The Effects of a One-Time Core Stability Intervention Protocol on Anterior Pelvic Tilt During a Dynamic Overhead Squat

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Abstract:

The Effects of a One-Time Core Stability Intervention Protocol on Anterior Pelvic Tilt During a Dynamic Overhead Squat Assessment

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Context: Injury at the lower extremity is related to core stability as well as Lumbo-Pelvic-Hip-Complex and lower extremity kinematics, including increased anterior pelvic tilt, trunk flexion, hip adduction, hip internal rotation, and knee abduction. Increases in these kinematic variables are known to occur in tandem with Lumbar Lordosis, resultant Lower Back Pain (LBP), and other injury at the lower extremity--particularly at the knee by increasing risk for ACL sprain. There is no clear empirical research drawing a cause and effect relationship between a core stability program and altered lower extremity kinematics, even though there is ample anecdotal evidence to speak to the connection. Objective: To determine if a core training protocol has an impact on anterior pelvic tilt, trunk flexion, hip internal rotation, hip adduction, and knee abduction during an Overhead Squat Assessment and if such a Core Stability Intervention Protocol (CSIP) could be an effective clinical tool in the treatment of LBP as well as other implications it might have for injury reduction at the lower extremity. Design: Paired samples t-test. Setting: Research laboratory. Participants: Thirty-eight (38) healthy participants (20 females, 18 males) assigned to the same treatment protocol (n = 38; age = 21.13 +/- 1.06 years; height = 171.97 +/- 8.77 cm; mass = 68.56 +/- 11.25 kg). Intervention: All participants performed 5 Overhead Squats, the CSIP, and then repeated the 5 Overhead Squats again. The Core Stability Intervention Protocol included eight (8) exercises with four (4) performed in supine and four (4) performed in prone position, each for 2 sets of 5 repetitions. The exercises were focused on engaging the Transverse Abdominis while also utilizing the extensors, flexors, and rotators of the hip, trunk, and neck. Main Outcome Measures: The Motion Monitor (MM) Flock of Birds electromagnetic motion analysis system was used to quantify joint kinematics through joint displacement (DSP) values for (Anterior Pelvic Tilt, Trunk Flexion, Hip Internal Rotation, Hip Adduction, Knee Abduction) during the squat tasks. All measures were performed pre- and post- Intervention. Five (5) paired samples t-tests were performed with a 95% confidence interval (P = .05). Results: No significant results were found with Anterior Pelvic Tilt (t = 0.754, P = 0.455, pre-test = 24.89 +/- 6.63, post-test = 24.33 +/- 6.85) Hip Internal Rotation (t = 1.789, P = 0.082, pre-test = 11.36 +/- 9.53, post-test = 9.69 +/- 7.90), or Knee Abduction (t = 1.014, P = 0.317, pre-test = -0.95 +/- 3.21, post-test = -1.37 +/- 2.99). Significant results were found with Trunk Flexion (t = 2.81, P = 0.008, pre-test = 29.99 +/- 11.77, post-test = 27.6 +/- 10.76) and Hip Adduction (t= 10.951, P < 0.001, pre-test = 1.12 +/- 3.0, post-test = -7.92 +/- 4.82). Trunk Flexion had weak clinical significance (d = 0.21) and Hip Adduction was clinically significant (d = 2.31). Conclusions: While there was no significant change in Anterior Pelvic Tilt, Hip Internal Rotation, or Knee Abduction, there was significantly less Trunk Flexion and Hip Adduction when comparing pre to post treatment displacement means. Trunk Flexion did not show enough of a change to be clinically significant, while the decrease in Hip Adduction was clinically significant. This has huge implications for rehabilitation programs with the goal of trying to lower hip adduction which is correlated to an increased risk of injury at the lower extremity, particularly at the knee with the ACL injury. There is now empirical evidence to say that the CSIP works as an intervention in altering lower extremity kinematics in the laboratory setting. Future research should examine the real world clinical effect of a multiple-session, longer term CSIP on more involved dynamic movements (jump-landing, cutting, running, etc.).
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Chapter I

Introduction

Lower Back Pain is a prevalent on-going issue in the developed world with over eighty-four percent of adults having reported symptoms in the United States alone (Deyo and Tsui-Wu, 1976). The condition of Lower Back Pain (LBP) can be very detrimental to productivity in the work place, activities of daily living, and overall quality of life. Lower Back Pain is a pervasive condition that is predictive of many other orthopedic injuries and muscular imbalances. Some etiologies of Lower Back Pain may include vertebral disc pathology, spinal column arthropathy, facet joint dysfunction, osteophytes encumbering nerves, spondylolisthesis, and spinal stenosis (Corliss et al., 2013). Aside from these chronic, nagging issues, the condition of Lower Back Pain can be very financially taxing in consideration of surgical costs, rehabilitation services, and prophylactic measures which range from hundreds to tens of thousands of dollars in treatment costs.

The condition of Lower Back Pain is an issue that has many derivations. They may range from improper ergonomics in the work place, improper mechanisms when lifting heavy objects, genetic abnormalities in boney alignment, changes in workout intensity and regimen, poor posture, excessive body weight, and physical inactivity. With so many factors accounting for Lower Back Pain, there is an obvious need for a solution that is not only effective but economical and long-term.

One of the main causes of Lower Back Pain with implications specific to both sedentary and athletic populations is that of Anterior Pelvic Tilt (APT) (Sahrmann, 2002; Van Dillen et al., 2007; Van Dillen et al., 2009; Van Dillen and Sahrmann, 2006). Anterior Pelvic Tilt can be
caused by muscular imbalances from physical inactivity and ergonomics associated with the sedentary work place. Improperly designed physical training regimens with overemphasis on strengthening and neglect of stretching can also cause muscular imbalances that aggravate Anterior Pelvic Tilt (Scholtes et al., 2009). The Pelvic Tilt Angle is more specifically described as the angle made by an imaginary horizontal plane and a ray connecting the Anterior Superior Iliac Spine and the Posterior Superior Iliac Spine, which are bony projections on the Iliac bone of the pelvis. When this angle is greater than fifteen degrees, then the individual is qualified as having a pelvis with Anterior Pelvic Tilt (Preece et al., 2008). This improperly tilted pelvis can cause Lower Back Pain by putting irregular pressure on the spinal column with the anterior portion put into excessive distraction and the posterior portion put into excessive compression (Hansraj et al., 2001). To go along with the altered pressure on the spinal column, many movement patterns in the lower extremity including increased trunk flexion, increased hip adduction, increased hip internal rotation, and increased knee valgum have been noted to occur in tandem with Anterior Pelvic Tilt, Lumbar Lordosis, and Lower Back Pain (Sahrmann, 2002). Not only is Anterior Pelvic Tilt associated with Lower Back Pain, but we see some concurrent kinematic deviations from the norm in the lower extremity with APT during dynamic movement. These include increased femoral internal rotation (Duval et al., 2010; Hruska, 1998; Ireland, 2002); hip adduction, (Duval, Lam, & Sanderson, 2010; Hruska, 1998; Ireland, 2002), and knee valgus (Padua et al., 2013, Neumann, 2010). All of these kinematic deviations increase the individual’s overall risk for injury but can be altered by fixing the instigating cause of excessive Anterior Pelvic Tilt, which is where the importance of a core protocol to increase neuromuscular control comes into play.

The emphasis of this study will not be on changes in boney alignment, which would require much more invasive procedures, but on changing pelvic tilt angle via changes in muscular
activation and neuromuscular control. As we have seen, Anterior Pelvic Tilt is influenced by poor core stabilization. Such poor core stabilization can take the form of muscular imbalances arising at the Lumbo-Pelvic-Hip Complex, of which a commonly seen example is that of Lower Cross Syndrome. The muscular imbalance condition of Lower Cross Syndrome consists of weakened or elongated hip extensors and abdominals, accompanied by overly strengthened or tightened hip flexors and back extensors (Cibulka et al., 1986; Croisier, 2004; Comerford and Mottram, 2001). More precisely, the underactive core musculature will be activated in static position and in dynamic activity during the Core Stability Intervention Protocol. In this study, significant findings from changes in Anterior Pelvic Tilt will indicate that core stabilization may influence Anterior Pelvic Tilt and have implications for the eradication of some Lower Back Pain conditions. While there has been anecdotal evidence to back up the importance of a Core Stability Program in the rehab setting, there has been little empirical evidence to say how core stability affects Anterior Pelvic Tilt and subsequently Lower Back Pain. This study endeavors to find empirical evidence in support of or in contrast to the efficacy of a one-time Core Stability Intervention Protocol in decreasing Anterior Pelvic Tilt or an individual during a dynamic Overhead Squat Assessment.
Statement of the problem

Regardless of the pathological population, more and more individuals are suffering from a multitude of conditions stemming from excessive anterior pelvic tilt. Anterior pelvic tilt can be assessed clinically by palpation of the ASIS and PSIS of one side of an individual and comparing that to a horizontal plane of 180 degrees. Said angle is compared to normative values which include the numerical limits of and fall into the category of anterior pelvic tilt if the angle is larger than 15 degrees and enter the category of posterior pelvic tilt if that angle is fewer than 8 degrees. Problems common to anterior pelvic tilt include chronic lower back pain, athletic pubalgia, spondylosis, spondylolisthesis, foot pronation, patellar tendonitis, and general muscle soreness and tightness among other conditions. In the clinical realm of athletic training, core stability routines including spinal stabilization and segmental stabilization have been utilized in an attempt to fix the altered length-tension relationships, force couples, and arthokinematics that arise at the hip, trunk, and leg with anterior pelvic tilt. Spinal stabilization is helpful in the eradication of chronic lower back pain (LBP) in athletic populations and sedentary individuals with a prevalence of 70% of all patients suffering from LBP (Corliss et al., 2013). Low back pain is a commonly occurring condition with Lumbar Lordosis during static and dynamic activity (Deyo and Tsui-Wu, 1976). Lumbar Lordosis can result from muscular imbalances including tight/overactive back extensors and hip flexors, along with loose/underactive trunk flexors and hip extensors that fit under the commonly used titles of “lower cross syndrome” and “cross pelvic syndrome.” Lack of neuromuscular control and core activation are co-existing conditions with Lumbar Lordosis and LBP (Scholtes et al., 2009). An easy to perform, time-efficient, and effective core stability program will have important implications for both sedentary and athletic populations.
Hypotheses

- Research Question: Will individuals showing anterior pelvic tilt during a squat continue to exhibit signs after implementation of a one-time core stability training protocol?

-Hypothesis 1: Anterior Pelvic tilt will be decreased during squat after the core stability training protocol is implemented.

-Hypothesis 2: Trunk flexion will decrease relative to the individual’s pelvis after the core stability training protocol is implemented.

-Hypothesis 3: Hip adductor displacement will decrease relative to the individual’s pelvis after the core stability training protocol is implemented.

-Hypothesis 4: Hip internal rotation displacement will decrease relative to individual’s pelvis after the core stability training protocol is implemented.

-Hypothesis 5: Knee valgus and varus displacement will decrease relative to individual’s pelvic after the core stability training protocol is implemented.
**Definition of terms**

-Anterior Pelvic Tilt (APT): angle measure from ASIS to PSIS compared to horizontal plane w/ neutral averaging around 10-13 degrees, anterior pelvic tilt measuring >15 degrees, and posterior pelvic tilt measuring <8 degrees

-Abdominal Drawing In Maneuver (ADIM): isometric contraction of the Transverse Abdominus that includes verbal cueing with phrases such as “drawing your belly button in to meet back bone” and “trying to fit into tight pair of jeans” while holding this position for 3-5 seconds, relaxing for another 3-5 seconds and repeating the series 10 times.

-Overhead Squat Assessment (OSA): test to measure biomechanical movement patterns in which the subject holds their fully extended arms over their head (180 degrees shoulder abduction) with feet facing straight forward and slightly farther than shoulder width apart. Subject squats into no more than 90 degrees of knee flexion 5 times while to clinician evaluates their technique by looking for pronation and ER at the foot, varus/valgus at the knee, excessive anterior pelvic tilt at the hip, excessive trunk flexion, arms falling forward into flexion compared to start position.

-Peak Angle: largest difference measured in the angle between ASIS and PSIS compared to a horizontal plane that the subject will go into during an Overhead Squat; different for each individual

-Starting Angle: starting value for each individual as measured by the difference of the angle between ASIS and PSIS compared to a horizontal prior to an Overhead Squat
-Descending Phase: the phase in which an individual starts their squat and whenever they go into maximum flexion at the knee (no more than 90 degrees). Does not include the individual returning to the start position.
Chapter 2

Literature Review

The “core” is the origin of movement and the center of gravity from which the extremities can operate efficiently and precisely and is essential to maintaining lifelong wellness and improved Activities of Daily Living. An all-encompassing definition of the Lumbo-Pelvic-Hip Complex, used interchangeably with the term “core,” takes into consideration the hip, pelvis, and trunk as they work together to stabilize statically and dynamically. This core or LPHC will be described as “the musculature that surrounds the lumbopelvic region and includes the abdominals anteriorly, the paraspinals and gluteals posteriorly, the pelvic floor musculature inferiorly, the hip abductors and rotators laterally, and diaphragm superiorly” (Bliss & Teeple, 2005). A properly balanced core (specifically consisting of the Transverse Abdominus, Multifidus, External Obliques, and Pelvic Floor muscles) has appropriate length-tension relationships of originating and inserting musculature, force-couple relationships of these muscles, and efficiency in resulting arthokinematics of the Lumbo-Pelvic-Hip Complex and kinetic chain (Hruska, 1998). Spinal stabilization provided by a core stability program, helps the patient effectively use neuro-muscular control, muscular strength, power, and endurance of their extremities while minimizing risk of injury (Corliss et al., 2013).

Spinal stabilization is helpful in the eradication of chronic lower back pain (LBP) in athletic populations and sedentary individuals, with a prevalence of 84% of all patients suffering from LBP (Corliss et al., 2013). Low back pain is a commonly occurring condition with Lumber Lordosis during static and dynamic activity (Deyo and Tsui-Wu, 1976). Lumbar Lordosis can result from muscular imbalances including tight/overactive back extensors and hip flexors, along
with loose/underactive trunk flexors and hip extensors that fit under the commonly used titles of “lower cross syndrome” and “cross pelvic syndrome.” Lack of neuromuscular control and core activation are co-existing conditions with Lumbar Lordosis and LBP (Scholtes et al., 2009). One of the main muscles of focus in this study’s core stability training protocol is the Transverse Abdominus, which can be palpated about an inch medially and superiorly from the ASIS. Research has shown that the Multifidi-- another muscle of interest in this study-- coincide in activation with the TA and function to create a girdle of muscular support that works in a feed forward mechanism to stabilize the spine in anticipation of extremity movement (Besier et al., 2001). Individuals with LBP have been shown to have poor muscular endurance of the core stabilizers resulting from a lack of neuromuscular control (Ebenbichler et al., 2001), but the implementation of the drawing-in maneuver before core training has shown to significantly increase EMG activity and pelvic stabilization (Snijders et al., 1998). Stability in the lumbosacral region results from cocontracting the TA and Multifidus (Richardson et al., 2002), which makes learning the technique essential to pain reduction and injury prevention.

Hip, lumbar, and pelvic movements happen concurrently in a combination of the three planes including Sagittal (Flexion/Extension), Frontal (Abduction/Adduction), and Transverse (Internal Rotation/External Rotation). When certain musculature is inhibited, a cycle of altered joint kinematics, or arthrokinematics, is initiated with altered length tension relationships in the muscle surrounding the joint. Altered force couples then result from these changed length tension relationships and in turn cause different movement patterns at the joint, also known as altered arthokinematics. These altered arthokinematics put new tension and compression on joint capsules and inserting musculature, putting these structures into precarious positions and loads during dynamic movement. When all of these factors are combined, the risk of injury during activity
is substantially increased and can occur anywhere down the kinetic chain. These patterns need to be altered in all planes of motion to reduce injury risk, but first need to start with the individual learning neuromuscular control of their core musculature. Once neuromuscular control is taught- as is the aim of the core stability intervention program-- altered length tension relationships, force couples, and arthrokinematics can be changed and the risk of injury can be substantially reduced.

To start, the Lumbo-Pelvic-Hip-Complex has some commonly seen overactive or tightened, and inhibited and loosened musculature that change normal movement patterns and can cause injury (Chou, 2013). The commonly tightened musculature the directly affects the Lumbo-Pelvic-Hip-Complex includes the iliopsoas, rectus femoris, tensor fascia latae, hip adductors (brevis, longus, magnus, minimus; pectineus, gracilis, and obturator externus), erector spinae, gastrocnemius, and soleus (Snijders et al., 1998; Richardson et al., 2002; Walker et al., 1987). Typically elongated musculature includes the gluteus muscles (maximus and medius), biceps femoris, semitendinosus, semimembranosus, transverse abdominus, multifidus, internal obliques, and tibialis muscles (anterior and posterior) (Snijders et al., 1998; Richardson et al., 2002; Walker et al., 1987). In combination, these tightened and loosened muscles contribute to the condition commonly known as Lower Cross Syndrome which is associated with anterior pelvic tilt, lumbar lordosis, lower back pain, and other injury to the lower extremity (Chou and Atlas, 2013).

Altered kinematics may originate from shortened musculature resulting in deficits in range of motion and neuromuscular control. Excessive anterior pelvic tilt and subsequent lumbar lordosis arise from tightened lattisimus dorsi and/or attached thoracolumbar fascia along with tightened trunk extensors, knee extensors, and/or hip flexors (Tateuchi, Taniguchi, Mori, &
Ichihashi, 2012; Neumann, 2010). Tightened triceps surae are correlated with knee valgus (Padua et al., 2012), and separate or combined with the aforementioned tightened structures can lead to antagonistic inhibition that enhances anterior pelvic tilt as lumbar lordosis follows. These inhibited antagonists include the hamstrings, gluteus maximus, and most notably the rectus abdominus (Workman, Docherty, Parfrey, & Behm, 2008; Neumann, 2010). These altered antagonists play a role in the neuromuscular control of the Lumbo-Pelvic Hip Complex, affecting hip adduction and femoral internal rotation which also influences anterior pelvic tilt and increases the overall risk of injury to the lower extremity (Duval, Lam, & Sanderson, 2010; Hruska, 1998; Ireland, 2002).

Anterior pelvic tilt is of particular interest with its indications for several types of injuries along the kinetic chain. Anecdotal evidence has shown that fixing an excessive anterior pelvic tilt can substantially decrease chronic pain and injury, so developing a core stability intervention program to accurately do this has enormous implications for decreasing the individual’s need for long term rehabilitation services. This particular study will evaluate the efficacy of such a core stability intervention program by using a dynamic overhead squat assessment to measure acute changes in Lumbo-Pelvic-Hip-Complex neuromuscular control that will theoretically result in changes in anterior pelvic tilt and lumbar lordosis.

Anterior pelvic tilt can cause a multitude of injuries. Knee injuries, particularly those to the anterior cruciate ligament (ACL), occur en masse with around 80,000 to 250,000 injuries a year for the physically active (Griffin et al., 2006). Other injuries that commonly occur as a result of anterior pelvic tilt include vertebral disc pathology, spinal column arthropathy, facet joint dysfunction, osteophytes encumbering nerves, spinal stenosis (Corliss et al., 2013), chronic lower back pain, athletic pubalgia, spondylosis, spondylolisthesis, osteoarthritis, foot pronation, pa-
tellar tendonitis, and general muscle soreness and tightness to name a few (Chou, 2013; Chou and Atlas, 2013). To go along with the lengthy list of orthopedic injuries arising from anterior pelvic tilt, overall themes of loss of quality of life, large financial cost of surgery from resulting injuries, and emotional cost when dealing with chronic pain or injury are serious issues for the injured party (Krawciw and Atlas, 2013; Sowa and Delitto, 2013). With these real world implications, is it essential that more empirical research be done to solidify previously found anecdotal evidence of the efficacy of a core stability intervention program.

There are many kinematic factors that predispose an individual to injury to the Lumbo-Pelvic Hip Complex, trunk, and lower extremity when the core musculature is weak and unable to perform its job of spinal stabilization. These kinematic risk factors include excessive hip internal rotation, knee valgus (Besier, Lloyd, Cochrane, & Ackland, 2001), hip adduction, trunk flexion, and anterior pelvic tilt (Fields et al., 2013) which have been shown to increase the risk of injury in the lower extremity and may also be concurrent with lack of neuromuscular control. It has also been found that another risk factor for unspecified injury is that of poor core endurance, especially trunk flexion endurance (Wilkerson et al., 2012). With the correlation of lower extremity injury and lateral torso flexion and torso rotation, it has been found that frontal plane trunk position increases overall injury risk (Dempsey et al., 2012). The lower extremities are put at biomechanically compromising and disadvantageous positions when the trunk departs from the individual’s center of mass, in turn increasing injury rates particularly when the athlete has other muscular weaknesses that don’t allow him to appropriately compensate for these kinematic patterns.

It has been found that increased trunk motion arises from weak gluteus medius and maximus muscles, affecting lower extremity kinematics and increasing risk of injury (Popovich et al.,
When lateral trunk flexion occurs, hip adduction and foot abduction do as well which can lead to altered lower extremity kinematics and subsequent injury because of improper hip abduction (Jamison et al., 2012). Leetun et al. found that in both genders, some Lumbo-Pelvic-Hip-Complex factors contributing to injury included a substantially smaller amount of strength into hip external rotation and hip abduction than uninjured counterparts (Leetun et al., 2004). It was also discovered in a study by Zazulak et al. that injury could be predicted by deficits in trunk neuromuscular control, particularly in females (Zazulak et al., 2007). Anterior pelvic tilt and femoral internal rotation have an established relationship (Duval et al., 2010; Hruska, 1998; Ireland, 2002; Walker, Rothstein, Finucane, & Lamb, 1987), and a study by McKeon et al. (2009) showed significantly more anterior pelvic tilt in women compared to men. Females already see an increased rate of knee injury, and with such correlations between knee injury and lack of Lumbo-Pelvic-Hip Complex control a core stability intervention program would do a lot to help reduce risk of the lower extremity. Anterior pelvic tilt is associated with increased tibial external rotation, foot pronation, femoral internal rotation, and lumbar lordosis, (Duval et al., 2010; Hruska, 1998; Ireland, 2002). As we can see, anterior pelvic tilt is associated with a multitude of lower extremity rotational changes that could be corrected with a core stability intervention program.

Further evidence of the efficacy of the importance of core activation to lower extremity kinematics is found in findings from Shirey et al. The study established that during a single leg squat, subjects who consciously activated their core musculature were in turn able to decrease hip frontal plane motion. Each of the fourteen subjects did the single leg squat task with and without the core musculature engaged. Subsequent performance as measured by medial hip dis-
placement and knee flexion was found to have increased significantly, indicating that the core 
plays a significant role in lower extremity kinematics (Shirey et al., 2012).

The above risk factors have been commonly evaluated using the Overhead Squat As-
sessment (Bell et al., 2008; Butler et al., 2010; Macrum et al., 2012; Padua et al., 2012). The 
Overhead Squat Assessment task will be used to identify any changes in LPHC and lower ex-
tremity kinematics (Bell et al., 2008; Butler, Plisky, Southers, Scoma, & Kiesel, 2010; Macrum, 
Bell, Boling, Lewek, & Padua, 2012; Padua et al., 2012) in a test, re-test method with the core 
stability protocol being put into place between squatting trials. Any changes from excessive ante-
rior pelvic tilt to ranges of normal anterior pelvic tilt after the core stability protocol may indicate 
changes that took place due to conscious motor learning used to activate the core musculature 
(Transverse Abdominus, Multifidus, External Obliques, and Pelvic Floor muscles) which is nec-
essary for normal pelvic tilt during dynamic movement. Changes in anterior pelvic tilt and lum-
bar lordosis may also result in other kinematic changes in the lower extremity, particularly de-
creased trunk flexion, femoral internal rotation, knee valgus, and hip adduction.

While the Overhead Squat Assessment is commonly used to assess movement pattern 
dysfunction of the lower extremity (Bell et al., 2008; Macrum et al., 2012; Padua et al., 2012; B. 
T. Zazulak et al., 2007), it only has theoretical implications for evaluating dysfunction of the 
Lumbo-Pelvic-Hip-Complex. Excessive anterior pelvic tilt/lumbar lordosis are correlated with 
weakened musculature of the deep Lumbo-Pelvic-Hip muscles, rectus abdominis, hamstrings, 
and Gluteus Maximus and Medius. Tightened or overactive musculature putting the individual at 
risk of increased anterior pelvic tilt/lumbar lordosis includes the hip flexors, erector spinae, and 
lattissimus dorsi. With weaknesses in the Lumbo-Pelvic-Hip Complex musculature as listed 
above, is it reasonable to ascertain that an individual with such weaknesses would display exces-
sive anterior pelvic tilt/lumbar lordosis. The Overhead Squat Assessment becomes as valid assessment tool in that it accurately measures dysfunction of the lower extremity, ergo measuring dysfunction in the LPHC. The only downfalls of the Overhead Squat Assessment are that it doesn’t take into account an assessment of the internal and external obliques and quadratus lumborum (QL), which make up the trunk’s lateral musculature. These muscles, particularly the quadratus lumborum, are essential players in spinal stability occurring in the frontal plane (S. McGill, Juker, & Kropf, 1996; S. M. McGill et al., 1999).

Today’s commonly used clinical interventions to increase core strength and endurance usually include concepts of stretching with a purpose; addressing altered neuromuscular patterns in order to regain proper movement patterns; and strengthening with musculature in the correct position (Van Dillen and Sahrmann, 2009). The clinician can tailor these programs to the individual depending on their initial ability to incorporate neuromuscular control into dynamic movement. This may provide more of a challenge for some individuals and they may need more coaching and time to practice appropriate activation of certain key musculature, particularly the transverse abdominus and multifidus. The core stability intervention program can be done several times a week and as evidenced, can help with not only the aim of fixing excessive anterior pelvic tilt, but many other orthopedic injuries regardless of injury and subsequent goals.

An elementary approach to core neuromuscular control can start with the individual in hooklying position on the floor. From here, the clinician can help the individual learn when appropriate contractions feel like and how to further incorporate them into smaller movements. The core stability intervention program doesn’t require special equipment and can be done at home, which allows the individual to get the most out of their rehabilitation services, which may be precluded to a certain number of sessions as dictated by the individual’s insurance plan. An in-
expensive exercise ball or unstable objects found in the household such and pillows or furniture can substitute for more expensive equipment and allow the individual to easily incorporate an injury preventing, core strengthening and stability program into their everyday routine. The individual can use this same equipment to progress through many levels of core stability once they understand neuromuscular control or the core musculature.

Some common exercises put into place for the goal of core stabilization are as follows. They are done in both supine and prone exercises in order to best teach and implement the learning of motor skills that use isometric co-contractions in more than one position (Richardson et al., 2000). Each exercise is typically performed for three to four sets of eight to twelve repetitions to help learn the motor skill and encourage strength and endurance gains (Clark et al., 2012). While lying supine on the floor, typical exercises include toe taps, dying bug, hip-ups, and hip-ups with knee extension. Toe taps are described as extending the knee slightly to bring one foot 6 inches off the ground at a pace of 1 second up and 1 second back down and then alternating feet (Sandry, 2012). Dying bug is described as starting with one arm extended to 135 degrees while the contralateral leg is in 120 degrees of hip flexion with the foot off the ground (the remaining arm and leg are resting on the ground at this point). The subject then flexes the arm and the hip to touch above the abdomen and after going back to resting point, starts the same series with the opposite arm and leg. A one second up and one second down rhythm is followed (Souza, Baker, and Powers, 2001). Hip-ups are described as starting by bringing the hip off the ground so that a straight line is formed with the knees, hips, and shoulders. Follow a one second up and one second down rhythm (Olson, 2013). Hip-ups with knee extension are described as hip-ups with one knee being extended after the knees, hips, and shoulders are in line so that now one knee is also in line. Bring the foot back to the ground before returning to the original
hooklyng position and repeating with the opposite knee being extended. Follow a one second up and one second down rhythm (Rosania, 2010). When in a prone position on the floor, some often utilized exercises include a head lift, head rotations, hip extensions, and quadruped. The head lift consists of the subject going into 45 degrees of cervical extension at a rhythm of one second up and one second down with the arms resting at the subject’s sides (Park et al., 2013). Head rotation consists of the subject going into 45 degrees of cervical extension and the going into 60 degrees of cervical rotation in either direction. The subject will then go back to the start position and repeat the series but go into 60 degrees of cervical rotation on the opposite side. A rhythm of one second into straight cervical extension, one second into cervical rotation, and one second back to starting position will be followed (Park et al., 2013) Hip extension will consist of the subject going into 20 degrees of hip extension by lifting one bent knee off the table at a rhythm of one second up and one second down. The subject will continue this patterns and alternate legs (Olson, 2013) The Quadruped consists of the subject getting on all fours while in a prone position on the table. The subject will extend one arm off the table 90 degrees and extend the opposite hip off the table 110 degrees off the table at the same time while using a one second up and one second down rhythm. The subject will return to the all fours position before repeating the sequence with the opposite arm and leg (Olson, 2013).

The main issue with a core stability intervention program is the individual’s ability to incorporate neuromuscular control of the core and Lumbo-Pelvic-Hip-Complex into dynamic activity after success with the intervention program. The individual may also mistake certain biofeedback with tilting the pelvis posteriorly as the appropriate solution to their lower back pain or as part of injury prevention, but this is inaccurate. Their pelvis may return to normal during exercise as a result of not appropriately gaining strength and endurance in the core musculature and
being able to incorporate this during activity. Diligence and positive reinforcement of appropriate core muscular activation on the part of the clinician and copied by the individual can solve this problem.

Biofeedback in the form of a placing a hand or Blood Pressure Cuff under the lumbar vertebrae while in hook-lying position and attempting to activate the core musculature are good tools in helping the individual learn appropriate force production for the musculature and pelvic positioning during an acute treatment session. Even if an individual displays neuromuscular control during hook-lying and the core stability intervention program, they still may not be able to convert this into changes in excessive anterior pelvic tilt during a dynamic Overhead Squat Assessment. A lack of change may be due to lack of practice, focus, or getting adjusted to the new activity at hand (Overhead Squat Assessment AND core stability activation, as opposed to simply the Overhead Squat Assessment activity only). Strength deficits in the core, as well as lack of mobility may account for lack of change in anterior pelvic tilt during a dynamic squat. These fall out of the scope of this study unfortunately and can’t be accounted for as a result.

In summary, Anterior Pelvic Tilt has been found to be a marker of poor core stabilization (Teyhen et al., 2005) and is influential in lower extremity biomechanics including increased trunk flexion, femoral internal rotation, knee valgus, and hip adduction. A practical solution in the physical therapy and athletic training settings is one that supports activation of the core musculature in order to return pelvic tilt to normative values. Such returns to neutral pelvic alignment would theoretically result in secondary improvements to the aforementioned kinematic patterns of the lower extremity during dynamic movement, in turn decreasing overall risk for hip and knee injury as well as the primary focus of the study that is Lower Back Pain.
Chapter 3

Subjects

Subjects will include a convenience sample of 38 students at the University of North Carolina who are either involved in any Varsity level athletic program or are any physically active individuals of the general student body who fit the inclusion criteria. “Physically active” will be defined according to the Center for Disease Control and Prevention’s 2008 Physical Activity Guidelines for Americans, which recommends at least 150 minutes of moderate-intensity aerobic activity (i.e. speed walking) and muscle strengthening activity at least 2 days a week, or 75 minutes of vigorous-intensity aerobic activity (i.e. jogging and running) and muscle strengthening activity at least 2 days a week (Centers for Disease Control and Prevention, 2011). Division 1 athletes are assumed to fulfill this requirement given their off-season and in-season scheduled activity while anyone in the general student body will qualify if they have the above CDC recommended activity levels in a given week. Other inclusion and exclusion criteria are listed below. Subjects have to meet four (3) of the five (4) inclusion criteria to participate in the study -- the subject will fit into either the general student body or the Division 1 student-athlete population. Subjects will be excluded if they meet at least one (1) of the exclusion criteria.

Inclusion Criteria:

- No low back, hip, knee, ankle or shoulder injuries (ligament sprains, muscle strains, and any chronic pain) within 6 months prior to the testing.
- Ages between 18 and 25.
- Physically active individuals from the general student population.
o Athletes who play sports at the Division I level.

Exclusion Criteria-

o History of low back, hip, knee, abdomen, or shoulder surgery.

o Excessive femoral anteversion or retroversion.

o Are unable to perform a squat or have pain while doing so.
**Apparatus/Equipment**

The apparatus will include one main pieces of technological equipment.

1. The electromagnetic motion capture system (MotionStar, Ascension Technology Corporation, Burlington, VT) with 3 corresponding Ascension Flock of Birds electromagnetic trackers used to measure lower body kinematics. Sampling frequency will be set at 100 Hz (Blackburn and Padua, 2009). The 3 Flock of Birds sensors will be placed on the subject’s dominant side on the midpoint of the tibia; midpoint of the lateral thigh; and sacrum on S1 spinous process. The Anterior Superior Iliac Spine and Posterior Superior Iliac Spine will be digitized. A segment linkage model will be used, with the spinal sensor placed on the L4 spinous process, and spinal column landmarks will be digitized at T12-L1 and C7-T1. A right hand coordinate system will be used to establish a world and segment axis system in which the positive direction for the x-axis is anterior, the y-axis is medial, and the z-axis is superior (Blackburn & Padua, 2008, 2009; Padua et al., 2012). Motions of particular interest are anterior/posterior pelvic tilt, hip flexion, abduction, and internal rotation, and spine position.
**Testing Procedures**

Once the subject has been approved for testing in consideration of the inclusion and exclusion criteria, the following seven testing procedures will be put into place.

1. Consent Form: The subject will read, sign, and date the consent form acknowledging the purpose of the study; his role in the study; the testing protocol; the time commitment and number of session associated with the study; any risks, benefits, and consequences accompanying participation or dropping out of the study; privacy protection; and contact information for questions, comments and grievances among other information for disclosure to the subject. See the Appendices section for the Consent Form.

2. Set up Instrumentation: While the subject is reading over the consent form, the clinician will ready the testing area by calibrating the x-, y-, z-axes of the the electromagnetic capture system. Once the consent form has been read, signed, and dated the clinician will then prepare the subject for data collection. The subject will stand on the platform. The clinician will then fixate the 3 Ascension Flock of Bird electromagnetic sensors on the subject’s dominant side on the midpoint of the tibia; midpoint of the lateral thigh; and sacrum on S1 spinous process. The clinician will digitize the ASIS and PSIS as well. To secure each sensor, double sided tape, prewrap, and athletic tape will be placed over each sensor with the exception of the sacral sensor which will also be secured using a Velcro belt. The wires attached to each sensor will be gathered to the lateral side of the subject according to their dominant leg which has the sensors attached to it in order to avoid any tangling or catching of the wires or sensors during the dynamic Overhead Squat movement.
3. Describe the Squat Task: The clinician will then describe the squat task for the subject. This script will be read before the first squatting session, which will occur before the core stability intervention:

“Standing with your feet facing forward and shoulder width apart, raise your arms above your head as if you are trying to touch the ceiling. From this position, you will go into a squatting position by first bending at the waste to bring your chest lower your chest to the ground, by then bending at the knee, and by then bending at the ankle to bring your knee closer to your toes. Squat so that your knee does not go into more than 90 degrees of flexion under the instruction of the clinician. Once you reach this position, you will go back the starting position with your hands over your head. You will perform this squat at an even pace of 1-2 seconds on the descent phase and 1-2 seconds on the ascent phase with 1 second of rest between each squat repetition. You will get three practice squats if needed and five trial squats with the Flock of Birds sensors will be recorded (Richardson et al., 2000). You will have 30 seconds of rest between the practice set of squats and the trial set of squats (Clark et al., 2012). Do you understand the instructions as I have read them? Do you have any questions?”

4. The subject will then perform one set 5 Overhead Squats to the beat of the metronome (80 bpm) while on the Force plate of the MotionStar Ascension Technology and attached to the Flock of Birds electromagnetic sensors. The subject will squat to 90 degrees of knee flexion each time by utilizing the clinician’s cueing to ensure the accurate joint angle.

5. Teach TA Contractions: The subject will lay in the supine hook-lying position on the padded clinical-use table and transverse abdominis activation will be taught by the investigator. The investigator will demonstrate the appropriate muscle contraction through verbal cueing in-
including “pull your belly button to your spine,” “make yourself as skinny as possible,” and “swallow your stomach,” and tactile cueing through palpation of the lower abdominals just medial to the anterior superior iliac spines. Subjects will then be instructed on how to posteriorly tilt the pelvis and flatten the lumbar spine against the table by “tucking your tailbone,” or “roll your hips back.”

6. Core Stability Protocol: The Core Stability Protocol will then be put into place with both supine and prone exercises in order to best teach and implement the learning of motor skills that will need to use isometric co-contractions in more than one position (Richardson et al., 2000). Each exercise may be performed for as many reps as it takes to relearn motor skill, but for purposes of time and to prevent muscle fatigue we will limit it to 5 repetitions to teach each individual and 3 extra if someone is having trouble co-contracting the TA and Multifidus and performing the exercise at the same time (Clark et al., 2012). While lying supine on the padded clinical-use table, the exercises will include toe taps, dying bug, hip-ups, and hip-ups with knee extension. Toe taps are described as extending the knee slightly to bring one foot 6 inches off the table at a pace of 1 second up and 1 second back down and then alternating feet (Sandry, 2012). Dying bug is described as starting with one arm extended to 135 degrees while the contralateral leg is in 120 degrees of hip flexion with the foot off the ground (the remaining arm and leg are resting on the ground at this point). The subject then flexes the arm and the hip to touch above the abdomen and after going back to resting point, starts the same series with the opposite arm and leg. A one second up and one second down rhythm is followed (Souza, Baker, and Powers, 2001). Hip-ups are described as starting by bringing the hip off the ground so that a straight line is formed with the knees, hips, and shoulders. Follow a one second up and one second down rhythm (Olson, 2013). Hip-ups with knee extension are described as hip-ups with one knee being
extended after the knees, hips, and shoulders are in line so that now one knee is also in line. Bring the foot back to the ground before returning to the original hook-lying position and repeating with the opposite knee being extended. Follow a one second up and one second down rhythm (Rosania, 2010). The subject will then move to a prone position on the padded clinical-use table and perform head lifts, head rotations, hip extensions, and quadruped. The head lift will consist of the subject going into 45 degrees of cervical extension at a rhythm of one second up and one second down with the arms resting at the subject’s sides (Park et al., 2013). Head rotation will consist of the subject going into 45 degrees of cervical extension and the going into 60 degrees of cervical rotation in either direction. The subject will then go back to the start position and repeat the series but go into 60 degrees of cervical rotation on the opposite side. A rhythm of one second into straight cervical extension, one second into cervical rotation, and one second back to starting position will be followed (Park et al., 2013). Hip extension will consist of the subject going into 20 degrees of hip extension by lifting one bent knee off the table at a rhythm of one second up and one second down. The subject will continue this patterns and alternate legs (Olson, 2013). The Quadruped consists of the subject getting on all fours while in a prone position on the table. The subject will extend one arm off the table 90 degrees and extend the opposite hip off the table 110 degrees off the table at the same time while using a one second up and one second down rhythm. The subject will return to the all fours position before repeating the sequence with the opposite arm and leg (Olson, 2013). See Appendix 2 (Core Stability Protocol) for detailed script instructions for each exercise.

7. Remeasure Squats: The clinician will instruct the subject to stand on the platform where the squats were first measured. The clinician will not need to reattach each of the 3 Flock of Birds sensors with new tape or redigitize the ASIS and PSIS since they would have remained
attached during all the exercises. After the reading of the script below, the subject will perform the Overhead Squat task. Upon completion and assurance that the data has been recorded appropriately, the sensors and all adhesive equipment will be removed and the subject will be free to leave. This script will be read before the second squatting session, which will occur after the core stability intervention:

“You will now perform 5 Overhead Squats in succession as you did prior to the Core Stability Intervention Protocol. Standing with your feet facing forward and shoulder width apart, raise your arms above your head as if you are trying to touch the ceiling. From this position, you will go into a squatting position by first bending at the waste to bring your chest lower your chest to the ground, by then bending at the knee, and by then bending at the ankle to bring your knee closer to your toes. Squat so that your knee does not go into more than 90 degrees of flexion under the instruction of the clinician. Once you reach this position, you will go back the starting position with your hands over your head. You will perform this squat at an even pace of 1-2 seconds on the descent phase and 1-2 seconds on the ascent phase with 1 second of rest between each squat repetition. You will get three practice squats if needed and five trial squats with the Flock of Birds sensors will be recorded. You will have 30 seconds of rest between the practice set of squats and the trial set of squats. Do you understand the instructions as I have read them? Do you have any questions?”
Core Stability Protocol

The core stability protocol will be put into place with both supine and prone exercises in order to best teach and implement the learning of motor skills the subject will need to use during isometric co-contractions in more than one position (Richardson et al., 2000). Clinically, each exercise is usually performed for as many reps as it takes to learn the motor skill, but for purposes of time and to prevent muscle fatigue we will limit it to 5 to teach each individual with 3 extra repetitions if the subject is having trouble co-contracting the transverse abdominis and multifidus and performing the exercise at the same time (Richardson et al., 2000). Between each set of exercises, the subject will rest 30-45 seconds (Clark et al., 2012). While lying supine on the floor, the exercises will include toe taps, dying bug, hip-ups, and hip-ups with knee extension.

1. The following script will be read to describe the **Toe Taps** task for each individual:

“The first exercise is Toe Taps. Toe Taps are described as starting in the hook lying position (back flat on ground with knees bent, feet flat on the ground, and hands at the side on the ground), extending (straightening) the knee slightly to bring one foot 6 inches off the ground. Slightly flex at the hip to bring one leg off the ground and lower the same leg by extending at the hip at a pace of 1 second up off the ground and 1 second back down to the ground. Now do this same motion while alternating which foot is lifted off the ground. (Sandry, 2012). Repeat this 5 times for each foot and 3 more if you feel you are unable to maintain the Transverse Abdominus contractions we previously discussed.” See Figure 1 for visual example.

2. The following script will be read to describe the **Dying Bug** task for each individual:

“Dying Bug is described as starting in the hook lying position (back flat on ground with knees bent and feet flat on the ground), with one arm extended to 135 degrees above the head while the
contralateral (opposite sided) leg is in 120 degrees of hip flexion with the foot off the ground (the remaining arm and leg are resting on the ground at this point). Flex the arm and the hip that are not in contact with the ground to touch above the abdomen. Go back to resting point and then start the same series with the opposite arm and leg. A one second up and one second down rhythm is to be followed. (Souza, Baker, and Powers, 2001). Repeat this 5 times for each side and 3 more if you feel you are unable to maintain the Transverse Abdominus contractions we previously discussed.” See Figure 2 for visual example.

3. The following script will be read to describe the **Hip-Ups** task for each individual:

“Hip-Ups are described as starting in the hooklying position (back flat on ground with knees bent, feet flat on the ground, and hands at the side on the ground), and then by bringing the hips off the ground so that a straight line is formed with the knees, hips, and shoulders. Focusing on pushing your hips through the ceiling by contracting your glutes will help with appropriate form. Follow a one second up and one second down rhythm (Olson, 2013). Repeat this 5 times for each foot and 3 more if you feel you are unable to maintain the Transverse Abdominus contractions we previously discussed.” See Figure 3 for visual example.

4. The following script will be read to describe the **Hip-Ups with Knee Extension** task for each individual:

“Hip-Ups with Knee Extension are described as Hip-Ups with one knee being extended after the knees, hips, and shoulders are in line so that the lower leg is also now in line. Bring the foot back to the ground before returning to the original hooklying position(back flat on ground with knees bent, feet flat on the ground, and hands at the side on the ground). Repeating with the opposite knee now being extended. Follow a one second up and one second down rhythm (Rosania,
Repeat this 5 times for each foot and 3 more if you feel you are unable to maintain the Transverse Abdominus contractions we previously discussed.” See Figure 4 for visual example.

The subject will then move to a prone position on the floor and perform head lifts, head rotations, hip extensions, and quadruped.

5. The following script will be read to describe the **Head Lift** task for each individual:

“The Head Lift will consist of the subject going into 45 degrees of cervical extension (lift you head straight off the ground while your eyes are still looking down at the ground) at a rhythm of one second up and one second down with the arms resting at the subject’s sides (Park et al., 2013). Repeat this 5 times for each foot and 3 more if you feel you are unable to maintain the Transverse Abdominus contractions we previously discussed.” See Figure 5 for visual example.

6. The following script will be read to describe the **Head Lift with Rotation** task for each individual:

“Head Lift with Rotation will consist of the subject going into 45 degrees of cervical extension and then going into 60 degrees of cervical rotation to either side (turn your head until your chin reaches the middle of your shoulder on one side). The subject will then go back to the start position with the head on the ground with eyes looking straight down into the ground and repeat the series by going into 60 degrees of cervical rotation on the opposite side. A rhythm of one second into straight cervical extension, one second into cervical rotation, and one second back to starting position will be followed (Park et al., 2013). Repeat this 5 times for each foot and 3 more if you
feel you are unable to maintain the Transverse Abdominus contractions we previously discussed.” See Figure 6 for visual example.

7. The following script will be read to describe the **Hip Extension** task for each individual:

“Hip Extension will start with the subject on all fours and eyes facing the ground. Go into 20 degrees of hip extension (20 degrees past the leg being in straightened position) by lifting one bent knee off the ground at a rhythm of one second up and one second down. The subject will continue this pattern and alternate legs (Olson, 2013). Repeat this 5 times for each foot and 3 more if you feel you are unable to maintain the Transverse Abdominus contractions we previously discussed.” See Figure 7 for visual example.

8. The following script will be read to describe the **Quadruped** task for each individual:

“The Quadruped consists of the subject starting on all fours while in a prone position on the ground. The subject will extend one arm off the table 90 degrees and extend the opposite knee and hip off the table 20 degrees past the straightened hip position at the same time while using a one second up and one second down rhythm. The subject will return to the all fours position before repeating the sequence with the opposite arm and leg (Olson, 2013). Repeat this 5 times for each foot and 3 more if you feel you are unable to maintain the Transverse Abdominus contractions we previously discussed.” See Figure 8 for visual example.

The subject will then stand and the sacral sensor will be placed back on the patient and recalibrated. The subject will then perform 5 consecutive overhead squats to the beat of a metronome set at 80 bpm (Bolling et al., 2006). Kinematic data will be recorded with the electromagnetic motion capture system for pelvic tilt (Mayer et al., 2002).
“Now stand with one foot on each force plate, with both feet facing forward as was done before with the previous set of squats. You will perform 5 consecutive Overhead Squats to the beat of the metronome as before with the only difference being that you will contract your Transverse Abdominis as you did with the 8 practiced exercises from the Core Stability Intervention Protocol. If you need to take a break it will be at the top of the squat and it needs to be very quick (under half a second as you pause at the top of the squat) as you need to stay on beat with the metronome for the ensuing squat. Ideally, you would perform the TA contraction throughout the entire set of five squats but ultimately you just need to make sure you are contracting your Transverse Abdominis during the descending phase and ascending phase of each squat with a very small break in between if you prefer.”
**Analysis and Data Reduction**

A paired samples t-test will be used in statistical analysis between each of the pelvic tilt baseline values prior to the core stability training protocol and the pelvic tilt values for the same population after the core stability training protocol (5 total paired samples t-tests). This will be measured by looking at the descent phase of the squat only which will start with the first movement of the subject towards a squat from static standing position to the body position when 90 degrees of knee flexion is attained during the squat. The ascending phase of the squat-- when the subject extends the knee to return to the static standing position-- will not be calculated into any statistical analysis. After the 5 trial squats are performed and data is collected for each of the 5 Independent Variables, an average for each Independent Variable will be attained. This process will be repeated for the pre-Core Stability Protocol intervention set of 5 trial squats and for the post-Core Stability Protocol intervention set of 5 trial squats. The averages for the pre and post intervention scores for each Independent variable will then be compared for any significant difference.

**DV1** -Trunk Flexion Displacement: Will consist of the difference in starting trunk flexion angle as measured by the Flock of Birds sensors on the midpoint of the lateral thigh, the sacrum on S1 spinous process (vertex), and the ASIS and the peak angle measured between the same Flock of Birds sensors at the end of the squat when the knee is flexed at 90 degrees.

**DV 2** -Anterior Pelvic Tilt Displacement: Will consist of the difference in starting pelvic tilt angle as measured by the Flock of Birds sensors on the ASIS, the sacrum on S1 spinous process (vertex) and the PSIS, and the peak angle measured between the same Flock of Birds sensors at the end of the squat when the knee is flexed at 90 degrees.
**DV 3 - Hip Adduction Displacement:** Will consist of the difference in starting hip adduction angle as measured by the Flock of Birds sensors on the ASIS, the midpoint of the lateral thigh (vertex), and the midpoint of the tibia and the peak angle measured between the same Flock of Birds sensors at the end of the squat when the knee is flexed at 90 degrees.

**DV 4 - Hip Internal Rotation Displacement:** Will consist of the difference in starting hip rotational angle as measured by the Flock of Birds sensors on the ASIS, the midpoint of the lateral thigh (vertex), and the midpoint of the tibia and the peak angle measured between the same Flock of Birds sensors at the end of the squat when the knee is flexed at 90 degrees.

**DV 5 - Knee Abduction Displacement:** Will consist of the difference in starting knee angle as measured by the Flock of Birds sensors on the ASIS, the midpoint of the lateral thigh (vertex) and the midpoint of the tibia and the peak angle measured between the same Flock of Birds sensors at the end of the squat when the knee is flexed at 90 degrees.
Chapter 4

Results

Data was collected from 38 participants for the current study ranging in age from 18-25 (21.1 +/- 1.1 years) (Table 2). The participants average mass was 68.6 +/- 11.25 kg and their average height was 172.0 +/- 8.8 cm. Participants were physically active individuals from the general population who fulfilled the Center for Disease Control and Prevention’s 2008 Physical Activity Guidelines for Americans, which recommends at least 150 minutes of moderate-intensity aerobic activity (i.e. speed walking) and muscle strengthening activity at least 2 days a week, or 75 minutes of vigorous-intensity aerobic activity (i.e. jogging and running) and muscle strengthening activity at least 2 days a week (Centers for Disease Control and Prevention, 2011). The subjects also had no known history of injury within the last 6 months or any surgical proceedings to the low back, hip, knee, ankle, abdomen, or shoulder. Craig’s Test for Femoral Anteversion was performed to determine whether the individual qualified for the study (excessive femoral anteversion or retroversion was a disqualifier). The participants all went through the exact same procedure including two sets of 5 Overhead Squats before and after the Core Stability Intervention Protocol consisting of teaching the participants to contract their Transverse Abdominus during 8 core exercises.

Along with the 5 paired samples T-tests for each dependent variable, a 95% confidence interval was utilized (p=.05) for the study. There were no significant differences between the pre- and post-intervention measures of anterior pelvic tilt displacement (p=.455), hip internal rotation displacement (p=.082), knee abduction (valgus) displacement (p=.317). However, there were significant changes from pre- to post-intervention for both trunk flexion (p=.008) and hip adduction (p=<.001) displacement (Table 1). There was a small, but statistically significant decrease
in trunk flexion displacement following the core stability intervention, which was then evaluated further with the descriptive statistic Cohen’s d to measure effect size-- or the measure of strength of the phenomenon. Cohen’s d was found to be 0.21 for trunk flexion, which is considered to be weak and indicates that the average 2.39 degree decrease in trunk flexion was not actually clinically significant. Hip adduction displacement was significantly decreased following the intervention as individuals showed 1.12 degrees of hip adduction displacement prior to the intervention. After the intervention, however, the participants displayed 7.92 degrees of hip abduction displacement (for an absolute value of 9.04 total degrees of change). The magnitude of change in hip abduction as measured by Cohen’s d was 2.31 and as such would be considered large and clinically meaningful (Table 1).
Chapter 5

Discussion

The most important finding in this study was that Trunk Flexion and Hip Adduction decreased significantly. While there was no significant change in Anterior Pelvic Tilt, Hip Internal Rotation, or Knee Abduction, there was significantly less Trunk Flexion and decreased Hip Adduction when comparing pre to post treatment joint displacement means. The fact that both Trunk Flexion and Hip Adduction saw significant statistical changes does not necessarily translate to clinical significance in which we would see meaningful change in Trunk Flexion and Hip Adduction in the real world. Such a meaningful change could indicate that there is enough of a change in kinematic patterns that the individual is now less prone to certain biomechanical movement patterns that predispose that individual to injury. Putting such a Core Stability Intervention Protocol into place could change these kinematic patterns with lessened Hip Adduction and theoretically lower injury risk and rates as a result. The significant difference in trunk flexion (m = 2.40; SD = 5.26; p = 0.008; d = 0.21) does not look to be clinically significant when the effect size was calculated, while the change in hip adduction (m = 9.03; SD = 5.08; p < 0.001; d = 2.31) and its effect size shows that it could be clinically significant-- this has huge implications for rehab programs if the goal is to try to lower hip adduction.

A larger hip adduction joint angle during dynamic activity is correlated with increased knee valgum, which puts the knee in a predisposed position for injury (Duval, Lam, & Sanderson, 2010; Hruska, 1998; Ireland, 2002). This results in a subsequently increased risk of injury at the lower extremity, especially with the anterior cruciate ligament (ACL) of the knee (Sahrmann, 2002; Griffin et al., 2006). Knee injuries, particularly those to the ACL, occur en masse with around 80,000 to 250,000 injuries a year for the physically active (Griffin et al., 2006). Females
already see an increased rate of knee injury and with such correlations between knee injury and lack of Lumbo-Pelvic-Hip Complex control (Fields et al., 2013), a core stability intervention program could do a lot to help reduce risk of the lower extremity. While it is not known what the direct effect of this Core Stability Intervention Protocol will be ACL injury rates, the Lumbo-Pelvic-Hip-Complex, and the rate and type of lower extremity injuries including vertebral disc pathology, spinal column arthropathy, facet joint dysfunction, osteophytes encumbering nerves, spinal stenosis (Corliss et al., 2013), chronic lower back pain, athletic pubalgia, spondylosis, spondylolisthesis, osteoarthritis, foot pronation, patellar tendonitis, and general muscle soreness and tightness (Chou, 2013; Chou and Atlas, 2013), changes in hip adduction would significantly change kinematic patterns, likely resulting in fewer of these complications. As was previously discussed with the cycle of muscular imbalances leading to altered length tension relationships, altered force couples, altered arthrokinematics, Lower Cross Syndrome, Anterior Pelvic Tilt, Lumbar Lordosis, and Lower Back Pain at the Lumbo-Pelvic-Hip-Complex (LPHC) (Hruska, 1998), it is not a stretch to think that these patterns can be reversed by returning the altered arthrokinematics to their appropriate movement patterns. Another benefit to an efficacious Core Stability Intervention Protocol is that it could help lower the overall loss of quality of life, large financial cost of surgery from the above orthopedic injuries, and emotional cost of having to deal with chronic pain or injury (Krawciw and Atlas, 2013; Sowa and Delitto, 2013). For the above reasons, it is an extremely important finding that hip adduction was significantly and clinically lessened by following the Core Stability Intervention Protocol.

Finding an inexpensive, easy to use, and efficacious intervention backed by empirical research is essential to help resolve these real world implications-- thankfully this intervention that was previously only backed by anecdotal evidence has been found to be efficacious in causing
real kinematic change through this study. It is essential, however, that more empirical research be done on the subject to quantify how much of a tangible effect this intervention has in the clinical setting on reduction of injury rates. Further evidence speaking to the efficacy of core activation to lower extremity kinematics was found in a study from Shirey et al. The study established that during a single leg squat, subjects who consciously activated their core musculature were in turn able to decrease hip frontal plane motion (hip adduction/abduction). Each of the fourteen subjects did the single leg squat task with and without the core musculature engaged. Subsequent performance as measured by medial hip displacement and knee flexion was found to have increased significantly, indicating that the core plays a significant role in lower extremity kinematics (Shirey et al., 2012). There was a previous foundation to say that activation of the core musculature would affect lower extremity kinematics as seen in Shirey et al., but not necessarily a foundation saying that this specific gathering of core exercises would be efficacious in doing the same thing. Other studies done by Bell et al., Butler et al., Macrum et al., and Padua et al. all utilized a dynamic Overhead Squat Assessment to look at changes in lower extremity kinematics, but did not necessarily find significant decreases in hip adduction from their studies that were more focused on looking at the efficacy of an Overhead Squat Assessment as clinical movement dysfunction assessment tool. Whereas we only previously had anecdotal evidence to speak to the efficacy of a Core Stability Intervention Protocol like this, we now have empirical evidence to say that this specific collection of core exercises works as an intervention in significantly altering lower extremity kinematics, particularly that of Hip Adduction during an overhead squat task.

To understand the overall implications, we have to consider that excessive hip adduction displacement during dynamic movement is known to be correlated with increased knee abduction, which increases the overall risk of injury (Fields et al., 2013). By lowering the hip adduc-
tion displacement-- as we did with the Core Stability Intervention Protocol-- it would theoretically then be possible to lower the risk and rate of injury to the lower extremity, particularly to the knee and ACL. Overall, the findings of the study mean that this specific Core Stability Intervention Protocol with these 8 collective exercises was efficacious in altering Lower Extremity kinematics, particularly that of hip adduction, during a dynamic overhead squat. We still need future research to investigate what the actual influence of this Protocol is on injury to the lower extremity. We need more research to help answer if this Core Stability Protocol Intervention actually changes the risk and rate of injury to the lower extremity in the real world.

Our original hypothesis and main motivation for carrying out the study was to look at changes in Anterior Pelvic Tilt (APT). We saw no isolated changes in APT but there was a significant change in trunk flexion, which would suggest APT should have changed. It may not have changed because the intervention itself was only a one-time session and may not have been potent enough as a result to elicit real change. As there was no requirement for the subject population to present with lumbar lordosis to fit the inclusion criteria, we may have had subjects who had no real room for change which would have then been measurable under our study. Performing future research that looks at a pathological population with APT and lumbar lordosis is definitely needed for future research to help us see what any potential changes the Core Stability Intervention Protocol could cause for such a pathological population. Had more emphasis also been placed on maintaining proper pelvic alignment during each of the 8 Core Stability Intervention Exercises and during the post-treatment squat session, we may have seen more change in Anterior Pelvic Tilt as well. The main focus of the cueing relied on contracting the Transverse Abdominis, with continual reminders to do so in each of the scripts for the 8 individual exercises and the post-intervention squats. There was teaching on what neutral pelvic alignment was along
with the Transverse Abdominis contraction teaching session, but that was the extent of the focus of that action. Incorporating more teaching sessions with “tucking the tailbone” and “flattening the back” against the treatment table would help instill what appropriate neutral pelvic alignment actually feels like for that individual.

In accounting for the lack of significant results dealing with Anterior Pelvic Tilt, there are a few things to consider. The study observed changes in hip adduction that were not necessarily associated with changes in APT, which could be because several of the selected exercises engaged the gluteal muscles by the nature of the exercise selection. These exercises would have included the Hip Lift (Figure 3), Hip Lift with Knee Extension (Figure 4), Hip Extension (Figure 7), and Quadruped (Figure 8). This exercise selection could have inadvertently taught hip adduction activation more than that of maintaining neutral pelvic activation during exercise. We also saw that there is a needed change in how the Core Stability Intervention Protocol was actually carried out. We may have gotten more hip adduction and less change in pelvic alignment by not specifically cueing for neutral pelvic alignment before each of the 8 exercises was performed as well as during the post-Intervention set of 5 Overhead Squats, which should have gone along with our TA contraction cueing more diligently.
Limitations and Future Research

There were three main limitations to the study at hand. The first is that this study did not look at a clinically pathologic population with excessive anterior pelvic tilt, but a healthy physically active one with no mention of anterior pelvic tilt in the inclusion criteria. There was no specific movement dysfunction such as excessive anterior pelvic tilt or a lack of core stability that was required for our population to be in our study. This means that the findings of our study aren’t secluded to a small sect of the population with a distinguishable and pathological problem, but are important to all individuals similar to those in our study. The results of the study can only be extrapolated to a general population with demographics matching that of the population in this study. Looking at a certain pathologic population (i.e. those with excessive Anterior Pelvic Tilt and Lumbar Lordosis) may have yielded different results but we can’t say for sure what they would have been by using any results from this study. This Core Stability Intervention Protocol is efficacious in potentially lowering the risk of injury for the general population, who may present with excessive hip adduction during a dynamic Overhead Squat. Despite only finding clinically significant results with decreasing hip adduction, by looking at a general population as we did we can now say this program would be an effective one in changing lower extremity kinematics and lowering injury risk for a healthy population with the simple goals of trying to prevent any future injury and stay athletically competitive. Kinematic risk factors for injury at the lower extremity occur with excessive trunk flexion and hip adduction and may result from a lack of neuromuscular control (Fields et al., 2013). This concurrent relationship holds more weight when considering that the current study elicited statistically significant decreases in both trunk flexion and hip adduction, and had clinical significance with decreases in hip adduction. As a consequence, clinicians using rehab programs with the specific goals of lowering hip adduction
and trunk flexion now have a quick and easy to use clinical tool to do so by using the Core Stability Intervention Protocol.

The second main limitation is that this was just an acute intervention, so we would theoretically see a larger difference and subsequent reduction in injury rates at the lower extremity with a series of longer treatment intervention sessions utilizing the same exercises. The goal of this study was to simply engage and activate the core musculature with a quick Transverse Abdominus contraction teaching session and following exercises - it wasn’t to increase muscular endurance or strength. With significant findings after such a short routine that only took around 10 minutes to complete, it is evident that cueing the Transverse Abdominus alone is enough to cause a significant impact on the kinematics of the lower extremity. The study by Fields et al. again points out the connection between neuromuscular control and excessive hip adduction, which is tied to increased injury at the lower extremity. The second is that this was an acute intervention, so a long-term study may have helped solidify learning patterns for the 8 exercises and helped the individuals gain neuromuscular control of their core musculature. This could have resulted in larger or overall different changes to lower extremity kinematics. Future research would do well to look at the effect of longer and more frequent practice sessions over a six to eight week period which would theoretically result in increased neuromuscular control and lead to lowered hip adduction and lowered risk and rate of injury to the lower extremity and knee.

The third main limitation is that this study only looked at movement patterns during a dynamic Overhead Squat Assessment, which means that these results can only be extrapolated to a very similar setting. While the Overhead Squat Assessment is commonly used to assess movement pattern dysfunction of the lower extremity (Bell et al., 2008; Macrum et al., 2012; Padua et al., 2012; B. T. Zazulak et al., 2007), it only has limited implications for evaluating dysfunction
of the Lumbo-Pelvic-Hip-Complex and lower extremity in application to other dynamic activity. To get a better idea of the effects of this Protocol, we would need to look at even more dynamic movement, including jump landing, cutting and change of direction, and running tasks. The Overhead Squat Assessment becomes a valid assessment tool in that it accurately measures dysfunction of the lower extremity, ergo measuring dysfunction in the LPHC, but that does not mean that those changes are the same ones seen during even more dynamic activity such as a jump landing activity, landing and cutting to change direction, or running progressions. It would be very beneficial to gather future research that looked more specifically at any potential carry over the Core Stability Intervention Protocol might have on more complicated dynamic movement than simply an Overhead Squat Assessment activity.

Another area for future research might include a different research design than a simple paired samples design-- possibly one in which two groups are compared. One simply performing the squat tasks with no Core Stability Intervention Protocol between pre and post squat measurements, and another with the Core Stability Intervention Protocol. This would allow us to see if changes occurred in the squat when comparing pre to post measurements as a result of the Core Stability Intervention Protocol itself or as a result of something previously not considered such as a learning curve associated with the squat task itself and performing more over time. A longer term study with multiple sessions would also allow us to perform the Core Stability Intervention Protocol and the Overhead Squat tasks several times and account for differences in learning these tasks among individuals partaking in the study.
Conclusion

The results of this study saw a clinically significant decrease in hip adduction as a result of the Core Stability Protocol Intervention, which could be very significant in future research related to changing lower extremity kinematics to alter patterns of injury specifically at the Anterior Cruciate Ligament of the knee. The Core Stability Protocol Intervention was shown to be efficacious in significantly altering lower extremity kinematics during a dynamic Overhead Squat. The study has sufficient power with its current sample size to conclude that the Intervention has clinical significance and could lead to a lowered potential for injury at the knee.

Overall, we need more research because there is still uncertainty as to what this all actually means in the real world. The scope of our study is very small right now, but optimistically speaking it could eventually lead to something larger if more research is done to iron out the details and verify or debunk these findings. Right now, it is only possible to hypothesize on any real change, but we do have some empirical back for this specific collection of 8 core exercises making up the Core Stability Intervention Protocol used in this specific manner as we did in the lab setting.

We still need to make sure that anyone reading these results does not misinterpret that a clinically significant change in one kinematic value equates to a change in all functional movement, lowered risk of injury, and lowered rate of injury.

In conclusion, these findings are exciting but also need to be seen through their true scope. They could be very clinically beneficial but only prove that a one-time core stability intervention lasting around 10 minutes could have significant change in the SMRL at this point. We need to do more functional activity and look at EMG of glute max, rectus abdominis and other musculature at the LPHC. Surface EMG may not work so well but intramuscular EMG
would allow us a better vantage point, despite having to jump through many more hoops with the IRB and working hard to find subjects who would agree to such a procedure. We could then use this information to determine how a longer term Protocol with these same 8 exercises would change Lower Extremity kinematics.
Appendix

-Figure 1: Toe Tapes Exercise. Keeping the knee bent to 120 degrees, the hip was flexed to bring one foot 6 inches off the ground.

-Figure 2: Dying Bug Exercise. Dying Bug starting position with arms flexed to 90 degrees and knees bent to 120 degrees. Dying Bug extended position with the opposite arm and leg flexing to meet above the umbilicus.

-Figure 3: Hip Lift Exercise. The upright bridged position with the shoulders, hips, and knees forming a straight line.

-Figure 4: Hip Lift with Knee Extension Exercise. Upright bridged position in which the knee is fully extended while hips remain level.

-Figure 5: Head Lift Exercise. Prone position in which the head is chin is lifted 3-4 inches off the ground.

-Figure 6: Head Lift with Rotation Exercise. Chin is lifted 3-4 inches off ground and rotation to either side occurs so that the chin is in line with the shoulder.

-Figure 7: Hip Extension Exercise. Prone position with the subject extended at the hip while both hands help maintain balance.

-Figure 8: Quadruped Exercise. Extended position with the opposite arm and leg being lifted off the ground, while balance is maintained with the remaining limbs.

-Table 1: Table with descriptive and inferential statistics that were run on the participant population specific to the 5 Dependent Variables.

-Table 2: Table describing demographic data for the participants of the study.
Figure 1: Toe Taps
Figure 2: Dying Bug
Figure 3: Hip Lift
Figure 4: Hip Lift with Knee Extension
Figure 5: Head Lift
Figure 6: Head Lift with Rotation
Figure 7: Hip Extension
Figure 8: Quadruped
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Table 2:

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Works Cited


Boling, Michelle C.; Padua, Darin A.; Blackburn, J Troy; Petschauer, Meredith; and Hirth, Christopher, "Hip Adduction Does not Affect VMO EMG Amplitude or VMO:VL Ratios During a Dynamic Squat Exercise" (2006). Clinical & Applied Movement Science Faculty Publications. Paper 1.


