries. Finally, posteriorly, the core boundary is found in the paraspinals and gluteal muscles (Bliss & Teeple, 2005; Bliven & Anderson, 2013). These muscle boundaries create the primary stabilization effect on the trunk and spine and are capable of controlling for external forces that can flex, extend, laterally flex, or rotate the spine (Bliven & Anderson, 2013; Leetun et al., 2004). Within these muscle boundaries, there are additional muscles that function in certain planes that also assist with core stability. In the sagittal plane, the rectus abdominis, erector spinae, multifidus, and glute maximus assist with stabilization. The gluteus medius, gluteus minimus, and quadratus lumborum are the primary lateral muscles that function in the frontal plane (Bliss & Teeple, 2005; Lehman, 2006; Willson et al., 2005). Finally, in the transverse plane, the primary muscles that fall into the boundaries defined above include the gluteus maximus, gluteus medius, and piriformis (Bliss & Teeple, 2005; Willson, 2005). The latissimus dorsi and psoas complex are also involved in providing core stability (Lehman, 2006; McGill, 2010). All of these muscles assist with spinal stabilization, as well as mobilization, and poor function of these muscles can lead to dysfunctional movement patterns, as well as create core instability (Bliven & Anderson, 2013; Shirey et al., 2012; Warren et al., 2014).

It is also relevant to break down the muscular anatomy of the core into local and global systems, as these two categories assist with achieving core stabilization (Bergmark, 1989; Bliss & Teeple, 2005; Sharma, 2012). Local stabilizers are muscles that have direct attachments to the spinal column and generate segmental movement (Bergmark, 1989; Bliss & Teeple, 2005; Sharma, 2012; Warren et al., 2014). These stabilizers are typically type I fibers that are resistant to fatigue due to their predominant function of maintaining posture and controlling the motion of the extremities (Sharma, 2012; Warren et al., 2014). The local stabilizers are further broken down into two categories of primary and secondary stabilization systems (Faries & Greenwood, 2007; Sharma, 2012). The primary local stabilizers are the transverse abdominis and the multifidi (Bliss & Teeple, 2005; Faries & Greenwood, 2007; Lehman, 2006; Sharma, 2012). These muscles do not create any movement of the spine, but do generate enough force to produce segmental stability of the spine (Faries & Greenwood, 2007; Sharma, 2012). This is compared to the secondary local stabilizers that are responsible for stabilizing the spine, as well as moving the spine (Faries & Greenwood, 2007). The secondary local stabilizers include the internal oblique, medial fibers of the external oblique, quadratus lumborum, diaphragm, pelvic floor, and the lumbar portions of the iliocostalis and longissimus (Faries & Greenwood, 2007; Lehman, 2006; Sharma, 2012). The global system consists of muscles that do not have direct attachment to the spine, but cross several joints while inserting into the hip and thorax, as well as intra-abdominal pressure (Bergmark, 1989; Bliss & Teeple, 2005; Warren et al., 2014). This system is primarily responsible for movement and torque of the spine (Faries & Greenwood, 2007; Sharma, 2012; Warren et al., 2014). It also assists with transferring loads between the thorax and the pelvis (Bergmark, 1989; Sharma, 2012). These muscles include the rectus abdominis, the lateral fibers of the external oblique, psoas major, erector spinae, and the thoracic portion of the iliocostalis (Bergmark, 1989; Bliss & Teeple, 2005; Faries & Greenwood, 2007; Sharma, 2012). The rectus abdominis is the abdominal power muscle. This muscle has a high threshold recruitment to allow for maintaining spinal stability during high load activities. Additionally, the obliques are stabilizing muscles that have a lower threshold, thus, they assist with maintaining posture and stability. These muscles should be the focus when attempting to improve core stability (Comerford & Mottram, 2006). Regardless of the separation of the musculature, biomechanical analyses has suggested that all muscles must contract together in order to appropriately stabilize the spine (Bliss & Teeple, 2005; Comerford & Mottram, 2006; Vera-Garcia et al., 2007). These coordinated contractions provide stiffness to the core, which ultimately increases spinal stability and protects the surrounding structures throughout the kinetic chain (Warren et al., 2014).

All of the muscular anatomy of the core is critical for stabilization of motions that exceed the neutral zone (Bliven & Anderson, 2013; Panjabi, 1992b). The neutral zone is a region of high flexibility, based on muscles, ligaments, and structural anatomy, and little resistance around the neutral spine position (Bliss & Teeple, 2005; Bliven & Anderson, 2013; Panjabi, 1992b). In the neutral spine position, stability initially occurs. This position is a midrange of joint movement that is a position of comfort (Bliss & Teeple, 2005). This information regarding the neutral zone and neutral spine position is illustrated by Crisco and Panjabi (1991) who identified that spinal buckling occurs at 88 Newtons, which is approximately 20 pounds, under the absence of muscular contractions.

Therefore, static (passive) structures were the primary stabilizer under this weight. The identification of this information was accomplished through developing a spinal model and subjecting the model to various loads (Crisco & Panjabi, 1991). The buckling indicates the necessity and imperative role of dynamic core stability as this load is significantly below loads that are common in athletics (Bliven & Anderson, 2013). While specific research regarding spinal loads during athletic movements has not been identified, literature has identified the effect of spinal compressive loads during a loaded half-squat. It was found that loads that ranged from 0.8 – 1.6 times the body weight of the subject were added to the performance of a half-squat, the compressive loads in the spine varied between six to ten times the body weight (Faries & Greenwood, 2007). Faries & Greenwood (2007) elaborated on this information and described this concept by applying it to a 200 pound athlete. If a 200 pound athlete was squatting under a 320 pound barbell, the compressive forces in the spinal column would be approximately 8,900 Newtons. Additionally, the spine can experience loads from 6,000 Newtons during activities of daily living to up to 18,000 Newtons during powerlifting (Cholewicki & McGill, 1996). These high spinal forces indicate the necessity for proper muscular contraction and control of the core and spine. When the trunk muscles co-contract, the spine is appropriately stabilized and spinal buckling is prevented (Lehman, 2006). The core contracts in response to spinal loading, however, when no spinal loading is present, the muscles that typically fire remain inactive and the stability of the lumbopelvic hip complex relies on passive elements (Willson et al., 2005).

The core is the basis for motion and is involved in almost all activities that involve the extremities. Prior to any movement in the extremities, the core must be stabilized. The prime movers of the body, such as the hamstrings and quadriceps, as well as majority of the large, stabilizing muscles, such as the hip rotators and gluteal muscles, all originate from the core and trunk. Therefore, the core should be treated and evaluated during all evaluations of extremity injuries (Kibler et al., 2006).

Core Stability

Core stability has become a pivotal topic in regards to biomechanical function of the human body. The interest surrounding the theory of core stability is that a higher degree of core stability is believed to maximize force generation and minimize joint loads (Kibler et al., 2006). Core stability is the ability of the body to control the position and the entire range of motion of a joint over the pelvis, in order to allow for optimal production, transfer, and control of forces through the entire kinetic chain (Faries & Greenwood, 2007; Kibler et al., 2006; Wilkerson et al., 2012). This stability references the stability of the spine and not the stability of the muscles (Faries & Greenwood, 2007). However, there is limited quantitative research on core stability and the minimization of these joint loads on the lower extremity (Willson et al., 2005). Additionally, research that has been completed on core stability and core strengthening has been conducted on individuals with low back pain, spondylolysis, or spondylolisthesis during daily activities (Faries & Greenwood, 2007; Hibbs et al., 2008). This research is conducted primarily in rehabilitative populations and cannot be applied to the athletic world due to the different demands that sporting activities place on the body. Thus, there is a lack of literature on core training programs and their effect on sport performance (Hibbs et al., 2008).

There is no single universally accepted definition of core stability (Kibler et al., 2006). In the simplest of terms, core stability is the combination of motor control and muscle capacity, which allows for maximization of athletic function (Kibler et al., 2006; Leetun et al., 2004). More specifically and for the purposes of this research, core stability will be defined as the ability of the trunk to maintain appropriate positioning over the pelvis, while transferring and controlling forces and motions directed towards the distal extremities, during athletic activities (Araujo et al., 2015; Bliss & Teeple, 2005; Bliven & Anderson, 2013; Hodges & Richardson, 1997; Kibler et al., 2006; Willson et al., 2005; Shirey et al., 2012). Core stability can only occur when the trunk is stabilized in all three planes of motion (Kibler et al., 2006). When this occurs appropriate positioning of the trunk over the pelvis maintains neutral spinal alignment. This alignment is a pain-free position halfway between lumbar flexion and extension that maximizes power and balance in athletics (Bliven & Anderson, 2013). Only small amounts of resistance occur in the neutral spine position. This is because the neutral spine position is one of high flexibility and laxity where internal stress and muscular effort are at a minimum (Panjabi, 1992b).

Core stability also controls for displacement by maintaining equilibrium following expected and unexpected perturbations, while maintaining structural integrity (Araujo et al., 2015; Bliven & Anderson, 2013; Kibler et al., 2006; Kulas et al., 2006; Willson et al., 2005; Zazulak et al., 2007). This stability is achieved through a balanced stiffening of all core musculature through instantaneous changes that are provided through the active, passive, and neural systems, in connection with the central nervous system (Bliven & Anderson, 2013; Hodges & Richardson, 1997; Panjabi, 1992a; Panjabi, 1992b). This stiffening of the core is critical in athletic events because it allows for the hips to be forcefully loaded. In sports, athletes do not flex their core to perform certain skills, they utilize force transfer (McGill, 2010). The information provided by neuromuscular control allows for appropriate muscle recruitment and firing, which produces core stability, thus allowing for control of mobility of the extremities (Bliven & Anderson, 2013; Zazulak et al., 2007). When muscles are recruited and fire properly, the trunk is able to produce, transfer, and control the forces that are directed towards the distal extremities much more effectively (Araujo et al., 2015; Kibler et al., 2006; McGill, 2010; Willson et al., 2005; Zazulak et al., 2007).

Muscles of the core cannot operate appropriately without core stability. The presence of core stability provides proximal stability for distal mobility (Araujo et al., 2015; Kibler et al., 2006; Shirey et al., 2012). In other words, motion at one segment will influence motion at the other segments (Warren et al., 2014). This is due to trunk muscle activity being initiated before lower extremity muscles in order to maintain normal spinal alignment, while creating a stable base for the extremities to move freely (Araujo et al., 2015; Warren et al., 2014; Willson et al., 2005). However, core stability would not be achieved without the assistance of anticipatory postural adjustments (APA's) (Kibler et al., 2006; Sharma, 2012). APA's position the body to withstand external perturbations to balance and precede the voluntary movements that occur (Friedli, Hallett, & Simon, 1984; Kibler et al., 2006). The concept of APA's indicates that initial posture counteracts the perturbations from voluntary motion (Zattara & Bouisset, 1988). This supports the proximal stability for distal mobility concept (Araujo et al., 2015; Kibler et al., 2006; Shirey et al., 2012). When APA's are not operating appropriately, decreased core stability results, which has been suggested to contribute to the development of lower extremity injuries, especially in the female population (Leetun et al., 2004). This is why research has predominantly been completed in this population.

The concept of proximal stability for distal mobility is displayed in research conducted by Hodges and Richardson (1997). Several individuals have identified that contractions of the rectus abdominis and erector spinae muscles occur prior to upper extremity contraction (Hodges & Richardson, 1997). Hodges & Richardson (1997) evaluated 15 participants to assess the muscle activation patterns of the abdominal muscles and the multifidus during hip flexion, hip abduction, and hip extension movements. It was identified through electromyographic (EMG) activity that the abdominals and multifidus were activated first during lower extremity movement, as compared to muscle activity in the limbs, regardless of the direction of movement (Hodges & Richardson, 1997; Willson et al., 2005). Only approximately 5-10% of maximum voluntary contraction in the multifidi and abdominal muscles is needed to stabilize the spinal column in daily activity and athletic activity (Kibler et al., 2006). Other research indicates that only 2-3% of maximum voluntary activity of the abdominal muscles is needed to provide adequate core stabilization during upright, unloaded tasks (Shirey et al., 2012). Additionally, other research states that for most daily activities, 10-15% of maximum abdominal contraction capability is sufficient for ensuring spinal stability (Vera-Garcia et al., 2007). These results indicate that trunk muscle activation assists with preparing the body for the sudden perturbation from the movements that will occur and allows for greater spinal stability (Faries & Greenwood, 2007; Hodges & Richardson, 1997).

Core stability is an imperative component of almost every gross motor activity (Willson et al., 2005). The core itself acts as a foundation for the kinetic chain by assisting with transferring the torque and momentum between the lower and upper extremities during the performance of gross motor skills (Bliven & Anderson, 2013; Kibler et al., 2006). While the involvement of core stability and its effect on the lower extremity is not well understood, research has been able to identify that appropriate core stability improves the function of the lower extremity during gross motor activities (Shirey et al., 2012). Shirey et al. (2012) conducted research that studied the activation of the core musculature and the resulting effects on hip and knee kinematics. In the study, all female participants were separated into two groups, low core and high core, based on their performance on the Sahrmann lower abdominal strength test, which is an assessment that identifies the level of abdominal activation through five different testing levels. The participants then performed a single leg squat under two different parameters, with intentional core activation and without intentional core activation (Shirey et al., 2012). Shirey et al. (2012) identified that during intentional core activation, smaller amounts of hip frontal plane displacement occurred on both right ($t(13) = -3.03$, $p =0.01$) and left ($t(13) = -3.04$, $p = 0.01$) hips. Additionally, there was a significant effect on knee range of motion with the intentional core activation displaying larger knee flexion angles ($55.78 \pm 6.55°$, $t(13) = 3.08$, $p = .009$) compared to the no core activation ($54.47 \pm 6.17°$) (Shirey et al., 2012). Though the procedure of Shirey et al. (2012) was not organized to assess the extent of core muscle recruitment in the participants during the study, the results that were identified indicates that intentional activation of the core musculature has a direct effect on lower extremity kinematics during a single leg squat in females.

The results indicate that there is a definite relationship between muscle activity in the core and lower extremity movement (Shirey et al., 2012; Willson et al., 2005). Therefore, the effect of muscle recruitment and activation patterns on the lower extremity warrants additional research.

Muscle Firing and Recruitment

Core muscle function can influence structures from the low back to the ankle (Willson et al., 2005). However, there has been minimal research completed that assesses the role of core muscle function in regards to movement patterns, especially when discussing the hips. Research has primarily focused on lower extremity muscle activation patterns in regards to lower extremity injuries. However, no connections have been made between muscle activation patterns and lower extremity kinematic movement patterns. Thus, no associations or assumptions can be made that would indicate that altered or decreased muscle activation patterns result in altered lower extremity movement tasks (Dwyer et al., 2010).

Much of literature utilizes strength assessment of the core as a tool to identify muscle recruitment and stability patterns (Araujo et al., 2015; Lehman, 2006; McGill, 2010; Nakagawa et al., 2015; Shirey et al., 2012; Stickler et al., 2015; Willson et al., 2006). However, performance of the core does not simply rely on muscular strength and muscular endurance, but also coordination, timing, and control of numerous structures (Warren et al., 2014). It has been identified that minimal levels of core contraction are needed to stabilize the spine (Hibbs et al., 2008; Lehman, 2006). Specifically, 1-3% of muscle contraction is needed to stabilize the spine, which supports the concept that muscular endurance may be more important than muscular strength (Hibbs et al., 2008;

Lederman, 2010; Lehman, 2006). Additionally, it has been found that trunk muscles are minimally activated during tasks of walking and standing. Specifically, during walking, the rectus abdominis has been found to average only 2% of maximal voluntary contraction during performance. The low level of activation of the rectus abdominis further supports the need to emphasize muscular endurance over strength and also suggests that strength losses are not a true problem in regards to spinal stabilization (Lederman, 2010). When a deficit in muscular capacity is identified, treatment protocols that focus on strengthening programs are most commonly implemented (Lederman, 2010; Warren et al., 2014). However, while the core must be strong and stable in all three planes in order to assist with facilitating the best performance in athletic events, strength is not always the issue when it comes to core stability (Bliven & Anderson, 2013; Leetun et al., 2004; McGill, 2010). Restoration of core motor control becomes more imperative compared to increasing core strength and endurance (Warren et al., 2014). If an individual has central nervous system integration dysfunction, increasing muscle strength is not appropriate training in order to develop proper neuromuscular control of the core (Warren et al., 2014; Wilkerson et al., 2012). Furthermore, if muscular strength is present without muscular control or endurance, an individual will most likely have insufficient core stability (McGill, 2010).

Core stability deficits may result from poor neuromuscular control and contribute to a decreased active neuromuscular control, decreased stability, poor motor recruitment throughout the kinetic chain, dysfunctional movement patterns, and uncontrolled joint displacement throughout the kinetic chain, especially in the lower extremity (Bliven & Anderson, 2013; Warren et al., 2014; Wilkerson et al., 2012; Zazulak et al., 2007).

Additionally, neuromuscular deficits and motor control deficiencies in the lumbopelvic hip complex have been associated with joint injuries that are distant from the affected musculature of the core, especially in the female population (Araujo et al., 2015; Chorba et al., 2010; Kang et al., 2014; Shirey et al., 2012; Stickler et al., 2015; Warren et al., 2014; Wilkerson et al., 2012). Specifically, since dynamic knee stability is achieved through neuromuscular control across the kinetic chain, proprioceptive deficits in the core musculature can have a direct effect on the biomechanics of the knee (Shirey et al., 2012; Zazulak et al., 2007). Since neuromuscular control deficits can cause unstable body positioning, abnormal knee biomechanics can result, specifically, increases in knee valgus, which can cause increased ligament strain (Zazulak et al., 2007). However, neuromuscular control deficits are able to be corrected by enhancing motor control through exercises that focus on joint stability, muscle contractions, balance, perturbation, plyometrics, and sport-specific skills (Hibbs et al., 2008; Warren et al., 2014). Motor control involves the generation and monitoring of movement commands by the central nervous system. The brain is a critical component of motor control due to its responsibility to create both anticipatory and reactive movements. Additionally, retraining the activation of deep trunk muscles assists with developing, unconsciously, a more functional motor pattern over a dysfunctional pattern (Warren et al., 2014). A more functional movement pattern results because every extremity movement is preceded by anticipatory core musculature contractions in order to create a stable base (Comerford & Mottram, 2006; Warren et al., 2014). When this anticipatory contraction occurs appropriately, movement patterns are performed successfully (Warren et al., 2014). Not only is a more appropriate motor pattern achieved, improvements in neural functioning also allow for more efficient recruitment patterns, faster central nervous system activation, improved synchronization of motor units, and lower inhibitory reflexes (Hibbs et al., 2008). However, it is important to recognize that control of the trunk musculature will alter during the performance of different activities. Therefore, there is not one universal exercise that will adjust and train the trunk to appropriately function during the performance of all activities (Lederman, 2010). While the benefits of neuromuscular training have been described, there have also been indications that common rehabilitation exercises for the trunk predispose individuals to additional injury due to high compressive and shear loads placed on the lumbar spine, resulting from excessive muscular co-contraction and extreme ranges of motion (Lehman, 2006). Ultimately, effective neuromuscular control of the core and lower extremity during athletic activities has been identified to assist with improving proper joint positioning, strength, and proprioception throughout the kinetic chain (Shirey et al., 2012).

While there is sound reasoning behind improving core neuromuscular, there are still opposing views to this concept. The common method to increase core stability is to teach individuals to actively engage the core musculature. While it was mentioned previously that improving core neuromuscular control allows for more functional movement patterns, there is the theory that teaching individuals to engage the core musculature can be seen as an abnormal, non-functional movement pattern. It is believed that this technique does not actually assist with enhancing the activation of trunk musculature (Lederman, 2010).

Lower extremity kinematics during closed-chain activities are influenced by the muscles of the trunk, hip, and knee (Willson et al., 2006). Research currently examines the correlation between diminished core stability and predisposition to injury, as well as training methods to reduce injury (Willson et al., 2005). Specifically, due to the high prevalence of knee injury rates in females compared to males, females have been the main population examined in this research (Araujo et al., 2015; Chorba et al., 2010; Kang et al., 2014; Pollard, Sigward, & Powers, 2007; Shirey et al., 2012; Stickler et al., 2015; Warren et al., 2014; Wilkerson et al., 2012; Willson et al., 2006). It has been identified that females place greater demands on the hip musculature during closed-chain activities, but lack the ability to appropriately recruit and generate muscular stiffness (Willson et al., 2006). Additionally, research completed on females indicates that deficient knee joint kinematics can be a result of poor proximal control and muscle activation (Leetun et al., 2004; Pollard et al., 2007). Specifically, improper hip muscle activation directly affects the force generation from the quadriceps and hamstring complexes, thus, suggesting that injury to the knee during athletic maneuvers may be directly related to poor core stability (Leetun et al., 2004). Therefore, researchers have become interested in analyzing the effect that core musculature may have on lower extremity function (Shirey et al., 2012; Willson et al., 2005). A prospective study by Leetun et al. (2004) explored this concept by examining the relationship between core stability measures between males and females, as well as between athletes who reported injuries during the season. The participants engaged in strength testing of the anterior, posterior, and lateral musculature associated with core stability by performing isometric testing for hip abduction, hip external rotation, and lumbar spine extension, as well as the side bridge test and the straight leg lowering test or flexor endurance test. Throughout the study, 35% of the females sustained a lower extremity injury, whereas only 22% of the males enrolled in the study sustained a lower extremity injury. In regards to strength, there was a significant difference identified between males and females for hip abduction and external rotation strength, as well as the side bridge test. Overall, the males in the study performed slightly better than the females in the abdominal muscle performance via the straight leg lowering test (males = 49 ± 10°, females = 59 ± 9°) and the flexor endurance test (males = 218 s ± 146, females = 204 s ± 149). Due to these differences in weaknesses between males and females, males are less likely to experience excessive movement in the hip or trunk in the transverse or frontal planes compared to females. This would account for the higher injury rates seen in female athletes. However, while the strength tests utilized in this study identify how much force can be generated in each muscle group, the results from this study do not reflect the muscle firing patterns during closed chain activities (Leetun et al., 2004). Additional research was also completed by Kulas et al. (2006) to investigate differences in abdominal muscle activation between males and females. A total of forty-two subjects (20 males and 22 females) participated in this study. EMG data for the transverse abdominis, rectus abdominis, and internal and external obliques, were collected while the participants performed a drop-landing (Kulas et al., 2006). Kulas et al. (2006) identified that males produced higher core activation in the transverse abdominis and internal oblique, compared to the rectus abdominis and external oblique. The females had significantly lower activation amplitudes in all muscle groups compared to the males. However, there was no gender difference regarding activation of the rectus abdominis and external oblique muscles. The results of this study cannot indicate if since females displayed no significant differences in abdominal activation, if females have an inability to control the trunk or if alternative muscle activation strategies were utilized compared to males (Kulas et al., 2006). However, the results of Kulas et al. (2006) do display that males activate the local abdominal muscles in preparation for athletic related tasks. The research by Kulas et al. (2006) and Leetun et al. (2004) assist with bridging the gap between core activation and lower extremity function. However, the need to investigate the effect of core musculature on trunk, hip, and knee kinematics in functional, closed chain activities is still warranted (Nakagawa et al., 2015).

Verbal Cues/Biofeedback

As was previously mentioned, studies have begun suggesting that all muscles contract together to appropriately stabilize the spine (Vera-Garcia et al., 2007). Additionally, the literature has suggested that initial core strengthening programs should focus on making individuals aware of motor patterns and learn how to individually recruit these muscles (i.e. neuromuscular control) through the use of biofeedback or verbal cues (Hibbs et al., 2008). Biofeedback can assist with instructing individuals on learning voluntary muscle control, while providing information on muscle activity during performance of the task (Kang, Kim, & Kim, 2014). Bressel et al. (2008) was one study conducted that assessed the influence of verbal instructions on free weight squats in 12 males under a total of four different conditions. These conditions included: standing on stable ground lifting 50% of the one repetition max, standing on a BOSU ball lifting 50% of the one repetition max, standing on stable ground lifting 75% of the one repetition max, and receiving verbal instructions to activate the trunk muscles while squatting with 50% of the one repetition max. EMG was collected for the rectus abdominis, external oblique, transversus abdominis/internal oblique, and erector spinae. It was identified that all of the abdominal muscles had more activity during the verbal instructions squats compared to the three other conditions. Specifically, the rectus abdominis had a 49% higher mean EMG activity when squatting following verbal instructions. The external oblique was 50 – 133% more active during the verbal conditions trial compared to the other three squatting trials. This increase in activity was also seen in the activity of the internal oblique and transverse abdominis, which had a 128 – 164% greater mean value of activity in the verbal instructions condition compared to the other squatting conditions. Finally, the erector spinae also displaced greater muscle activity, between 18 – 31%, but this increase was seen in the 75% one-repetition max condition. Ultimately, all of the abdominals were more active during squats with verbal instructions compared to the other three squatting conditions by anywhere between 39 – 167% (Bressel et al., 2008). Therefore, Bressel et al. (2008) identified that instructions on a method to activate the trunk muscles during a squat exercise leads to higher mean and peak EMG activity levels in the abdominal complex, which includes the rectus abdominis, external oblique, internal oblique, and transverse abdominis. Consequently, it can be interpreted that since co-contraction of the trunk muscles assists with spinal stability and stiffness, the use of verbal cues is a potentially useful strategy to assist with stimulating abdominal trunk muscle activity (Bressel et al., 2008). However, it is imperative to reiterate that there is a theory that increasing activation of the trunk predisposes individuals to injury due to increasing the compressive and shear loads placed on the lumbar spine, as well as instructing on ineffective sequencing of the abdominal muscles (Bressel et al., 2008; Lehman, 2006). At the time of this study, it is not believed that any research studies have been conducted analyzing lower extremity kinematics and kinetics, while utilizing biofeedback on the core musculature.

Additional studies examining EMG activity on abdominal bracing and abdominal hollowing have been performed. Maeo et al. (2013) examined the activity of trunk musculature during various static and dynamic exercises, with abdominal bracing and abdominal hollowing being two of the static exercises. For the current study, abdominal bracing was defined as maximally activating the abdominals without hollowing of the abdomen and abdominal hollowing was defined and instructed to patients as drawing the navel toward the spine (Maeo et al., 2013). Maeo et al. (2013) examined the muscle activity of the rectus abdominis, external oblique, internal oblique, and erector spinae during the performance of these static exercises. During the performance of abdominal bracing, the max EMG values for the muscles included 18% in rectus abdominis, 27% in the external oblique, 60% in the internal oblique, and 19% in the erector spinae. In regards to abdominal hollowing, the rectus abdominis, external oblique, and erector spinae all had lower maximum EMG activation levels when compared to the abdominal bracing maximum values. The internal oblique had slightly higher muscle activation during abdominal hollowing compared to abdominal bracing, however, the three other main muscles involved in core stability where higher, indicating that abdominal bracing is a more effective stabilization technique. While trunk muscles cannot be fully activated during abdominal bracing, it should be noted that abdominal bracing does allow for higher activity of the abdominal muscles, which contributes to appropriate stabilization of the spine (Maeo et al., 2013).

Finally, building off of Maeo et al. (2013), Vera-Garcia et al. (2006) also compared the effectiveness of abdominal bracing and abdominal hollowing on control of the spine. The same definitions from Maeo et al. (2013) in regards to abdominal bracing and abdominal hollowing were the same descriptions utilized in Vera-Garcia et al. (2006). EMG biofeedback pads were applied to the participants right internal oblique and right rectus abdominis during performance of two abdominal maneuvers. The participants were instructed to achieve three predetermined maximum voluntary isometric contractions of 10%, 15%, and 20% of internal oblique contraction. After collection of the maximum contractions, the participants underwent a no preactivation and activation condition of the abdominal muscles to external loads (Vera-Garcia et al., 2006). Vera-Garcia et al. (2006) identified that abdominal bracing allowed for higher levels of preactivation compared to abdominal hollowing trials. This indicates that abdominal bracing is a more effective technique in stabilizing the spine against external perturbations. Additionally, the use of abdominal bracing allows for trunk muscle co-contraction and reduced lumbar displacement, but does increase spinal compression, which was a concern mentioned previously. It was also identified that smaller amounts of compressive forces affected the spine under known perturbations that allowed for preactivation of the core musculature (Vera-Garcia et al., 2006). Therefore, in conclusion, Vera-Garcia et al. (2006) provides rationale for the use of abdominal bracing in exercise and its benefits in stabilizing the spine.

There are limited studies that have investigated the effect of intentional core activation on lower extremity kinematics and kinetics during the performance of a functional task (Shirey et al., 2012). Research that is present that supports a relationship between decreased core muscle capacity and lower extremity injury is predominantly retrospective or cross-sectional. This makes it difficult to identify if injuries were a cause or an effect of the decreased core muscle capacity (Willson et al., 2005). Additionally, during the time of this research, no literature that has investigated core muscle activation during a functional activity in a healthy, athletic population has been identified. While the literature indicates that muscular endurance may be a more imperative component of core stability than muscular strength, this concept is not well supported in the literature (Hibbs et al., 2008; Lederman, 2010; Lehman, 2006; Warren et al., 2014). This body of literature leads into the studies that have identified that bracing of the abdominals assist with providing stabilization to the spine (Bressel et al., 2009; Maeo et al., 2013; Vera-Garcia et al., 2007). Therefore, it is warranted to identify if this increase in core stabilization has an effect on lower extremity kinematics and kinetics in functional activities, thus indicating the purpose behind this study.

Chapter 3 - Methods

The purpose of this study is to compare hip and knee kinematics, as well as vGRF of the lower extremity during the performance of a squat without intentional core activation and a squat with intentional core activation. Participants completed both conditions of this study. As previously mentioned, research focused on the effect of core activation and its influence on lower extremity movement is limited and not well understood. Since an athlete is only as strong as their weakest link, which could be the core, research investigating the functioning of the core on lower extremity movement is indicated (Bliss & Teeple, 2005). Therefore, the investigation of intentional core activation and non-intentional core activation during a squat and its effect on lower extremity kinematics and kinetics is a valid analysis towards enhancing the body of literature of core activation.

Participants

Forty collegiate, male athletes at Barry University, an NCAA Division II institution were recruited for participation in this study. This sample size was determined through a power analysis with the alpha level being set at 0.05, a power of 0.80, and an effect size of 0.3. This power analysis was also based off of a correlation factor between .4 and .5 during repeated measures. The participants spanned a variety of athletic teams. Criteria for exclusion included individuals under the age of 18, current lower extremity injury, which included injury to the spine or abdomen, previous lower extremity injury that the participant is still currently rehabilitating, lower extremity surgery (<12 months post-operation), or inability to perform any portion of the testing protocols.

All participants were required to read and sign written informed consent forms approved by Barry University prior to involvement in this study. Approval for this study was granted from the Barry University Institutional Review Board.

Procedure

All data was collected in the Movement Analysis Center (MAC lab) at Barry University's Miami Shores, Florida campus. All data was collected in a single testing session. The participants performed a deep squat, squatting as low as the participant could while maintaining control. The deep squat was performed under two conditions, non-intentional core activation and intentional core activation. All participants performed the non-intentional core activation squatting trials first in order to prevent a learning curve in the intentional core activation trials. Five trials were performed for each condition, ensuring that quality trials were collected for each condition. A quality trial was determined as appropriately performing a squat in each condition with proper technique and no faltering throughout the entire movement pattern. Each trial was initiated by the researchers command to the participant to begin each movement.

There was no specific instruction on squat performance given to the participants prior to beginning the trials. However, a general overview was provided to each participant indicating that the participant was being requested to perform a squat, in order to prevent biomechanical flaws from occurring. During the non-intentional core activation squatting condition, participants were also instructed to place both hands on top of their head in order to replicate the performance of a normal back squat. In the intentional core activation squatting condition, the participants were instructed to hold a Swiss ball to their chest. The participant received instructions prior to performing the intentional core activation trials. The participants were instructed to simultaneously lower their hips slightly and squeeze the Swiss ball to their chest. During the squeeze and intentional core activation portion of the squat, the participant was informed if the desired firing level of 5 microvolts (uV's) or above was reached and the participant then completed the remainder of the squat (Khazan, 2013). This level was determined following discussion with Thought Technology, the manufacturer for the MyoTrac Infiniti.

Each participant performed a 10 minute bike warm-up and were allowed to perform any dynamic stretching that was desired prior to participating in the trials. This warm-up provided a sufficient amount of preparation time for the participants to become prepared to perform the squatting conditions. The participants wore skin-tight compression shorts, shirt, and were barefoot during all trials. In-between each trial, the participant had approximately one minute rest. This rest time was chosen in order to prevent fatigue from occurring. The participant had approximately five minutes of rest in-between the two conditions. This rest time was allocated due to the researcher requiring sufficient time in order to ensure that each trial was accurately and appropriately recorded. Each rest time length was monitored by the researcher to ensure consistent periods between trials.

Instrumentation

Kinematic.

Reflective markers were placed on the participant's lower extremity, following the Vicon Plug-In Gait standard lower body marker set. The size of the reflective markers was approximately 14 millimeters (mm) in diameter. The reflective markers were placed on the posterior superior iliac spine, lateral thigh, lateral knee joint line, lateral shank, lateral malleolus, calcaneus, and head of the 2nd metatarsal. The inter-anterior superior iliac spine (ASIS) distance between right and left ASIS's was calculated. The center between these distances was identified. From the center point, the ASIS marker was modified to be on the lateral iliac crest bilaterally. The placement of the reflective markers were positioned in the same locations on both the right and left sides of the body, with the left side slightly lower in order to assist with identification of markers during analysis. Anthropometric data was collected prior to performing static calibrations, according to Vicon Nexus 1.8.5 (Centennial, CO, USA) guidelines. Body mass, height, left leg length, right leg length, left and right knee width, and left and right ankle width was entered in as anthropometric data prior to data collection for each participant. Three dimensional data was gathered in Vicon Nexus 1.8.5 (Centennial, CO, USA) with eight Vantage high speed 240 Hertz (Hz) cameras. The data collected in Vicon Nexus 1.8.5 (Centennial, CO, USA) was smoothed utilizing a Woltring quantic spline, low-pass filter with a cutoff frequency of 6Hz.

Kinetic.

One AMTI (Watertown, MA) force plate was utilized to gather kinetic data. Force plate data was collected at 960Hz. Each force plate was zeroed prior to the participant assuming the squat stance on the force plate. The participant was instructed to stand in their squat stance as motionless as possible on the force plate for approximately three seconds so that the researcher could record the body weight. While in this position, tape was used to mark the foot positioning and angulation of the participant's squat stance to maintain consistency when performing each trial. When performing the squats in both conditions, the participant stood with each foot orientated approximately shoulder width apart, facing in the negative y direction of the MAC lab.

Biofeedback

The MyoTrac Infiniti (Warren, MI, USA) was utilized on the rectus abdominis during the intentional core activation squatting condition in order to identify the presence of a contraction in this muscle. Prior to application of the pads, the skin surface of the rectus abdominis was cleaned with alcohol pads. Two channels of electromyography were utilized on the rectus abdominis, which allowed for the use of four pads on the muscle. Two pads were placed on the right side of the rectus abdominis and two pads were placed on the left side of the rectus abdominis. The MyoTrac Infiniti was set to a level of 5 uV (Khazan, 2013). When this level was reached by the rectus abdominis during the intentional core activation condition, the participant was able to complete the remainder of the squat.

Data Processing

Averages of the five trials combined for each condition was utilized for analysis in this study. This allowed for an appropriate representation of the kinematic and kinetic data across a series of trials instead of determining the "best" trial that was performed. Peak knee and hip flexion average angles were assessed, as well as the average peak vGRF in each condition. Data was presented and analyzed with Vicon Polygon 3.5.2 (Centennial, CO, USA) software and Microsoft Excel (2013).

Statistical Analysis

vGRF's were normalized by body mass. A within-subjects multivariate analysis of variance (MANOVA) with repeated measures was used to assess the differences among joint angles and vGRF’s in the trials. The data was analyzed using SPSS (ver. 21, IBM corp., Chicago, IL, US) statistical software.

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Manuscript

The effect of core activation on lower extremity kinematics and kinetics

Core activation is an essential component of movement, especially in athletics, as it allows the body to easily distribute forces and control distal extremity movement. The purpose of this study was to identify the effects of core activation on hip and knee flexion, as well as vGRF. Results indicated no significant difference in hip and knee flexion or vGRF ($p > .05$) between non-intentional and intentional core activation conditions. With individual variability present in the results, the need to further examine the effect of core stability on distal extremity movement is warranted.

Key Words: Core Stability, Neuromuscular Control, Biomechanics, Kinetic Chain

Core stability has become a pivotal topic in regards to biomechanical function of the human body. Core stability, which is compromised of the lumbopelvic hip complex, is the ability of the body to control the position and the entire range of motion of a joint over the pelvis, in order to allow for optimal production, transfer, and control of forces and motions directed towards the distal extremities, while minimizing joint loads.[1-9] This stability can only occur when the trunk is stabilized in all three planes of motion.[6] When utilizing core stability, athletic function is maximized due to a neutral spine alignment, which allows for high flexibility, maintenance of equilibrium, and low amounts of internal stress, as well as low muscular effort.[1,3,5-6,9-14] The hips are then able to be forcefully loaded, which is imperative in sports since athletes do not flex their core to perform certain skills, but instead utilize force transfer.[15]

Muscles of the core cannot operate appropriately without core stability. The stability of the proximal structures is essential as this affects distal extremity mobility.[1,6-7,11,16] In other words, motion at one segment will influence motion at the other segments.[17] This is due to trunk muscle activity being initiated before lower extremity muscles in order to maintain normal spinal alignment, while creating a stable base for the extremities to move freely.[1,9,17] It was identified through electromyographic (EMG) activity that the abdominals and multifidus were activated first during lower extremity movement, as compared to muscle activity in the limbs, regardless of the direction of movement.[5,9] These results indicate that trunk muscle activation assists with preparing the body for the sudden perturbation from the movements that will occur and allows for greater spinal stability.[4-5] When muscles are recruited and fire properly, the trunk is able to produce, transfer, and control the forces that are directed towards the distal extremities much more effectively.[1,6,9,14-15] It is critical to recognize the impact that this stability has biomechanically on the body, both positively and negatively.[18] If the distal segments have too much or too little mobility, injury will likely occur.[2] This concept is imperative to clinical practice because it is relevant to recognize that all structures in the body are connected in various ways, both anatomically and biomechanically.[18]

The level of core contraction necessary to stabilize the spine varies throughout literature. Some research indicates a level as low as 1-3% of maximum muscle contraction is needed to stabilize the spine during upright, unloaded tasks, while others state approximately 5-10% of maximum voluntary contraction in the multifidi and abdominal muscles is needed to stabilize the spinal column in daily activity and athletic activity.[7,18-20] Even higher, 10-15% of maximum abdominal contraction capability has been identified as being sufficient for ensuring spinal stability.[21] In the absence of muscular contractions, spinal buckling occurs at 88 Newtons, which is approximately 20 pounds.[22] This load is significantly below loads that are common in athletics.[3] The spine can experience loads from 6,000 Newtons during activities of daily living to up to 18,000 Newtons during powerlifting.[23] These high spinal forces indicate the necessity for proper muscular contraction and control of the core and spine. When the trunk muscles co-contract, the spine is appropriately stabilized and spinal buckling is prevented.[20]

The deep squat is a common athletic maneuver that is associated with high power generation, as well as pelvic and core stability, with the rectus abdominis playing a critical role in stability.[20,24-25] Furthermore, the deep squat assesses neuromuscular control and full body mechanics, including mobility of the hips and knees, by placing the human body in a vulnerable position where functional stability and mobility must occur in order to keep proper positioning and alignment of the body.[16,26-29] The body is forced to work together as a kinetic chain by providing a stable base through core stability in order to transfer loads appropriately.[3,8,16-17] Additionally, this positioning allows for the extremities to move more accurately and with more force. The appropriate transfer of loads occurs as a result of co-activation of trunk muscles to provide stiffness, stability and compression of the spine.[24] If the body is loaded with improper technique or under poor biomechanics, an individual is placed at a higher risk of sustaining injury.[30]

The core itself acts as a foundation for the kinetic chain by assisting with transferring the torque and momentum between the lower and upper extremities during the performance of gross motor skills.[3,6] While the involvement of core stability and its effect on the lower extremity is not well understood, research has been able to identify that appropriate core stability improves the function of the lower extremity during gross motor activities.[7] Shirey et al.[7] identified a significant effect on knee range of motion with the use of intentional core activation displaying larger knee flexion angles (55.78 ± 6.55°, t(13) = 3.08, p = .009) compared to the no core activation condition (54.47 ± 6.17°).

These results indicate that intentional activation of the core musculature has a direct effect on lower extremity kinematics.

There are limited studies that have investigated the effect of intentional core activation on lower extremity kinematics and kinetics during the performance of a functional task.[7] Additionally, during the time of this research, no literature that has investigated core muscle activation during a functional activity in a healthy, athletic population has been identified. While the popularity of core functioning has increased, the influence that the core has on the lower extremity segments is not well understood. The purpose of this research study is to compare hip and knee kinematics, as well as vertical ground reaction force (vGRF) of the lower extremity during the performance of a squat without intentional core activation and a squat with intentional core activation. It was hypothesized that the intentional core activation trials would have higher degrees of peak knee flexion, smaller degrees of peak hip flexion, and lower vGRF when compared to the non-intentional core activation trials.

Methodology

Participants

Thirty-six collegiate, male athletes from an NCAA Division II institution were recruited for participation in this study. Thirty-five participants (mean age: 21.0 ± 1.9; mean height: 1822.3 ± 75.0 cm; mean weight: 80.9 ± 11.4 kg) were utilized in analysis after data screening and removing outliers from the sample group. The participants spanned a variety of athletic teams. Criteria for exclusion included individuals under the age of 18, current lower extremity injury, which included injury to the spine or abdomen, previous lower extremity injury that the participant is still currently rehabilitating, lower extremity surgery (<12 months post-operation), or inability to perform any portion of the testing protocols. All participants were informed of the procedures and risks of the study prior to partaking. Participants were required to read and sign written informed consent forms prior to involvement in the study. Approval for this study was granted from the University Institutional Review Board.

Procedure

All data was collected in a single testing session. The participants performed a deep squat, squatting as low as the participant could while maintaining control. The deep squat was performed under two conditions, non-intentional core activation and intentional core activation. All participants performed the non-intentional core activation squatting trials first in order to prevent a learning curve in the intentional core activation trials. Five trials were performed for each condition, ensuring that quality trials were collected for each condition. A quality trial was determined as appropriately performing a squat in each condition with proper technique and no faltering throughout the entire movement pattern.

No specific instruction on squat performance was given to the participants prior to beginning the trials. However, a general overview was provided to each participant indicating that the participant was being requested to perform a squat, in order to prevent biomechanical flaws from occurring. During the non-intentional core activation squatting condition, participants were also instructed to place both hands on top of their head in order to replicate the performance of a normal back squat. In the intentional core activation squatting condition, the participants were instructed to hold a Swiss ball to their chest and received instructions prior to performing these trials (Figure 1). The participants were instructed to simultaneously lower their hips slightly and squeeze the

Swiss ball to their chest (Figure 2). During the squeeze and intentional core activation portion of the squat, the participant was informed if the desired firing level of 5 microvolts (uV's) or above was reached and the participant then completed the remainder of the squat.[31] This level was determined following discussion with Thought Technology, the manufacturer for the MyoTrac Infiniti.

Each participant performed a 10 minute bike warm-up and were allowed to perform any dynamic stretching that was desired prior to participating in the trials. In-between each trial, the participant had approximately one minute rest. This rest time was chosen in order to prevent fatigue from occurring. The participant had approximately five minutes of rest in-between the two conditions. This rest time was allocated due to the researcher requiring sufficient time in order to ensure that each trial was accurately and appropriately recorded. Each rest time length was monitored by the researcher to ensure consistent periods between trials.

Instrumentation

To collect kinematic data, reflective markers (14 millimeters) were placed on the participant's lower extremity bilaterally, following the Vicon Plug-In Gait standard lower body marker set. The inter-anterior superior iliac spine distance was utilized in this set. Three dimensional data was gathered in Vicon Nexus 1.8.5 (Centennial, CO, USA) with seven Vantage high speed 240 Hertz (Hz) cameras. The data was smoothed utilizing a Woltring quantic spline, low-pass filter with a cutoff frequency of 6Hz.

One AMTI (960 Hz, Watertown, MA) force plate was utilized to gather kinetic data. Each force plate was zeroed prior to the participant assuming the squat stance on the force plate. The participant's body weight was collected on the force plate for use in analysis of the vGRF.

The MyoTrac Infiniti (Warren, MI, USA) was utilized on the rectus abdominis during the intentional core activation squatting condition in order to identify the presence of a contraction in this muscle. Prior to application of the pads, the skin surface of the rectus abdominis was cleaned with alcohol pads. Two channels of electromyography were utilized on the rectus abdominis, which allowed for the use of four pads on the muscle. Two pads were placed on the right side of the rectus abdominis and two pads were placed on the left side of the rectus abdominis (Figure 1). The MyoTrac Infiniti was set to a level of 5 uV.[31] When this level was reached by the rectus abdominis during the intentional core activation condition, the participant was able to complete the remainder of the squat.

Data Processing and Statistical Analysis

Averages of the five trials combined for each condition was utilized for analysis in this study. This allowed for an appropriate representation of the kinematic and kinetic data across a series of trials instead of determining the "best" trial that was performed. Peak knee and hip flexion average angles from the participant's dominant limb (right limb dominant: n = 28; left limb dominant: n = 7) were assessed, as well as the average peak vGRF in each condition. Data was analyzed with Microsoft Excel (2013).

vGRF's were normalized by body mass. A within-subjects multivariate analysis of variance (MANOVA) with repeated measures was used to assess the differences among joint angles and vGRF in the trials. The data was analyzed using SPSS (ver. 21, IBM corp., Chicago, IL, US) statistical software.

Results

A one-way MANOVA with repeated measures was performed and the multivariate effects revealed no significant effect. Therefore, the univariate main effects were assessed. It was identified that there was no significant difference between peak hip flexion angles (F(1, 34) = 2.63, $p > .05$, partial eta squared = .023, power = .139), peak knee flexion angles (F(1, 34) = .795, $p > .05$, partial eta squared = .072, power = .351), or peak vGRF (F(1, 34) = .012, $p >.05$, partial eta squared = .000, power = .051) between the non-intentional and intentional core activation conditions.

The means and standard deviations of the dependent variables are displayed in Table 1. The intentional core activation condition was characterized by a slight increase in hip and knee flexion. The vGRF mean was slightly lower in the intentional core activation condition when compared to the non-intentional core activation condition. Overall, as a result of intentional core activation, 54% of participants experienced a decrease in hip flexion, 60% demonstrated an increase in knee flexion, and 45% displayed a reduction in vGRF.

Discussion

The purpose of this study was to investigate the effect of core activation on flexion range of motion in the hip and knee, as well as vGRF. The assumption was that higher knee flexion angles and lower hip flexion angles and vGRF would be identified during the intentional core activation trials. The study has identified that no significant differences exist in peak knee flexion angles, peak hip flexion angles, or peak vGRF in the intentional core condition when compared to the non-intentional core condition. Although not significant, the hypotheses for this study regarding peak knee flexion and peak vGRF are still supported in the results.

Based on the results of this study, it is evident that there is a biomechanical change in the performance of a double leg squat when utilizing intentional core activation. Though not significant, the athlete's mechanics are changing and results in alterations in lower extremity kinematics and kinetics. The results of this study do not support those found by Shirey et al.[7] who found a significant effect that intentional core activation conditions displayed higher amounts of knee flexion when compared to non-intentional core activation conditions. Though not significant, the current studies results indicate an increase of 2° on average of knee flexion in the intentional core activation condition compared to the non-intentional core activation condition. Furthermore, a participant saw an increase of 29.03° while another saw a 12.69° reduction in knee flexion angles between the non-intentional and intentional core activation conditions. Coinciding with Shirey et al. (2012), the increase in knee flexion results are indicative of higher lower extremity functioning when performing a squatting maneuver in activities of daily living and sporting activities. While a 2° change in knee flexion may not be significant in a clinical setting, a change of 29° and 12° can be a crucial component of angular range of motion that is being affected in a patient.

In the present study, some participants experienced an increase in hip flexion, a decrease in hip flexion, or no change when comparing the intentional core activation range of motion to the non-intentional averages. Alterations in hip flexion included a 13.58° increase in hip flexion for one participant, as well as a 7.3° reduction in hip flexion in another between the two conditions. These two participants also experienced increases in knee flexion during the performance of the double leg squat between both conditions. The differences seen validate the presence of a biomechanical change through the use of intentional core activation. Again, while group means overshadow individual effects of the use of core activation and no notable change is identifiable in these averages, a change of 13° of hip flexion may be beneficial for a patient in achieving full restoration of angular range of motion and being able to return to normal activity.

No significant difference was identified in vGRF between the non-intentional and intentional core activation conditions. The effect size indicates extreme similarity between the two conditions. However, similar to the hip and knee flexion results, the larger effects of the vGRF are overshadowed by the means utilized in analysis. Certain individuals saw reductions in vGRF of 103.04 Newtons while others saw an increase in vGRF of 95.21 Newtons following the implementation of core activation in the squatting trials. Additionally, there were also individuals who experienced no dramatic change in vGRF between conditions, thus maintaining stability and appropriately transferring forces. These results could have been affected by the muscle firing capacity of the rectus abdominis and can validate the statistical analysis of this study. If an individual already had appropriate firing of the rectus abdominis, there would not be as much of a change identified when comparing the non-intentional core activation trials to the intentional core activation trials. Furthermore, if an appropriate amount of core activation and stability is already present, the implementation of additional core activation on top of this could take the individual to a level that they are unable to control. Therefore, this would explain the wide variation of vGRF, as well as angular range of motion, results seen in this study.

While this study does not directly correlate with functional activity, understanding the influence of core activation can be of benefit to clinicians when developing rehabilitation protocols and individualized exercises for patients. Core stability rehabilitation and core activation training are treatment methods utilized by clinicians, commonly in the treatment of low back pain. However, the results of this study demonstrate the potential need to incorporate core activation training and core stability rehabilitation into all phases of rehabilitation and for all extremity injuries, not just those affecting the back or core itself. The core is the basis for motion and is involved in almost all activities that involve the extremities. Prior to any movement in the extremities, the core must first be stabilized. The prime movers of the body, such as the hamstrings and quadriceps, as well as majority of the large, stabilizing muscles, such as the hip rotators and gluteal muscles, all originate from the core and trunk. Therefore, the core should be treated and evaluated during all evaluations of extremity injuries.[6]

The results of this study also demonstrate that core activation and stability is teachable. While the core may not be appropriately trained and may not fire during activity, the current study displays that the implementation of core activation results in altered kinematics and kinetics in the lower extremity. An inactive core can be related to a dormant piriformis or gluteus medius where rehabilitation is targeted towards reactivating the muscle and regaining neuromuscular control. These corrections are important to address in the core due to the fact that neuromuscular deficits and motor control deficiencies in the lumbopelvic hip complex have been associated with joint injuries that are distant from the affected musculature of the core.[1,7-8,17,32-34] Specifically, since dynamic knee stability is achieved through neuromuscular control across the kinetic chain, proprioceptive deficits in the core musculature can have a direct effect on the biomechanics of the knee, leading to an increase in injury.[7,14] This effect was demonstrated in the current study as individual participants saw identifiable increases or decreases in knee angular range of motion between non-intentional and intentional core activation conditions.

The main outcome of this study is to demonstrate the influential nature of core stabilization. While no significant effects were found, biomechanical differences were identified when looking at peak hip flexion, peak knee flexion, and peak vGRF between non-intentional and intentional core activation conditions. While larger individual effects disappear when examining means, these numbers still demonstrate alterations in biomechanics as a result of core activation. Furthermore, these results establish the proximal stability for distal mobility concept. Although some individuals saw positive changes in angular range of motion and vGRF, others also saw negative changes as a result of the implementation of core activation into a double leg squat. This stresses the importance of evaluating each patient individually and gathering a baseline of a patient's starting core activation and control, whether it be excellent or poor, prior to utilizing core stability rehabilitation or implementing the use of intentional core activation.

Limitations

One limitation of this study is that some participants were in-season during the time of data collection. In-season practices and training sessions can have an effect on an individual's mobility and soreness level, which would affect the performance of a squat. A second limitation is that the consistency of the core contraction was not assessed for once the activation level was met. In other words, once the participant reached the desired core activation level, the maintenance of the core contraction was not identified throughout the remaining portion of the squat trial. While it was assumed that participants contracted the rectus abdominis during all trials of the intentional core activation squat, it is understood that this may not have been the case. The participants may have initially reached the desired core activation level, but then discontinued the activation level while actually performing the squatting task. A third limitation to this study is that the speed and depth of the squat for both the intentional and the non-intentional core activation condition was not controlled for. During both conditions, the participants were instructed to squat how they normally would on their own. The speed of the movement pattern could have an effect on the amount of force distribution through the lower extremity. Additionally, the depth of the squat was varied throughout individual trials. An additional limitation was the use of one force plate. Using one force plate forced the squat to be performed in a narrow stance. The results of this study may be altered with a wider squat stance. A final limitation is that the actual numerical firing activity level was not assessed. The rectus abdominis was only assessed to identify if muscle activity was occurring up to the 5 uV's level. It may be relevant to identify if various electromyographic activation levels of the rectus abdominis have an effect on core stability, lower extremity kinematics, or lower extremity kinetics.

Clinical Implications

The present study demonstrates a biomechanically proven difference in the lower extremity as a result of intentional core activation. The results indicate that core activation is teachable, even if the core is not presently trained to activate on its own. Retraining the activation of deep trunk muscles assists with developing, unconsciously, a more functional motor pattern over a dysfunctional pattern through the use of motor control.[17] A more functional movement pattern results because every extremity movement is preceded by anticipatory core musculature contractions in order to create a stable base.[17,25] However, this functional movement pattern, associated with core activation and stability, does not have immediate results following its implementation. It requires repeated training in order to teach the body to properly fire the core and develop a functional movement pattern. Thus, its implementation into all phases of rehabilitation is critical. The use of intentional core activation during post-injury rehabilitation is can assist with improving proper joint positioning throughout the kinetic chain and achieving proper core stability. When rehabilitating the lower extremity post-injury, clinicians are predominantly focused on one specific joint. Clinicians get tunnel vision and often forget about the proximal stability for distal mobility concept until it is too late. With the body working as one kinetic chain, the core should be evaluated and implemented in all rehabilitation programs, in all phases, whether preventative or post-injury.

Future Research

Future research should examine the effect of proximal stability on distal mobility. There is a connection between core activation and its influence on lower extremity kinematics and kinetics. With the core being involved in all movements of the human body, functional tasks should be performed with the cores involvement being assessed for activation and contraction consistency, as well as the resulting effect on the extremities, dependent on the functional task being performed.

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APPENDIX A
INSTITUTIONAL REVIEW BOARD PROTOCOL FORM

Barry University

Research with Human Participants
Protocol Form

PROJECT INFORMATION

1. **Title of Project** The Effect of Core Activation on Lower Extremity Kinematics and Kinetics

2. **Principal Investigator** (please type or print)

Student Number or Faculty Number: 2985660
Name: Kristin A. Sitte
School – Department: Barry University School of Human Performance and Leisure Sciences – Athletic Training
Mailing Address: 11300 NE 2nd Ave. #611, Miami Shores, FL, 33161
Telephone Number: (414) 550 - 1259
E-Mail Address: Kristin.sitte@gmail.com; Kristin.sitte@mymail.barry.edu

*NOTE: You **WILL NOT** receive any notification regarding the status of your proposal unless accurate and complete contact information is provided at the time the proposal is submitted.*

3. **Faculty Sponsor** (If Applicable)

Name: Dr. Sue Shapiro
School – Department: Barry University School of Human Performance and Leisure Sciences – Athletic Training
Mailing Address: 11300 NE 2nd Ave, Miami Shores, FL, 33161
Telephone Number: 305-899-3574
E-Mail Address: sshapiro@barry.edu

Faculty Sponsor Signature:______________________________ Date: _____________

4. **Is an IRB Member on your Dissertation Committee? Yes _____ No: ___X____**

5. **Funding Agency or Research Sponsor**
Not Applicable

6. **Proposed Project Dates**
Start __02/01/2016_______
End __02/01/2017_______

Note: It is appropriate to begin your research project (i.e., the data collection process) only *after* you have been granted approval by this board. Proposals that list starting dates occurring before the date of submission will be returned without review. Please allow time for approval when determining your start date. It is best if the end date you choose is one year after the start date.

Please Provide the Information Requested Below

A. Project activity STATUS is: (Check one of the following three as appropriate.)

_X_ NEW PROJECT
___ PERIODIC REVIEW ON CONTINUING PROJECT
___ PROCEDURAL REVISION TO PREVIOUSLY APPROVED PROJECT
(Please indicate in the **PROTOCOL** section the way in which the project has been revised.

B. This project involves the use of an **INVESTIGATIONAL NEW DRUG (IND) OR AN APPROVED DRUG FOR AN UNAPPROVED USE** in or on human participants.
___ YES **_X_** NO
Drug name, IND number and company:
____

C. This project involves the use of an **INVESTIGATIONAL MEDICAL DEVICE (IMD)** or an **APPROVED MEDICAL DEVICE FOR AN UNAPPROVED USE.**
___ YES **_X_** NO

D. This project involves the use of **RADIATION** or **RADIOISOTOPES** in or on human participants.
___ YES **_X_** NO

E. This project involves the use of Barry University students as participants. (If any students are minors, please indicate this as well.)
_X_ YES Barry Students will be participants (Will minors be included? ___ YES **_X_** NO)
___ NO Barry Students will participate

F. **HUMAN PARTICIPANTS** from the following population(s) would be involved in this study:

___ Minors (under age 18)
___ Abortuses
___ Prisoners
___ Mentally Disabled
___ Other institutionalized persons (specify)
_X__Other (specify) Barry University Student-Athletes___

___ Fetuses
___ Pregnant Women
___ Mentally Retarded

G. Total Number of Participants to be Studied: ___40____

Description of Project

1. **Abstract** (200 words or less)

Athletes are only as strong as their weakest link. Core functioning has increasingly become more popular in an attempt at determining if the core is an influential component to other segments of the body. However, the influences of the core on lower body movement is not well understood. Therefore, the purpose of this study is to compare hip and knee kinematics, as well as ground reaction forces of the lower extremity during the performance of a squat without intentional-core activation and a squat with intentional-core activation. Peak hip flexion, peak knee flexion, and peak ground reaction forces will be calculated. The investigation will also involve assessment of the presence of core contraction during the intentional-core activation condition. Forty participants will be recruited for this study and will complete both conditions in one testing session. It is intended that the results of this study will assist in providing a more thorough understanding of movement patterns and muscle activation during performance in order to allow clinicians to properly develop rehabilitation protocols, based on joint motion and forces in the lower body during a squat.

2. Recruitment Procedures

Describe the selection of participants and methods of recruitment, including recruitment letter if applicable. (**NOTE**: If the investigator has access to participants by virtue of his or her position within the study setting, please provide a brief description of such access.)

This study will involve the Barry University athletic population. Male athletes will be attempted to be recruited. Research in this area has predominantly been examined in a female population and no research exclusively on males has been identified. The literature has indicated the need for research examining the male population individually. Additional inclusion criteria that will be utilized during the recruitment procedures of this study include being over the age of 18, having the ability to perform a squat, and being free from lower body, spinal, or abdominal injuries.

Once the Barry University Institutional Review Board has approved the use of human participants, flyers (see Appendix A) will be placed in the athletic training room, male athlete locker room, as well as on bulletin boards in the Sport and Exercise Science department. Participants will indicate their willingness to volunteer for the study by contacting the primary researcher. Once the participant contacts the primary researcher and has agreed to be part of the study, a convenient date and time will be decided for data collection. However, participants can still withdraw from the current study at any time.

3. Methods

Describe procedures to which humans will be subjected. Include a description of deceptive techniques, if used, and debriefing procedures to be used on completion of the study. Use additional pages, if necessary.

When the participant has contacted the primary researcher about their interest in participating in the study, a convenient date and time will be selected for data collection in the Movement Analysis Center at Barry University. All data will be collected during one testing session and will last approximately one hour. Participants will perform both conditions for this study.

Each participant will be required to wear skin-tight compression shorts and be barefoot during the duration of the study, in order to allow for collection of data. Upon the participant's arrival for their data collection, consent will be collected. Measurements of the participants left and right leg length, left and right knee width, and left and right ankle width with a measurement tool will be taken. Participants also will self-report their height and body mass to the researcher. Reflective markers will be applied to the participant's lower extremity. The locations of the reflective markers include the posterior superior iliac spine, lateral thigh, lateral knee joint line, lateral lower leg, lateral malleolus, calcaneus, and head of the 2nd metatarsal. The anterior superior iliac spine (ASIS) marker was modified to be located in the inter-ASIS location. This location requires measuring the distance between both the right and left ASIS, dividing by two, and then measuring the distance laterally from the right ASIS for the right marker and the left ASIS for the left marker. These markers will allow for the lower extremity to be recorded on infrared cameras. No identifying criteria are recorded during the capture.

After the placement of the markers, the participant will perform a ten minute stationary bike warm-up and perform any additional stretching that the individual desires, prior to performing any condition of the study. This warm-up will allow appropriate preparation time for the participants to become prepared to perform both squatting conditions involved in this study.

During this study, a squat will be performed under two different conditions. The first condition will require the participant to perform a normal squatting pattern. This condition is termed a non-intentional core activation condition. The second condition requires the participant to perform the same squatting pattern, but with the addition of intentional core activation, prior to completing the squatting pattern. During both conditions, a device entitled the MyoTrac Infiniti will be utilized to track muscle activity. Pads will be placed on the participant's rectus abdominis, the core muscle, to track contraction of the muscle during performance of the squatting pattern. A contraction level of five microvolts (uV's) is utilized as this level indicates appropriate muscle activity within the core.

The first skill that the participant will perform is a deep squat under a non-intentional core activation condition. No specific instructions on squat performance will be provided to the participants in order to ensure that their normal squatting pattern was utilized. However, a general overview of the squatting pattern will be provided to the participants to ensure that biomechanical flaws are avoided. The deep squat will be performed on a force plate, which will collect ground reaction force information. Each participant will perform five trials under this condition. The researcher will ensure that each trial is of quality. A quality trial is considered to be one where the squat was performed appropriately with proper technique and no faltering throughout the movement pattern.

The second condition that the participant will perform is a deep squat with intentional core activation. All participants will receive instructions on the performance of the intentional core activation squat prior to initiating the movement pattern themselves. During this condition, participants will hold a Swiss ball to their chest. Simultaneously, the participant will squeeze the Swiss ball and lower their hips, in order to allow for intentional core activation to occur before performing the remainder of the squat. The MyoTrac Infiniti will indicate when the core activation has reached a level of five uV's, based on activity in the muscle. When this threshold has been reached, the participant will be instructed to continue the remainder of the squat. Five quality trials will also be collected under this condition. This condition will also be performed on a force plate in order to collect ground reaction force data.

Through the data gathered, peak knee flexion, peak hip flexion, and peak ground reaction forces will be assessed for under both conditions.

Participants will be given rest time throughout their participation in this study. Specifically, participants will have one minute of rest time in-between each individual trial during both conditions. Additionally, the participant will have five minutes of rest in-between the two conditions. Completion of trials in both conditions will conclude the participant's involvement in the study.

4. Alternative Procedures

Describe alternatives available to participants. One alternative may be for the individual to withhold participation.

Participation will be strictly voluntary and subjects may decline to participate at any stage of the protocol. Participants are free to stop and/or withdraw from the testing at any time. Should they choose to not participate or withdraw completely from the study, there will be no adverse effects on them.

5. Benefits

Describe benefits to the individual and/or society.

There are no direct benefits to the individual participating in the study.

6. Risks

Describe risks to the participant and precautions that will be taken to minimize them. Include physical, psychological, and social risks.

There is minimal risk to the individual participating in the study. A non-weighted squat is a familiar and low-risk exercise for student-athletes. Inclusion criteria also states that they must be free from injury, thus further lowering the level of risk for participants. The exercise is nothing beyond what is usually expected of student-athletes on a regular strength and conditioning training session.

7. Anonymity/Confidentiality

Describe methods to be used to ensure the confidentiality of data obtained.

The informed consent forms will be stored in a locked filing cabinet in the Faculty Advisor's (Dr. Sue Shapiro) office. The data collected for this study will be collected using the Vicon system and will be automatically uploaded to the primary researcher's password protected login. The primary researcher will be the only individual who has direct access to the data collected. The primary researcher will be the only individual in the laboratory when data collection takes place.

Each participant will be assigned a number (e.g., participant #1), which will correspond to their consent form. Only the primary researcher will have access to the assigned numbers linking participants consent forms and their data. This information will also be kept on the primary researchers password protected computer. If any published results occur from this study, participants will not be discussed individually, but instead will be discussed collectively as group averages. No participants will be referenced by name in any published documents. All data will be maintained for a minimum of five years upon completion of the study and will be kept indefinitely.

8. Consent

Attach a copy of the consent form(s) to be signed by the participant and/or any statements to be read to the participant or informational letter to be directed to the participant. **(A copy of the consent form should be offered to each participant.)** If this is an anonymous study, attach a cover letter in place of a consent form.

Please see Appendix B.

9. Certification

I certify that the protocol and method of obtaining informed consent as approved by the Institutional Review Board (IRB) will be followed during the period covered by this research project. Any future changes will be submitted to IRB review and approval prior to implementation. I will prepare a summary of the project results annually, to include identification of adverse effects occurring to human participants in this study. I have consulted with faculty/administrators of any department or program which is to be the subject of research.

__________________________________ ____________________

Principal Investigator *Date*

***Reminder*: Be sure to submit sixteen (16) individually collated and bound (i.e. stapled or paper clipped) copies of this form with your application.**

*NOTE: Your proposal **<u>WILL NOT</u>** be reviewed until the completed packet is received in its entirety.*

APPENDIX B
INSTITUTIONAL REVIEW BOARD INFORMED CONSENT FORM

Barry University
Informed Consent Form

Your participation in a research project is requested. The title of the study is The Effect of Core Activation on Lower Extremity Kinematics and Kinetics. The research is being conducted by Kristin A. Sitte, ATC, LAT, a student in the Sport and Exercise Science department at Barry University, and is seeking information that will be useful in the field of Athletic Training. The aims of the research are to identify biomechanical differences between intentional and non-intentional core activation during a deep squat. In accordance with these aims, the following procedures will be used: measurement of lower extremity leg length, knee width, and ankle width, identification of participants height and weight, placement of reflective markers on lower extremity, performance of a deep squat in Barry University's Movement Analysis Center, and capturing of deep squat via infrared cameras in order to create a three-dimensional figure. The infrared cameras only display lower extremity movement patterns and no identifying criteria can be gathered from this data. In order to participate in this research study, inclusion criteria involves being over the age of 18, being a current student-athlete, have the ability to perform a squat, and are free of lower body, spinal, or abdominal injuries.

If you decide to participate in this research, you will be asked to contribute approximately one hour of your time. During this time, a ten-minute warm-up will be performed, as well as ten trials of a deep squat. For the duration of data collection, the participant must wear tight-fitting clothing and either remove the shirt or tie the shirt above the hip level so that the markers can be seen on the infrared cameras. Five trials will be performed under the non-intentional core activation squat condition and five trials will be performed under the intentional core activation squat condition. During both trials, a biofeedback machine will be placed on the rectus abdominis muscles, in order to track activity.

Your consent to be a research participant is strictly voluntary and should you decline to participate or should you choose to drop out at any time during the study, there will be no adverse effects on you. There is minimal risk to the individual participating in the study. A non-weighted squat is a familiar and low-risk exercise for student-athletes. Inclusion criteria also states that you must be free from injury, thus further lowering the level of risk for you. The exercise is nothing beyond what is usually expected of you on a regular strength and conditioning training session.

At the present time, while there are no direct benefits to you, your participation in this study may assist in the understanding of human hip and knee movement when performing a deep squat under normal conditions, as well as during intentional core activation. As a participant, there is the potential for inquiring about your individual hip and knee flexion angles, as well as your ground reaction forces, during a squat performance, if this information is of interest to you personally.

Your informed consent form will be stored in a locked filing cabinet in the Faculty Advisor's (Dr. Sue Shapiro) office. The data collected for this study will be collected using the Vicon system and will be automatically uploaded to the primary researcher's password protected login. The primary researcher will be the only individual who has direct access to the data collected. The primary researcher will be the only individual in the laboratory when data collection takes place.

You will be assigned a number (e.g., participant #1), which will correspond to your consent form. Only the principle investigator will have access to the assigned numbers linking your consent forms and your data. This information will also be kept on the primary investigators password protected computer. If any published results occur from this study, you will not be discussed individually, but instead will be discussed collectively as group averages. You will not be referenced by name in any published documents. All data will be maintained for a minimum of five years upon completion of the study and will be kept indefinitely.

If you have any questions or concerns regarding the study or your participation in the study, you may contact me, Kristin A. Sitte ATC, LAT, at (414) 550-1259, or Kristin.sitte@gmail.com, my supervisor, Dr. Sue Shapiro, at (305) 899-3574 or via email at SShapiro@barry.edu, or the Institutional Review Board point of contact, Barbara Cook, at (305) 899-3020, or via email at bcook@barry.edu. If you are satisfied with the information provided and are willing to participate in this research, please signify your consent by signing this consent form.

Voluntary Consent

I acknowledge that I have been informed of the nature and purposes of this experiment by Kristin A. Sitte, ATC, LAT and that I have read and understand the information presented above, and that I have received a copy of this form for my records. I give my voluntary consent to participate in this experiment.

______________________ __________

Signature of Participant *Date*

______________________ __________ ______________________ ____

Researcher *Date* *Witness* *Date*

(Witness signature is required only if research involves pregnant women, children, other vulnerable populations, or if more than minimal risk is present.)

APPENDIX C
RECRUITMENT FLYER

Barry University

SQUATTING & CORE MECHANICS

Do you have a poor squat?

You may be eligible to participate in a research study if you:

- Are currently a Barry University student-athlete
- Can perform a squat
- Are free of lower body, spinal, or abdominal injuries
- Can meet for at least one hour in the Movement Analysis Center in HPLS 139

If you are interested and/or you have any questions regarding the study please contact, Kristin Sitte, cell: (414) 550 -1259, email: Kristin.sitte@mymail.barry.edu, Dr. Sue Shapiro, at sshapiro@barry.edu, or the Institutional Review Board point of contact, Barbara Cook, at (305) 899-3020, or bcook@barry.edu.

APPENDIX D
MANUSCRIPT TABLES AND FIGURES

Dependent Variable	Non-Intentional Core Activation	Intentional Core Activation
Peak Hip Flexion	96.57 (10.80)	96.91 (11.32)
Peak Knee Flexion	102.43 (10.68)	104.53 (14.21)
Peak vGRF	219.77 (75.91)	219.03 (73.42)

Table 1. Means and standard deviations

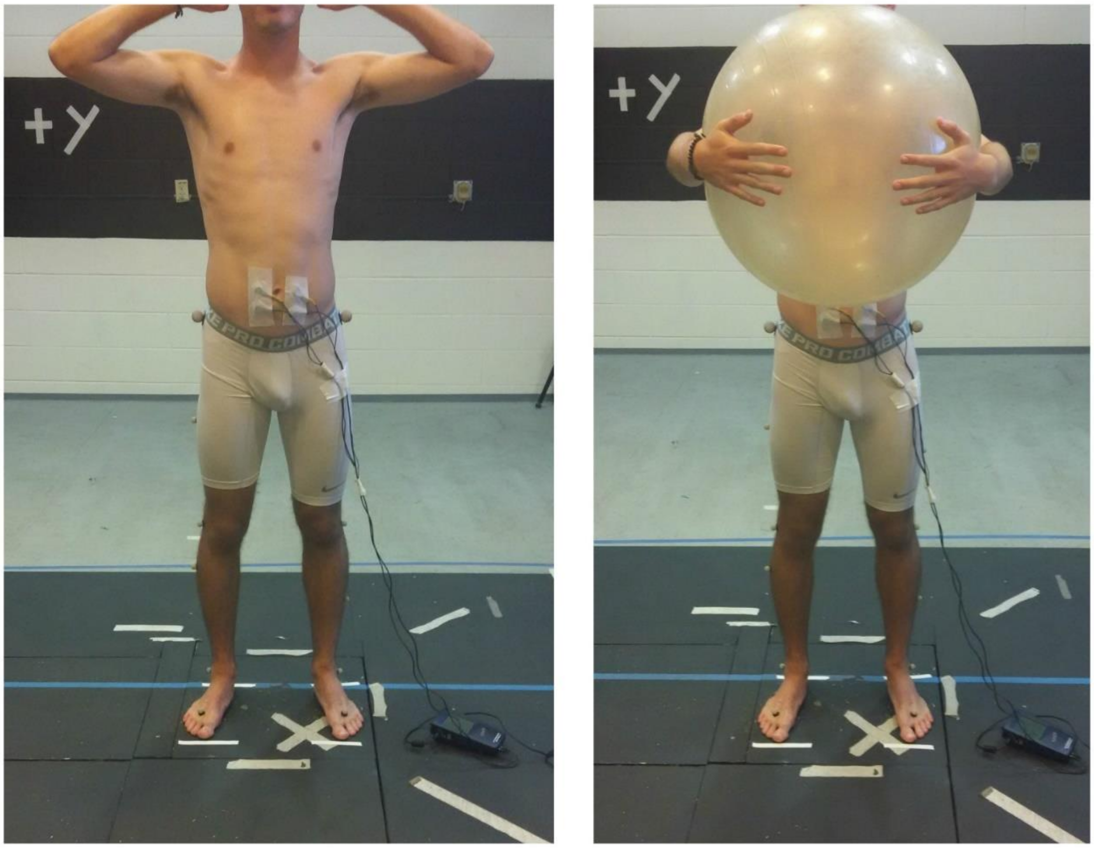

Figure 1. Left: Non-intentional core activation set-up. Right: Intentional core activation set-up.

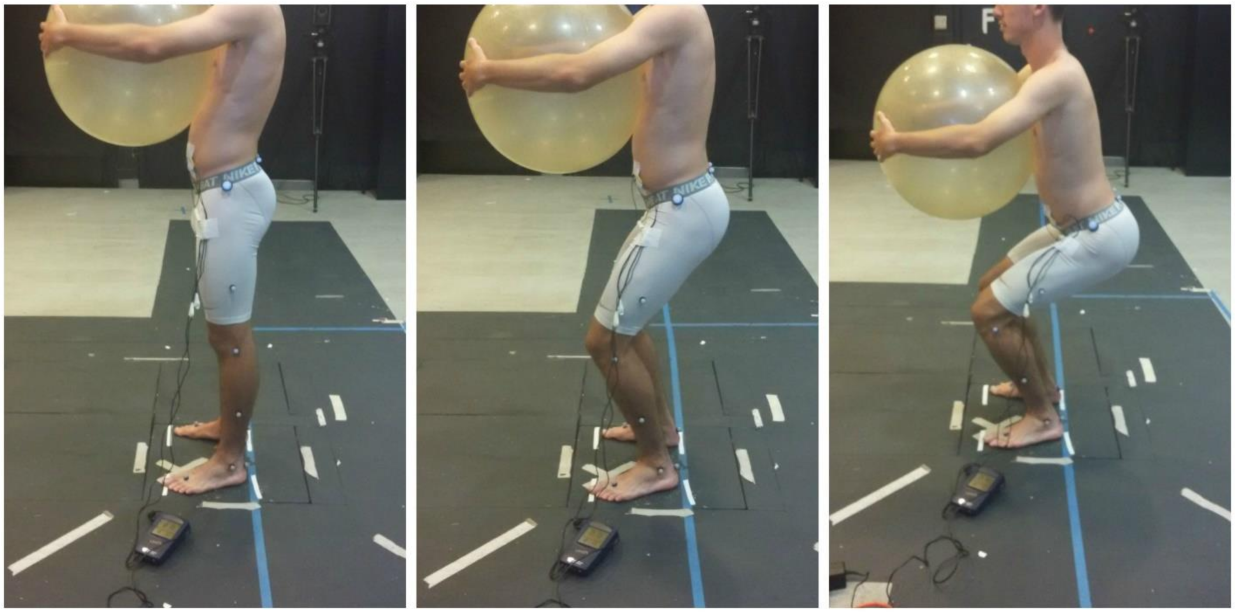

Figure 2. Left: Intentional core activation starting position. Center: Simultaneous ball squeeze and hip lower. Right: Performance of remaining squat pattern.