Clinical Tests of Lumbo-Pelvic-Hip Complex Function in Individuals with and without Scapular Dyskinesis: Implications for Identifying Individuals at Risk for Upper Extremity Injury

by

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ABSTRACT

Scapular dyskinesis reflects suboptimal scapular function that may have damaging effects on surrounding structures. Due to its association with nearly all shoulder injuries, it has been recommended that the dynamic scapular dyskinesis test be performed during the clinical evaluation process of shoulder injury or pain. However, the shoulder complex relies on more than just the scapula for safe and efficient function. The ability of the shoulder complex to function efficiently depends greatly upon the lumbo-pelvic-hip complex to provide proximal stability for distal mobility, as well as to generate the forces and energy necessary to perform many upper extremity tasks. Therefore, previous research has also suggested the use of clinical tests of lumbo-pelvic-hip complex function to identify any proximal dysfunction that may decrease upper extremity function. Specifically, the single-leg squat has been proposed as an appropriate test of lumbo-pelvic-hip complex stability, due to its ability to reveal dysfunction at multiple segments of the kinetic chain in multiple planes of motion. While this recommendation has existed in the literature for quite some time, no authors have examined kinematics of the single-leg squat in individuals with upper extremity dysfunction. Therefore, the primary purpose of the current study was to examine trunk, pelvis, hip, and knee kinematics during a single-leg squat in individuals with and without scapular dyskinesis. Additionally, a single-leg drop landing test was used as a secondary test due to its more dynamic nature compared to the single-leg squat, which may be more revealing of lumbo-pelvic-hip complex dysfunction not evident in the prior test. Based on results from the scapular dyskinesis test, 32 participants were identified as having scapular dyskinesis, and 32 participants were healthy controls. The scapular dyskinesis test consisted of 5 repetitions of weighted shoulder flexion. Dyskinesis was considered present if there was excessive superior migration, inferior angle or medial border prominence, or dysrhythmia. After the scapular dyskinesis test, kinematics were collected while participants performed 3 repetitions of the single-leg squat and single-leg drop landing tests. Results indicated that trunk rotation, hip rotation, and knee valgus during the single-leg squat were significantly greater in the dyskinesis group compared to the control group. These findings may be valuable for clinicians during the shoulder evaluation process, as well as for the development of corrective exercise strategies for patients with shoulder injuries. There were some limitations to the current study. First, although scapular dyskinesis is associated with shoulder pain/injury, it is not considered an injury in and of itself. Therefore, the scapular dyskinesis group included participants with and without injury. Second, although previous research has highlighted some sex differences in single-leg squat and single-leg drop landing performance, both sexes were included in the current study in an attempt to generalize findings across sexes. Future research should consider examining single-leg squat and single-leg drop landing kinematics in individuals with and without shoulder dysfunction with sex as an additional factor.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER I

INTRODUCTION

The shoulder complex offers the greatest range of motion of any joint in the body due to its unique anatomy, which is comprised of articulations between the humerus, scapula, thorax, clavicle, and sternum (Clark, 2014). Specifically, the glenohumeral (GH) joint allows for circumduction of the humerus due to its ball-and-socket configuration, and primarily relies on musculature (as opposed to static ligamentous structures) for its stability. In turn, the GH joint sacrifices stability for an increase in mobility, and must depend on its surrounding structures for the adequate stability necessary to complete a wide range of upper extremity tasks. Due to the complexity and lack of stability present in the GH joint, it is susceptible to dysfunction that may lead to pain or injury. Shoulder pain has been reported in up to 21% of the general population, contributing to an estimated cost of $39 billion per year in the United States (Bongers, 2001; Johnson, 2005; Urwin, 1998). With a small percentage of reported shoulder pain being a result of traumatic shoulder injuries, many of these injuries have an insidious onset and are often associated with abnormal positions and motions of the scapula (Kibler, 1998; Matsen, 1990).

Efficient function of the upper extremity relies greatly upon the ability of the scapula to fulfill its responsibilities to: (1) provide a stable base for GH articulation, wherein the scapula must move in a coordinated manner with respect to the humerus to accommodate motion in multiple planes; (2) allow for the cooperative activation of the scapular musculature, thereby providing shoulder girdle stability; (3) serve as a stable base for attachment for the scapular stabilizing musculature as well as the prime movers of the humerus; (4) allow for elevation of the humerus above 120°, by upwardly rotating to increase the subacromial space through which the biceps brachii and rotator cuff tendons pass; and (5) allow for the efficient transfer of forces from the lower extremity and trunk, thereby reducing the stress placed on the smaller upper extremity muscles to meet the demand of many upper extremity movements (Kibler, 1998; Kibler, 2016).

When the scapula is functioning properly, the trapezius, rhomboid, levator scapulae, and serratus anterior muscles work to stabilize and rotate the scapula. During arm elevation, the scapula moves into a position of upward rotation, and posterior tilt (Lopes, 2015). This is accomplished by the cooperative activation of the upper trapezius (UT), lower trapezius (LT), and serratus anterior (SA) working as a force couple to elevate the acromion and allow the humerus to move through its full range of motion (Cools, 2007; Yamauchi, 2015). Alterations in the normal positions and motions of the scapula have been termed scapular dyskinesis, which is indicated by a loss of control of retraction and posterior tilt of the scapula, resulting in protraction, anterior tilt, and excessive internal rotation (Kibler, 2003; Kibler, 2016).

Scapular dyskinesis has many causes, which may include bony (thoracic kyphosis, clavicle fracture), neurologic (long thoracic or spinal accessory nerve palsy), joint (acromioclavicular (AC) or GH instability), or most commonly soft tissue (muscle imbalance, inhibition, tightness, or injury). (Kibler, 2010; Kibler, 2013) Regardless of its cause, scapular dyskinesis reflects suboptimal scapular function that can have damaging effects on surrounding structures. Although dyskinesis itself is not an injury, nor is it directly related to any specific shoulder pathology, it is associated with decreased GH abduction and external rotation strength, and has been reported to be present in 67-100% of shoulder injuries, such as subacromial impingement syndrome, rotator cuff strains and tears, labral tears, and shoulder instability (Hebert, 2002; Illyes, 2006; Kibler, 2013; Ludewig, 2000; Ogston, 2007; Paletta, 1997). Therefore, it has been suggested that an assessment for identifying scapular dyskinesis should be performed during the clinical evaluation process for shoulder pain (Kibler, 2003; Kibler, 2008).

The current recommendation for the clinical assessment of scapular dyskinesis is the visual assessment of the scapula statically, as well as during a dynamic scapular dyskinesis test (SDT). The SDT uses a “yes/no” rating system to denote the presence of dyskinesis (Kibler, 2013). The SDT involves the identification of scapular winging (any medial border or inferior angle prominence away from the thorax), excessive superior migration of the scapula, or dysrhythmia (a non-smooth, stuttering, or rapid movement of the scapula) during elevation or lowering of the arms in the sagittal or scapular plane (Kibler, 2013; Kibler, 2016). This method for identifying scapular dyskinesis has yielded high specificity (79%) and predictive value (74%), and therefore has been adopted for clinical use (Kibler, 2013; Uhl, 2009).

In addition to the evaluation of scapular function, it has been suggested that particular attention should be given to areas proximal to the scapula, in an attempt to identify dysfunction of the trunk and lower extremities (Kibler, 2003; Kibler, 2008; Sciascia, 2012). Common proximal causes of upper extremity dysfunction have been identified, and include: poor rear foot control, a lack of hip range of motion, hip extensor and abductor tightness and/or weakness, limited spinal mobility, limited pelvic motion and/or strength, and poor scapular control (Sciascia, 2012). Since a major role of the scapula is to be the link in the kinetic chain that acts as a funnel for the transfer of forces and energy from the lower extremity and core to the upper extremity, it is imperative that the proximal segments function efficiently to provide proximal stability for distal mobility of the upper extremity. This requires adequate strength, stability, and mobility of the trunk, pelvis, hips, and legs.

Trunk stability is achieved by adequate function of the intrinsic core stabilizing musculature, namely the multifidi, internal obliques, transverse abdominus, diaphragm, and pelvic floor muscles. The functional arrangement of these muscles and their appropriate activation allows for increased intra-abdominal pressure, which subsequently creates a rigid cylinder in the trunk. When these muscles are functioning properly, they increase trunk stability preceding movement of the upper limbs (Cholewiski, 1999; Daggfeldt, 1997; Kibler, 2006). In addition to the intrinsic core stabilizers, structures such as the quadratus lumborum, latissimus dorsi, and thoracolumbar fascia contribute to trunk stability and function. Quadratus lumborum is primarily viewed as a frontal plane stabilizer during lateral flexion movements. However, because it attaches at the 12th rib and iliac crest, it also activates to stabilize the spine during sagittal plane trunk movements (McGill, 2001). The latissimus dorsi, primarily regarded as an adductor, extensor, and internal rotator of the humerus, originates at the spinous processes of the T7 through T12 vertebrae, the iliac crest of the pelvis via the thoracolumbar fascia, and ribs 9-12; and it inserts at the inferior angle of the scapula and the intertubecular groove of the humerus. Together, the latissimus dorsi and the thoracolumbar fascia cover many of the deep muscles of the spine and trunk and assist in trunk and pelvis stabilization, while also making a direct connection between the lower extremity (via the gluteus maximus), pelvis, scapula, and upper extremity (Kibler, 2006; Sciascia, 2012).

The hips and pelvis, along with associated musculature, serve as a base of support for the trunk. As well as providing stability to the trunk, the muscles that attach to the hips and pelvis (i.e. gluteals) control movements of the lower extremity, and can generate large forces that are transferred to the trunk and upper extremity (Kibler, 1995; Kibler, 2006). Additionally, the hips, pelvis, and trunk collectively work to generate anticipatory postural adjustments based on pre-programmed motor patterns (Kibler, 2006; Sciascia, 2012). These activations are developed in the lumbo-pelvic-hip complex (LPHC) and create interactive moments that provide proximal stability, thereby allowing efficient distal mobility (Frieldi, 1984).

It has been reported that the hip and pelvis provide over half of the kinetic energy and force associated with dynamic overhead movements (e.g. throwing and serving in tennis), and a 20% decrease in kinetic energy generated by the LPHC would require either a 34% increase in arm velocity or an 80% increase in shoulder mass to deliver the same amount of energy to the upper extremity and onto the ball (Kibler, 1995). In terms of trunk position and scapular function during less dynamic movements, it has been reported that trunk rotation to the ipsilateral side during traditional scapular retraction and GH external rotation exercises results in increased scapular external rotation and posterior tilt, as well as increased LT activation and decreased UT activation when compared to the conventional seated position accompanying these exercises (Yamauchi, 2015). Others have also reported altered activity of the scapular stabilizers with varied lower extremity, pelvis, and trunk positions (Maenhout, 2009; De Mey, 2013).

Due to associations between upper extremity function and hip, pelvis, and trunk position, dysfunction of these structures has been linked with upper extremity injury. To emphasize the major implications for understanding the connection of the LPHC to upper extremity injury, one study reported that nearly half of patients who sustained labral tears of the shoulder also had decreased hip range of motion coupled with decrease hip abductor strength (Burkhart, 2000). Additionally, another study found a high incidence of scapular dyskinesis in preadolescent and adolescent baseball players coupled with a universally poor performance of the single-leg squat (SLS) test (Beckett, 2014). The findings from these studies indicated significant associations between LPHC dysfunction and upper extremity impairment, and provide support for the recommendation to examine more proximal segments of the kinetic chain when assessing shoulder function.

The SLS is commonly used to assess LPHC function, and has previously been suggested as an appropriate test to examine multiple points of the kinetic chain during evaluation for shoulder injury or dysfunction (Beckett, 2014; Kibler, 2006; Sciascia, 2012; Wilk, 2016). However, while several authors have suggested its use during the upper extremity clinical evaluation process, none have examined the kinematics of the SLS in individuals with and without scapular dyskinesis or any other shoulder pathology. The SLS is a controlled functional task meant to resemble athletic activities (e.g. running, cutting maneuvers) as well as activities of daily living (e.g. stair ascent and descent), and has been studied extensively in the realm of lower extremity dysfunction (Claiborne, 2006; Crossley, 2011; Hollman, 2014; Nakagawa, 2012; Whatman, 2011; Whatman, 2013).

Individuals with LPHC weakness or lower extremity injury have exhibited increased movement deviation in the frontal and transverse planes, specifically: trunk lateral flexion and rotation, pelvis lateral flexion and rotation, hip adduction and rotation, and knee valgus during the SLS (Ageberg, 2010; Claiborne, 2006; Crossley, 2011; Dwyer, 2010; Graci, 2015; Hollman, 2014; Kulas, 2012; Munkh-Erdene, 2011; Nakagawa, 2012; Souza, 2009; Willson, 2006; Yamazaki, 2010; Zeller, 2003). Differences in SLS performance have been largely associated with measures of hip muscle strength, with increased frontal and transverse plane movement deviation of the trunk, hip, and knee, and decreased sagittal plane motion of the knee, hip, and trunk indicating weakness of the LPHC musculature and kinetic chain dysfunction.

A similar, yet more dynamic functional test compared to the SLS, is a single-leg drop landing (SLDL). The SLDL is most commonly used to assess LPHC function and readiness for return to sport due to its likeness to dynamic athletic movements (Jacobs, 2007; Myer, 2015; Whatman, 2013; Zazulak, 2005). Although kinematics of the SLDL have been reported less in the literature, they tend to follow a similar trend when compared to the SLS – with increased frontal and transverse plane movement and decreased sagittal plane movement indicating LPHC weakness and an increased risk for lower extremity injury (Ali, 2013; Coventry, 2006; Jacobs, 2007; Kerzonek, 2008; Kiriyama, 2009; Myer, 2015; Nagano, 2009; Orishimo, 2006; Orishimo, 2009; Oritz, 2008; Patrek, 2011; Schmitz, 2007). While SLDLs are similar to the SLS in that they require adequate strength, balance during single-limb support, and neuromuscular control of the lower extremity and LPHC musculature, the dynamic nature of this assessment may give further insight into possible LPHC dysfunction not apparent during the SLS. Although many functional tests for detecting LPHC dysfunction exist, no standard test has been adopted for clinical use. Tests such as the SLS and SLDL which mimic conditions of daily living or athletic maneuvers, are easy to administer in a clinical setting requiring minimal equipment or space, and are valid for assessing multiple segments of the kinetic chain simultaneously are most practical and beneficial for clinicians.

Statement of the Problem

The ability of the upper extremities to function efficiently depends greatly on the ability of the LPHC to provide proximal stability for distal mobility. While clinical tests of kinetic chain function have been suggested during the evaluation process for shoulder injury and dysfunction, there is currently no information available regarding the association between kinematics of clinical tests of LPHC function, such as the SLS or SLDL, and the presence of scapular dyskinesis. The main goal of this study is to examine the association between the presence of scapular dyskinesis and kinematics of the trunk, pelvis, hip, and knee during tests that are used clinically. If there is an association between SLS or SLDL performance and scapular dyskinesis, clinicians may be able to identify individuals who may be at risk for developing shoulder dysfunction before pain or injury occurs.

Statement of Purpose

The purposes of this research were: (1) to examine the association between scapular dyskinesis and kinematics during the SLS and SLDL by comparing maximum trunk, pelvis, hip, and knee movement deviation; and (2) to determine if any common movement compensations during the SLS and SLDL have a greater prevalence in individuals with scapular dyskinesis.

Hypotheses

Primary Objective (RQ1) – To examine the association between scapular dyskinesis and the maximum excursion from neutral (absolute value) during the SLS and SLDL.

1) This objective was addressed by comparing maximum excursion kinematics of the knee, hip, pelvis, and trunk during the SLS and SLDL in participants with and without scapular dyskinesis.

   H_1: It was hypothesized that the maximum excursion trunk of flexion/extension in those with scapular dyskinesis is different than those without scapular dyskinesis during the SLS and SLDL.

   H_2: It was hypothesized that the maximum excursion of trunk lateral flexion in those with scapular dyskinesis is different than those without scapular dyskinesis during the SLS and SLDL.

   H_3: It was hypothesized that the maximum excursion of trunk rotation in those with scapular dyskinesis is different than those without scapular dyskinesis during the SLS and SLDL.

H_4: It was hypothesized that the maximum excursion of pelvis lateral flexion in those with scapular dyskinesis is different than those without scapular dyskinesis during the SLS and SLDL.

H_5: It was hypothesized that the maximum excursion of pelvis rotation in those with scapular dyskinesis will be different than those without scapular dyskinesis during the SLS and SLDL.

H_6: It was hypothesized that the maximum excursion of hip flexion/extension in those with scapular dyskinesis is different than those without scapular dyskinesis during the SLS and SLDL.

H_7: It was hypothesized that the maximum excursion of hip adduction/abduction in those with scapular dyskinesis is different than those without scapular dyskinesis during the SLS and SLDL.

H_8: It was hypothesized that the maximum excursion of hip rotation in those with scapular dyskinesis is different than those without scapular dyskinesis during the SLS and SLDL.

H_9: It was hypothesized that the maximum excursion of knee flexion/extension in those with scapular dyskinesis is different than those without scapular dyskinesis during the SLS and SLDL.

H_{10}: It was hypothesized that the maximum excursion of knee valgus/varus in those with scapular dyskinesis is different than those without scapular dyskinesis during the SLS and SLDL.

Secondary Objective (RQ2) – To determine if any specific movement compensations during the SLS and SLDL have a greater prevalence in individuals with scapular dyskinesis.

1) This objective was evaluated by comparing positional kinematics (i.e. not absolute value of movement deviation) of the knee, hip, pelvis, and trunk during the SLS and SLDL in participants with and without scapular dyskinesis.

   H_1: It was hypothesized that those with scapular dyskinesis would exhibit an increased degree of trunk lateral flexion toward the test limb.

   H_2: It was hypothesized that those with scapular dyskinesis would exhibit an increased degree of trunk rotation toward the test limb.

   H_3: It was hypothesized that those with scapular dyskinesis would exhibit an increased degree of pelvis lateral flexion toward the non-test limb.

   H_4: It was hypothesized that those with scapular dyskinesis would exhibit an increased degree of pelvis rotation toward the non-test limb.

   H_5: It was hypothesized that those with scapular dyskinesis would exhibit an increased degree of hip adduction.

   H_6: It was hypothesized that those with scapular dyskinesis would exhibit an increased degree of hip internal rotation.

   H_7: It was hypothesized that those with scapular dyskinesis would exhibit an increased degree of knee valgus.

Limitations

The limitations of the current research study are as follows:

1) Participants with and without shoulder pain who have scapular dyskinesis were included in the dyskinesis group. Although scapular dyskinesis is present in individuals with shoulder injuries, scapular dyskinesis itself is not an injury nor do all individuals with scapular dyskinesis have shoulder pain or injury. Therefore, the dyskinesis group may have had a mixture of uninjured and injured participants.
2) Prior research has noted some sex differences in SLS and SLDL performance. However, the current study included both males and females in attempt to generalize the findings of the current study across sexes.

Delimitations

1) Kinematic data were collected using a tethered electromagnetic tracking system.
2) The SDT was filmed with a video camera for visual analysis by the rater.
3) Participants were physically active individuals between the ages of 19-30 years and have no lower extremity injury within the past 6 months or upper extremity surgery within the past 1 year.
4) All data collection protocols took place in a controlled setting inside the Auburn University Sports Medicine & Movement Laboratory located on the Auburn University campus.

Glossary

Kinematics – branch of mechanics that describes motion without regard to the involved forces causing said motion. Variables include both linear and angular displacements, velocities, and accelerations.

Kinetic Chain – a model that describes the series of interdependent, linked body segments that (1) function in a proximal-to-distal pattern in order to impart the desired action on the most distal segment, and (2) allow for execution of coordinated, efficient body movements.

Lumbo-pelvic-hip Complex (LPHC) – a component of the musculoskeletal system that includes the proximal femurs, pelvis, and lumbar vertebrae as well as all musculature originating or inserting on these body segments.

Range of Motion – the amount of motion available at a specific joint.

Scapular Dyskinesis – the alteration of normal scapular position or motion that presents as protraction, anterior tilt, and excessive internal rotation.

CHAPTER II

REVIEW OF LITERATURE

The ability of the extremities to function efficiently depends greatly on proximal stability provided by the lumbo-pelvic-hip complex (LPHC). However, the vast majority of the literature examining the use of clinical tests of LPHC function has only examined their use in regard to detecting risk of lower extremity injury and dysfunction. Recent literature regarding upper extremity dysfunction has suggested the use of functional tests of LPHC stability during the evaluation process for individuals with upper extremity injuries but, no studies have examined the association between single-leg squat (SLS) and single-leg drop landing (SLDL) kinematics and the presence of scapular dyskinesis. This study will attempt to identify the association between LPHC stability and the presence of scapular dyskinesis. The ability of functional tests that are commonly used in the clinical setting to assess kinetic chain function will be employed to determine whether these tests can predict the risk of upper extremity injury in the general population of females.

This chapter is divided into two sections: (1) examination of literature on two clinical tests of LPHC stability, specifically the kinematics relevant to the current study and implications for detection of kinetic chain dysfunction, and (2) literature pertaining to the clinical assessment of scapular dyskinesis.

Clinical Tests of Lumbo-Pelvic-Hip Complex Stability

The LPHC has been described as the functional center of the kinetic chain, providing a stable proximal base for proper function and mobility of the distal extremities (Tarnanen, 2012). Although there have been several definitions in previous literature, LPHC stability can be summarized as the neuromuscular control and capacity of the LPHC to control the position and motion of the trunk over the pelvis and leg to allow for optimum transfer of energy and forces throughout the kinetic chain (Kibler, 2006). Due to the role of the LPHC in facilitating efficient movement and energy transfer to the extremities, recent literature has highlighted the importance of including the LPHC in the evaluation and rehabilitation of both lower and upper extremity injuries. (Kibler, 2006; Kibler 2008)

Although there are many methods for measuring LPHC strength and control, no standard functional test has been adopted for clinical use. Clinical tests of neuromuscular function are meant to resemble conditions of daily life, as well as more strenuous activities, and are easy to administer in clinical and research settings. For use in a clinical setting, assessment methods that require little equipment, space, and time, and that are capable of assessing overall neuromuscular control at multiple segments and in multiple directions, are most practical and efficient. For this reason, functional tests are indispensable to clinicians and researchers due to their ability to quickly and easily detect movement patterns associated with dysfunction.

Single Leg Squat

The SLS test is a controlled functional task commonly used to assess LPHC strength, dynamic flexibility, balance, and overall neuromuscular control relating to a number of athletic tasks (running, cutting, and landing tasks) as well as activities of daily living (ambulation, stair ascent and descent) (Bolgla, 2008; Brindle, 2003; Claiborne, 2006; Crossley, 2011; DiMattia, 2005; Nakagawa, 2012; Willson, 2006). Due to the multi-segmental and multi-directional movements associated with the SLS, control of the entire lower extremity, as well as eccentric control of trunk, pelvis, hip, and knee musculature is required to perform this test with minimal movement deviation in frontal and transverse planes (Crossley, 2011; McCurdy, 2010; Munkh-Erdene, 2011; Zeller, 2003). Several studies of two-dimensional (2D) and three-dimensional (3D) kinematics have revealed that the SLS is a valid and reliable functional test of LPHC function (Claiborne, 2006; Crossley, 2011; DiMattia, 2005; Graci, 2012; Graci, 2015; Ireland, 2003; Nakagawa, 2012; Willson, 2006).

SLS kinematics have been reported in numerous studies, with the majority of studies examining the SLS in populations with lower extremity dysfunction such as anterior knee pain (AKP), patellofemoral pain syndrome (PFPS), and anterior cruciate ligament (ACL) injury. Thus far, no normative data have been established for SLS kinematics in healthy or injured populations, however the data from previously published studies provide overall trends for both healthy and injured populations. For the purposes of describing SLS kinematics, previously reported data on healthy populations will be discussed first, followed by reported kinematics associated with injury or dysfunction. Finally, kinematics from several of the studies reviewed have analyzed at different events during the SLS. The majority of these studies have derived their values from subtracting a double- or single-leg "static trial" or neutral stance value, and have reported SLS kinematic data as the maximum excursion from neutral throughout the entire SLS. Therefore, kinematics will be discussed in correspondence with this approach, with further explanation for studies whose methodologies differ.

Trunk flexion has been previously reported in a healthy population in only two studies. In the first, Zeller et al. (2003) reported maximum excursion of trunk flexion to be 30.5° ± 13.7 for males, and 29.5° ± 10.1 for females (relative to a global reference frame). Another study, which examined trunk flexion relative to the pelvis at the events of 45° of knee flexion and peak knee flexion, found that at 45° knee flexion males and females displayed trunk flexion values of 11.49° ± 6.58 and 19.12° ± 8.87, respectively, and at peak knee flexion, males and females displayed 7.04° ± 7.91 and 19.28° ± 9.24, respectively (Graci, 2012). Although significant differences were only found in the second of these studies, both suggest that healthy females tend to flex their trunk less than males during the SLS. Graci et al. (2012) theorized that this posture in females may be a result of inadequate hip extensor strength to control the forward displacement of the center of mass during the descent phase of the SLS (Graci, 2012). In support of this concept, Nakagawa et al. (2012) found significantly decreased activation of the gluteus maximus during the SLS in healthy females compared to males. Other studies have reported greater concentric and eccentric hip extensor strength in males than in females, as well as decreased forward trunk flexion in females during drop landing tasks and cutting maneuvers (Claiborne, 2006; Decker, 2003; Hewett, 2009; Shimokochi, 2013).

Due to its effects at the hip and knee joints, decreased forward trunk flexion during landing tasks has been described as a possible contributor to the increased incidence of ACL injury in females. It has been previously reported that increasing trunk flexion during drop landings produces concomitant increases in knee and hip flexion (Blackburn 2008), as well as decreased anterior shear forces at the knee and decreased ground reaction forces (GRF) (Blackburn, 2009). With regard to ACL injury and the SLS, one study required participants to perform a SLS under two conditions: (1) minimizing the amount of forward trunk lean throughout the squat, and (2) moderately increasing the amount of forward trunk lean throughout the squat. The results of this study demonstrated that increasing the amount of trunk flexion (from 15° ± 6.6 in the first condition to 38.3° ± 5.9 in the second condition) during the SLS resulted in lower peak ACL forces (24%) and ACL strain (16%) (Kulas, 2012). Therefore, decreased forward trunk flexion during the SLS is likely indicative of possible LPHC dysfunction that may place an individual at risk for injury during more dynamic athletic maneuvers.

Maximum excursion of trunk lateral flexion has been shown to occur in the direction of the test limb and ranges from 6.4° ± 2.3 to 26.4° ± 20.1 for males, and 7.5° ± 3.5 to 9.8° ± 9.1 for females (Nakagawa, 2012; Zeller, 2003). Of the two studies that have reported trunk lateral flexion, one found significantly greater trunk lateral flexion in females than in males (Nakagawa. 2012), while the other found significantly greater trunk lateral flexion in males (Zeller, 2003). Data from an additional study provide a different representation of frontal plane trunk motion suggest that while females tend to laterally flex the trunk toward the ipsilateral side throughout the motion, at 45° of knee flexion males tend to laterally flex the trunk slightly in the direction contralateral to the test limb, and then shift toward the side ipsilateral to the test limb at maximum knee flexion (Graci, 2012).

Regarding lateral trunk movement associated with injury, one study reported that individuals with PFPS demonstrate significantly greater trunk lateral flexion than healthy controls (Nakagawa 2012). In this study, healthy controls (both sexes combined) exhibited 6.7° ± 3.0 of trunk lateral flexion toward the ipsilateral side (i.e. toward the test leg) versus 9.3° ± 5.3 in individuals with PFPS. This finding is consistent with other studies that have found increased lateral trunk motion as well as decreased hip abduction strength in individuals with PFPS during the SLS and stair descent (Bolgla, 2008; Crossley, 2011) Furthermore, it has been reported that individuals with AKP demonstrate delayed and reduced activation of the gluteus medius during stair ascent and descent (tasks that are closely related to the SLS) compared to healthy controls. (Brindle, 2003)

It has been proposed that laterally flexing the trunk toward the weight-bearing side during the SLS may reduce the demand placed on the gluteus medius to stabilize the trunk in the frontal plane due to changes in the position of the center of mass over its base of support (Nakagawa, 2012). Additionally, it has been stated that because the trunk and upper extremities comprise approximately 60% of total body mass, ipsilateral trunk motion increases the ground reaction force (GRF) passing lateral to the knee, and consequently, the knee abduction load (Hewett 2009). This suggests that while trunk lateral flexion toward the weight-bearing side serves as compensation for weak hip abductor strength, it also exposes dysfunction at more distal locations of the kinetic chain.

The compensation of trunk lateral flexion during athletic movements has also been associated with directional change during cutting and sidestepping maneuvers known to contribute to ACL injury. Particularly, foot position away from the midline with the vertical GRF passing lateral to the knee joint center, and the trunk leaning in the direction of the plant leg have been shown to contribute to increased knee valgus and internal rotation loads at the knee during the weight acceptance phase of cutting maneuvers (Dempsey, 2007). Furthermore, a study by Dempsey and colleagues (2009) determined that trunk lateral flexion toward the ipsilateral side during cutting maneuvers is indicative of hip abductor weakness, and that trunk lateral flexion reduces the demand on the gluteus medius to stabilize the LPHC (Dempsey, 2009). Therefore, it is likely that the SLS compensation of increased ipsilateral trunk lean is an appropriate indicator of inadequate hip abductor strength, and thus LPHC control.

Transverse plane trunk rotation in healthy males and females has only been reported in one study. It was reported that at the event of 45° of knee flexion, healthy males and females displayed -3.56° ± 2.74 and -0.96° ± 2.27, respectively; and at maximum knee flexion, males and females displayed -2.21° ± 3.39 and -0.34° ± 3.10, respectively (Graci 2012). In terms of overall movement, both males and females rotate their trunk in the same direction (toward the weight-bearing limb), with females rotating to a slightly lesser degree. Another study by Graci et al. (2015) reported trunk rotation values of -4.06° ± 4.31 at maximum knee flexion in females with PFPS. These data suggest that individuals with dysfunction tend to have a greater movement deviation of the trunk in the transverse plane, particularly toward the test limb.

Kinematics of the pelvis during the SLS have been reported in the frontal and transverse planes. Two studies have reported pelvis lateral flexion in healthy participants. In the first of these studies, maximum excursion during the SLS was reported to be 6.4° ± 2.3 for males, and 7.5° ± 3.5 for females (Nakagawa, 2012). The data from this study suggest that both males and females tend to exhibit pelvic lateral tilt toward the contralateral test limb (a compensation that is also referred to as contralateral pelvic drop), with no significant differences between sexes. Similarly, the study by Graci et al. (2012) did not find significant differences between sexes in pelvis lateral flexion, however the data from this study were extracted from the events of 45° knee flexion and maximum knee flexion (as opposed to the maximum excursion throughout the entire motion) (Graci, 2012). At 45° knee flexion, the authors reported 0.58° ± 2.58 of pelvis lateral flexion in males and -0.49° ± 2.40 in females, suggesting that at this point in the SLS, males exhibit slight pelvis lateral flexion toward the contralateral side and females exhibit slight pelvis lateral flexion toward the ipsilateral side. At maximum knee flexion, however, both sexes laterally flex the pelvis toward the side contralateral to the test limb (males = 3.04° ± 3.42; females = 3.02° ± 2.33). (Graci 2012)

While no significant differences between sexes have been reported for pelvis lateral flexion during the SLS, Nakagawa et al. (2012) reported significantly greater pelvis lateral flexion toward the contralateral side in participants with PFPS compared to healthy controls. It was postulated that the increased degree of pelvis lateral flexion was a result of weak hip abductor strength. In further support of this theory, the authors reported significantly decreased eccentric hip abductor strength in the PFPS group when compared to healthy controls (Nakagawa, 2012).

Only one study has reported pelvis transverse rotation in healthy participants. Significant differences were found between sexes at 45° of knee flexion, but not at maximum knee flexion. At 45° of knee flexion males tend to rotate the pelvis toward the non-test limb (1.17° ± 1.96), while females rotate the pelvis toward the test limb (-1.49° ± 1.46); but at maximum knee flexion, both sexes rotate their pelvis toward the non-test limb (Graci 2012).

Although the study by Graci et al. (2012) was the only study to report transverse plane pelvis kinematics in healthy individuals, more information about the pelvis may be extracted by examining values of hip internal and external rotation. One study that examined 2D knee frontal plane projection angle (FPPA) in relation to three-dimensional kinematics found hip external rotation in participants who presented with knee valgus in 2D (Willson 2008). However, because knee valgus is partially a result of adduction and internal rotation of the hip, the authors clarified that the cause for the appearance of hip external rotation was actually due to transverse plane pelvis rotation away from the test limb, and if hip rotation had been examined relative to a global coordinate system (as opposed to the pelvis), kinematic values would have displayed internal rotation of the hip in participants with knee valgus.

Previous studies reporting hip flexion during the SLS have presented a range of 35.7° ± 14.9 to 86.5° ± 10.6 in males, and 48.0° ± 11.3 to 76.2° ± 18.0 in females. (Dwyer, 2010; Graci, 2012; Hollman, 2014; Kulas, 2012; Weeks, 2012; Whatman, 2011; Yamazaki, 2010; Zeller, 2003) This large range in values for hip flexion is partially accounted for by differences in instructions given to participants for performing the SLS. For example, participants in one study were instructed to squat down to a depth that they could maintain for 10 seconds without losing balance (Kulas, 2012), whereas participants in other studies had to perform the SLS in much less time (Hollman, 2014; Zeller, 2003) Furthermore, of the studies that reported hip flexion angles, some required participants to squat down as low as possible (Graci, 2012; Weeks, 2012; Yamazaki, 2010; Zeller, 2003) while others had a specific squat depth or knee flexion angle that needed to be reached (Hollman, 2014; Whatman, 2011). Therefore, caution should be taken when interpreting previously reported hip flexion values.

Results from several studies that have examined hip flexion during the SLS have been mixed, with just as many reporting greater hip flexion in females as in males. In studies that found greater hip flexion in males, the lesser degree of hip flexion in females was believed to be due to sex differences in hip extensor strength and neuromuscular control during the eccentric phase of the squat (Dwyer, 2010). Additionally, the presence of greater hip flexion in males may also help explain the more erect trunk posture in females found in the study by Graci et al. (2012). On the other hand, a study that found greater hip flexion in females questioned whether this finding could be causally related to the characteristic loss of valgus/varus control at the knee, subsequently affecting control at the hip (Zeller, 2003).

Maximum excursion of hip adduction/abduction kinematics for healthy males and females have ranged from 7.2° ± 3.8 to 15.5° ± 5.0 and 14.3° ± 4.6 to 20.8° ± 7.1 of hip adduction, respectively (Dwyer, 2010; Nakagawa, 2012; Weeks, 2012; Zeller, 2003). Two studies found significantly greater hip adduction in females than in males (Weeks, 2012; Zeller, 2003), while the results of other studies followed a similar trend (Dwyer, 2010; Nakagawa, 2012). Furthermore, one study found significant increases of hip adduction in females compared to males at the events of 45° of knee flexion and peak knee flexion (Graci 2012), and two studies that examined the SLS as a step-down from a raised platform also saw similar hip adduction values in females (Hollman, 2014; Souza, 2009).

It has been suggested that the increased degree of hip adduction in females may indicate that females have more difficulty controlling the hip musculature, especially the gluteus medius, during dynamic movement. (Zeller, 2003) Crossley et al. (2011) reported significantly greater hip abduction isometric strength and earlier onset of the anterior and posterior gluteus medius in individuals visually rated as “good” performers of the SLS, and subsequently determined that the SLS was a valid indicator of hip abductor muscle function when using visually identified hip adduction as a criterion for the assessment. Similarly, Nakagawa et al. (2012) found significantly decreased eccentric hip abductor torque coupled with significantly increased hip adduction in females compared to males.

Once the hip moves into adduction during the SLS, the femur internally rotates and the knee is placed in a valgus position. Due to the ball-and-socket configuration of the hip joint and its subsequent multi-directional range of motion, performance of the SLS relies greatly upon the eccentric control of the hip extensors, abductors, and external rotators during descent, and concentric control during the ascent phase. If weakness or dysfunction occur in any of these muscles, the result is decreased stabilization in any or all planes. Therefore, it is no surprise that individuals with PFPS, AKP, and ACL injuries, who all present with decreased gluteal activation, display greater amounts of hip adduction during the SLS and stair descent (Bolgla, 2008; Brindle, 2003; Levinger, 2007; Nakagawa, 2012; Souza, 2009; Weeks, 2012; Yamazaki, 2010).

A wide range of hip rotation kinematics has been reported in healthy participants during the SLS. Hip internal rotation in males and females has ranged from 5.5° ± 3.2 to 9.5° ± 4.3 and 1.2° ± 7.3 to 9.7° ± 5.4, respectively (Ageberg, 2010; Bolgla, 2008; Graci, 2012,; Hollman, 2014; Nakagawa, 2012; Weeks, 2012) and values of hip external rotation have ranged from -0.7° ± 3.87 to 16.04° ± 6.4 and 1.04° ± 4.40 to 15.7° ± 6.1 in males and females, respectively (Dwyer, 2010; Weeks, 2012; Yamazaki, 2010; Zeller, 2003). However, to better understand these values, the movements of the structures above and below the hip may require attention and consideration.

Since it has been established that the pelvis typically moves in the opposite direction of the weight-bearing limb during the SLS, hip rotation data obtained relative to the position of the pelvis may not accurately reflect the true direction of rotational movement of the femur (i.e. relative to a global coordinate system), thus comparison of the data both within and between different studies is somewhat difficult. Unfortunately, while most of the aforementioned studies examined hip rotation relative to the pelvis, only one also reported values of pelvis transverse rotation at specific events of the SLS (Graci, 2012). Finally, one particular study provided a valuable perspective that may assist in explaining why such a large range of hip rotation values exists in the SLS literature. Willson and colleagues (2008) unexpectedly found values reflecting hip external rotation in individuals who also exhibited knee valgus during the SLS, and cautioned readers attempting to understand hip rotation kinematics reported for the SLS. While it is known that knee valgus is, in part, a result of hip adduction and internal rotation, the authors suggested that the hip rotation values observed in their study would likely be more accurate if the pelvis were somewhat more constrained with regard to transverse plane rotation, as it is with bilateral weight-bearing tasks (Willson, 2008).

While several studies have controlled for squat depth of the SLS, others have not in order to mimic a clinical situation. In the studies that did not control for depth, the majority have found greater knee flexion in males (range: 66.8° ± 9.7 to 89.5° ± 6.2) than females (range: 60.0° ± 13.3 to 95.4° ± 6.2) (Dwyer, 2010; Graci, 2012; Weeks, 2012; Whatman, 2011; Yamazaki, 2010; Zeller, 2003), with one study observing greater knee flexion in female participants (Zeller, 2003). It has been reported that females typically display less normalized isometric torque in the knee flexors and hip extensors than males (Willson, 2006), which could explain the generally decreased degree of knee flexion in females reported by Zeller et al. (2003).

Knee valgus has been the most commonly studied kinematic variable in the SLS in both healthy and injured populations due to its association with ACL injury as well as other lower extremity pathologies. Knee valgus is often a combination of internal rotation and adduction of the femur coupled with lower leg abduction. Analysis of 3D knee valgus kinematics in healthy participants has revealed a range of 2.75° ± 5.27 to 14.1° ± 8.8 for males, and 3.67° ± 4.58 to 12.4° ± 9.10 for females (Ageberg, 2010; Claiborne, 2006; Dwyer, 2010; Graci, 2012; Nakagawa, 2012; Zeller, 2003). In addition to 3D kinematic assessments of the SLS, 2D analysis has been employed as a less expensive, faster, and clinically practical method for analyzing knee valgus. The most common of these, is the use of 2D FPPA. Several studies have measured FPPA in healthy participants. 2D FPPA values in healthy males and females have ranged from -1.6° to 8.64° and 2.8° ± 1.0 to 16.8° ± 12.4 (positive numbers reflecting a more valgus position), respectively (Ageberg, 2010; Bittencourt, 2012; Munkh-Erdene, 2011; Munro, 2012; Willson, 2006; Willson, 2008). Finally, varus values have been shown to range from 6.48° ± 4.45 to 16.9° ± 15.1 of varus for males, and 3.85° ± 2.78 to 14.1° ± 11.5 for females (Bolgla, 2008; Claiborne, 2006; Crossley, 2011; Yamazaki, 2010; Zeller, 2003).

One study suggested that differences in pelvic width to femoral length ratios observed in males and females may have predisposed females toward more extreme FPPA values because they began the movement with a more valgus FPPA. (Willson, 2006). However, another study examined the differences in individuals with high and low standing FPPA and found no significant differences of FPPA during the SLS (Ageberg, 2010). Furthermore, a study was conducted to examine the differences in 2D knee valgus (also measured by pelvis width/femur length ratios) in individuals with high and low quadriceps angles (Q-angles), and found that Q-angle had no significant effect on the amount of frontal plane knee movement observed in the SLS (Pantano, 2005). Therefore, it is unlikely that greater standing FPPA values (i.e. static stance with a greater valgus FPPA) in females caused the differences in frontal plane knee movement between sexes.

Differences in strength and neuromuscular control of proximal and local stabilizing musculature have also been studied with regard to knee valgus. One study found that differences in hip abduction, knee flexion, and knee extension strength were significant predictors of knee valgus during the SLS (Claiborne, 2006). Moreover, previous research observed that increased quadriceps and hamstring muscle strength was associated with decreased frontal plane knee movement during the landing phase of a drop jump (Hewett, 1996). However, because these muscles have small abduction and adduction moments, the authors speculated that the co-contraction of these two muscles may reduce varus and valgus movement via increases in joint compression and stiffness.

In addition to studies examining kinematics of the SLS, there have been numerous studies that provide support for the use of the SLS as a valid clinical test of LPHC function. Several studies have examined strength and muscle activity of trunk, hip, knee, and ankle musculature during the SLS. Of particular interest has been onset and amplitude of the gluteal muscles in injured populations as well as healthy populations that display excessive frontal plane knee motion. One study found delayed onset of the anterior fibers of the gluteus medius during the SLS in healthy individuals who were rated by trained clinicians as "poor" performers of the SLS, coupled with 29% lower hip abduction strength (Cowan, 2009). In addition to the findings regarding hip abduction strength, the authors of this study also found that individuals rated as "good" performers had increased force production during a trunk side bridge. This study highlighted valuable clinical implications regarding the use of the SLS as a well-suited test for the clinical environment. While many clinicians do not have access to sophisticated equipment, it was concluded that the SLS was a functional task that could be used to indicate hip and trunk muscle strength when assessing at-risk persons or guide and monitor treatments.

Additional studies have found similar results in regard to SLS performance and hip strength. Two studies that examined hip muscle strength and average activation of the gluteal muscles found that individuals who displayed greater peak hip internal rotation exhibited a decrease in hip extension and abductor strength, but 64% greater activation of gluteus maximus activity (Hollman, 2014; Souza, 2009). It was thus speculated that these individuals may have been attempting to recruit a weak muscle (gluteus maximus) in an attempt to control hip rotation (Souza, 2009). Furthermore, one study found that participants who presented with increased trunk lateral flexion, hip adduction, hip internal rotation, and knee abduction during the SLS, generated less peak eccentric hip abduction and external rotation strength, as well as diminished activation of gluteus medius and increased gluteus maximus activity (Nakagawa, 2012). Finally, in terms of hip muscle weakness, the external rotators of the hip have been found to demonstrate decreased strength in individuals who display medial knee displacement in studies examining 2D kinematics (Munkh-Erdene, 2011; Willson, 2006), providing additional support for the use of the SLS as a clinical test of LPHC strength.

It is known that the lower extremity and LPHC are critical for both power generation and support during dynamic upper extremity tasks (Burkhart, 2000; Kibler, 1995; Putnam, 1993). However, very little has been examined specifically in terms of the SLS and upper extremity injury. It has been reported that the hips and pelvis provide over half of the kinetic energy and forces associated with overhead athletic tasks such as the tennis serve and overhead throwing motion (Kibler, 1995). Furthermore, one study found decreased hip range of motion coupled with decreased hip abductor strength in nearly half of the patients who sustained labral tears of the shoulder, indicating a significant association between LPHC function and upper extremity injury (Burkhart, 2000). Therefore, the SLS has been suggested as a clinical test to evaluate kinetic chain function during the evaluation of individuals with upper extremity injuries (Kibler, 2008).

Only one study has examined the SLS test in regard to dysfunction of the upper extremity (Beckett, 2014). This study employed video assessment of the SLS in preadolescent and adolescent baseball players to test functional gluteal and core strength and its association with scapular dyskinesis. While scapular dyskinesis was present in 50% of the adolescent group and 25.9% of the preadolescent group, there was universally poor performance of the SLS in both groups, with 0% of the preadolescent group and only 13% of the adolescent group able to perform the SLS with no compensatory motions in the frontal and transverse planes. While this could point to an association between single leg squat performance and upper extremity dysfunction, it could also mean that the participants in this study simply lacked adequate control of the LPHC musculature and were unable to perform the SLS. However, more research is needed to quantify kinematic values of SLS performance in this population and examine the association between SLS performance and upper extremity dysfunction in other populations.

The use of the SLS as a clinical assessment of trunk, hip, and knee strength, and overall LPHC control has been shown to be both valid and reliable across several studies. Studies that have examined kinematics, strength, and EMG indicate that decreases in LPHC strength and neuromuscular control are often associated with compensations observed in the trunk, pelvis, hips, and knee during the SLS. Of these compensations, several are known risk factors associated with injury or kinetic chain dysfunction, making the SLS a valuable tool for both researchers and clinicians.

Single-Leg Drop Landing

A similar, yet more dynamic functional assessment compared to the SLS, is the single-leg drop landing (SLDL) test. The SLDL is commonly used by clinicians and researchers to examine lower extremity and LPHC function due to its likeness to athletic movements known to be associated with ACL injury (Jacobs, 2007; Myer, 2015; Whatman, 2013; Zazulak, 2005). Like the SLS, the SLDL requires sufficient balance as well as dynamic neuromuscular control and strength of the LPHC and lower extremity musculature to perform the test with minimal movement deviation in the frontal and transverse planes. Although much of the literature has focused primarily on ACL injury and rehabilitation, many of the same kinematic variables examined for the SLS have been described for the SLDL and show similar trends when compared to the SLS literature presented earlier. In this section, available kinematics for each segment will be described briefly to provide information regarding trends in healthy participants during the SLDL.

Trunk kinematics during the SLDL have only been described in one study and were only examined in the sagittal plane (Ali, 2013). In this study, the authors reported sagittal plane trunk flexion means ranging from 17.63° ± 6.80 to 21.88° ± 9.30. Previous research on bilateral drop landing tasks has revealed that increasing trunk flexion causes concomitant increases in hip and knee flexion, coupled with decreased GRF (Blackburn, 2008; Blackburn, 2009). While single- and bilateral landing mechanics are different in nature, it is reasonable to anticipate that a relatively decreased degree of trunk flexion during landing is indicative of LPHC weakness or dysfunction.

Pelvis kinematics have only been reported in one study and only in one plane during the SLDL (Patrek, 2011). The results of this study yielded pelvis lateral flexion values of 12.5° ± 6.1 at initial contact, and 13.9° ± 6.5 60 milliseconds after initial contact in healthy female athletes. Although these data are from two specific time events of the drop landing and cannot directly be compared to maximum excursions previously described for the SLS, it can be noted that pelvis lateral flexion during both of these clinical assessments tends to occur in the same direction and that a greater pelvis lateral flexion angle during the SLDL is an indicator of LPHC weakness.

Hip flexion has been studied extensively in the SLDL, and has yielded peak hip flexion ranges from 21.3° ± 15.0 to 32.5° ± 13.2 in males, and 23.51° ± 8.73 to 61.2° ± 6.4 in females (Coventry, 2006; Jacobs, 2007; Kerzonek, 2008; Myer, 2015; Oritz, 2008; Orishimo, 2009). Studies examining sex differences have had mixed results, with two studies reporting greater peak hip flexion in females (Kerzonek, 2008; Orishimo, 2009), and one with greater hip flexion in males (Jacobs, 2007). Furthermore, while these ranges are quite large in magnitude, it should be noted that different methodologies exist between studies in terms of height of the drop landing which may affect the observed kinematic values for hip flexion values. For example, studies have required participants to perform the SLDL from platforms 30cm (Orishimo, 2009), 31cm (Myer, 2015), 40cm (Oritz, 2008), and 50cm (Kerzonek, 2008), while another required participants to hang from a bar and drop from a height that corresponded with 80% of their maximum vertical jump height (Coventry, 2006). Therefore, comparison of peak hip flexion angles between some of these studies is difficult.

Hip adduction/abduction has been studied in the SLDL literature primarily due to its association with ACL injury risk. Peak hip adduction angles for males have ranged from 3.9° ± 5.6 to 10.33° ± 5.61, while females exhibit a slightly higher range of 4.37° ± 5.04 to 12.49° ± 6.93 (Jacobs, 2007; Myer, 2015; Oritz, 2008; Orishimo, 2009; Yeow, 2011). Furthermore, one study found that females exhibited slightly greater peak hip abduction during a SLDL task (6.44° ± 4.92 in females versus 1.22° ± 6.95 in males) (Kerzonek, 2008). After a fatiguing protocol, males and females began to move in opposite directions, with males displaying increased peak hip abduction post-fatigue, and peak hip abduction decreasing by 40% in females.

Relatively few studies have provided values for hip rotation in a healthy population. One study reported 13.36° ± 5.54 of peak hip internal rotation in healthy males (Jacobs, 2007), and three studies reported peak hip internal rotation values ranging from 1.89° ± 2.19 to 10.96° ± 6.89 in healthy females. (Jacobs, 2007; Oritz, 2008; Myer, 2015) Furthermore, females with ACL reconstruction displayed increased hip internal rotation on the affected limb when compared to the uninjured side (Oritz, 2008). Only one study has reported hip external rotation, with a range between 3.1° ± 5.6 and 6.6° ± 6.9 in healthy young females (Myer, 2015). This study showed side to side differences in the degree of peak hip external rotation in females, with the dominant leg exhibiting slightly greater hip external rotation values.

Due to the association between landing mechanics and ACL injury, the knee has been the most frequently studied segment in SLDL literature (Coventry, 2006; Jacobs, 2007; Kerzonek, 2008; Kiriyama, 2009; Myer, 2015; Nagano, 2009; Oritz, 2008; Orishimo, 2009; Schmitz, 2007). Although the use of different methodologies and drop heights must be borne in mind, healthy males tend to display higher peak knee flexion angles (42.04° ± 8.79 to 67.24° ± 11.79) than females (39.38° ± 13.75 to 64.7° ± 6.3). While the majority of the studies that included both male and female participants reported higher peak knee flexion values in males (Coventry, 2006; Jacobs, 2007; Kerzonek, 2008; Orishimo, 2009; Schmitz, 2007), one study reported greater knee flexion at the event of foot contact in females compared to males both pre- and post-fatigue (Brazen, 2010). Finally, it has been reported that decreased knee flexion during single-leg landing was associated with increased vertical GRF (Kerzonek, 2008; Wikstrom, 2006). This provides further evidence that a decreased degree of maximum knee flexion is indicative of LPHC weakness or dysfunction.

Knee valgus has been reported in previous literature (males: 0.97° ± 4.11 to 7.29° ± 4.51; females: 3.4° ± 11.2 to 9.89° ± 5.34), as has varus (males: 1.4° ± 0.3 to 15.26° ± 9.41; females: 1.6° ± 0.3 to 3.86° ± 5.15) during a SLDL task (Brazen, 2010; Jacobs, 2007; Kerzonek, 2008; Kiriyama, 2009; Myer, 2015; Nagano, 2007; Orishimo, 2006; Oritz, 2008; Russell, 2006). Results of these studies have suggested that the loss of frontal plane control of the knee, regardless of cause (i.e. sex, LPHC dysfunction, etc.), is the primary contributor to ACL injury (Brazen, 2010; Jacobs, 2007; Kerzonek, 2008; Oritz, 2008; Russell, 2006). Finally, peak tibial rotation in females has generally been reported to be higher for both internal and external rotation in females (internal rotation: 10.7° ± 3.2 to 13.7° ± 9.1; external rotation: 3.85° ± 5.35 to 5.64° ± 5.18) than in males (internal rotation: 9.4° ± 0.9 to 10.1° ± 5.5; external rotation: 3.72° ± 2.67) (Kiriyama, 2009; Myer, 2015; Nagano, 2007; Oritz, 2008).

Clinical Tests of Scapular Function

Optimal function of the upper extremity depends heavily on the ability of the scapula to act as a link for the transfer of forces derived from the lower extremity and core (Kibler, 2009). Furthermore, safe and efficient movement of the shoulder complex requires a balance between the optimum amount of mobility to accommodate its wide range of motion, while maintaining an adequate amount of stability provided by the scapular stabilizing musculature (Struyf, 2012). Due to the demands placed on the glenohumeral (GH) joint, this balance is often lost, resulting in the high prevalence of shoulder pain and dysfunction in athletic and non-athletic populations (Luime, 2004; Walker-Bone, 2004). Therefore, a sufficient understanding of normal and abnormal scapular function is crucial for both researchers and clinicians.

Normal scapular motion during arm elevation consists of upward rotation, posterior tilt, and retraction (Lopes, 2015). This is achieved by the cooperative activation of the scapular stabilizing musculature, acting as a force couple to facilitate proper positioning of the scapula in relation to the thorax, and in turn, the proper positioning of the humerus in relation to the scapula (Yamauchi, 2015). For example, during arm elevation and upward rotation of the scapula, the upper trapezius (UT), serratus anterior (SA) perform elevation and protraction, respectively, and the middle trapezius (MT) and lower trapezius (LT) resist the actions of UT and SA, thereby maintaining the position of the scapula by creating an axis about which the scapula can rotate during arm elevation (Figure 1) (Cools, 2007). Failure of these muscles to appropriately activate leads to inadequate scapular movements and positions, known to be associated with shoulder dysfunction and pain (Cools, 2007; Ludewig, 2009).

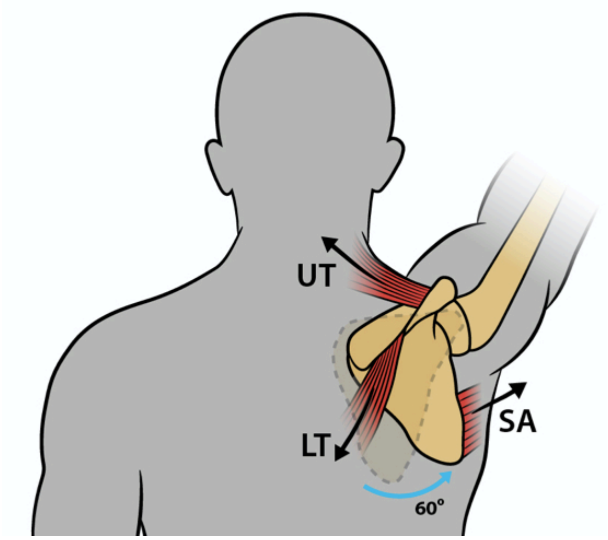

Figure 1: Force couple of upper trapezius (UT), lower trapezius (LT), and serratus anterior (SA) performing upward rotation of the scapula during arm elevation.

The alteration of scapular motion has been termed scapular dyskinesis, and signifies a loss of normal scapular control (Kibler, 2009; Kibler, 2013). The appearance of the scapula in individuals with scapular dyskinesis has been identified as increased protraction, anterior tilt, and inadequate acromioclavicular elevation (Lopes, 2015). Although dyskinesis itself is not an injury, nor is it directly related to any specific shoulder pathology, it has been identified in populations with shoulder impingement (Hebert, 2002; Laudner, 2006; Lin, 2005; Ludewig, 2000; McClure, 2006), rotator cuff tendinopathy (Lin, 2005; Mell, 2005), rotator cuff tears (Deutsch, 1996; Mell, 2005; Paletta, 1997), and GH instability (Illyes, 2006; Ogston, 2007; Ozaki, 1989; Paletta, 1997; von Eisenhart-Roth, 2005). Due to the association between scapular dyskinesis and the vast majority of shoulder injuries, it has been suggested that the management of shoulder pathology should include evaluation and restoration of normal scapular movement and kinetic chain function (Kibler, 2003; Kibler, 2008).

Several clinical assessment methods have been developed for the identification of scapular dyskinesis, however the current recommendation is the use of visually assessed dynamic scapular dyskinesis tests (SDT) (Kibler, 2013). The current method of performing the SDT was first developed by Kibler and colleagues (2002), and has since been refined. The original SDT consisted of a visually based classification system for scapular dysfunction that defined three different types of scapular abnormalities during weighted abduction and scaption: type I – inferior angle prominence (tilting), type II – medial border prominence (winging), type III excessive superior border elevation, and normal symmetrical scapular motion was considered type IV (Kibler, 2002; Struyf, 2012). However, results from the initial study yielded less than satisfactory intra-rater (kappa coefficient = 0.5) and inter-rater reliability (kappa coefficient = 0.4), and the authors suggested that while the observation of scapular tilting or winging of the scapula during movement is a clinically applicable tool, the test required modification before its widespread use as a standard for identification of dynamic scapular dysfunction patterns (Kibler, 2002; Struyf, 2012).

The SDT was further developed by McClure et al. (2009), who determined that reliability was improved when the scapula was not rated and differentiated into the specific movements of tilting or winging. Instead, the authors classified scapular motion as normal, subtle dyskinesis, or obvious dyskinesis, with excessive protraction or elevation, non-smooth or stuttering motion during arm elevation or lowering, or rapid downward rotation of the scapula during arm lowering indicating the presence of scapular dyskinesis. In this version of the SDT, subtle dyskinesis was described as a mild or questionable evidence of abnormality which was not consistently present, and obvious dyskinesis was defined as striking, clearly apparent abnormality, evident on at least three of five trials of arm elevation and lowering (McClure, 2009). This described rating system by McClure et al. (2009) achieved a satisfactory level of clinical reliability. Furthermore, a follow-up study examining 3D scapular kinematics in individuals rated as having subtle or obvious dyskinesis showed distinct alterations, further supporting the validity of this method (Tate, 2009). However, because there is no particular aspect of scapular dyskinesis (winging, tilting, or dysrhythmic motion) that correlates with any one specific shoulder pathology, the test was modified again to reflect the current recommendation for the SDT, which simply states whether scapular dyskinesis is present or absent (Uhl, 2009).

The currently accepted adaptation of the dynamic SDT was developed by Uhl and colleagues, and uses a classification system that consists of a “yes/no” rating for the presence of scapular dyskinesis (Uhl, 2009). In this test, a rating of “yes” is considered as the presence of one or more of the first three types of Kibler’s rating system or a non-smooth, stuttering, or rapid movement of the scapula, and a rating of “no” being normal scapular motion during forward shoulder flexion and return from full flexion (Figure 2). The use of the “yes/no” method for identifying scapular dyskinesis yielded a high specificity (79%) and high predictive value (74%). Furthermore, when compared to Kibler’s four-type rating system, the “yes/no” method for identifying scapular dyskinesis was considered to be more reliable and acceptable for clinical use (Uhl, 2009). While there have been many other suggestions for the identification of scapular dyskinesis, the “yes/no” method for evaluating scapular function is currently recommended, and therefore is the most widely used clinical assessment.

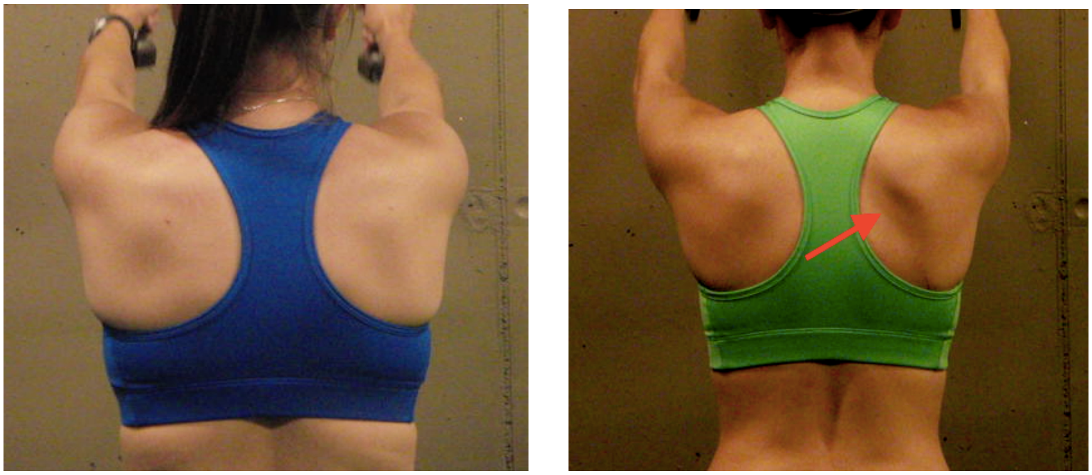

Figure 2: Left: Normal scapular positioning during arm elevation. Right: Medial border prominence during arm elevation, indicating the presence of scapular dyskinesis.

Although scapular dyskinesis itself is not considered an injury, it has been reported to be present in 67-100% of shoulder injuries, including subacromial impingement syndrome, rotator cuff strains and tears, labral tears, and shoulder instability (Hebert, 2002; Illyes, 2006; Kibler, 2013; Kibler, 2016; Ogston, 2007; Paletta, 1997). With such a strong association between scapular dyskinesis and shoulder pathologies, valid and reliable tests of scapular function are essential for clinicians throughout the evaluation and rehabilitation process.

Summary

Scapular dyskinesis is the visually identified alteration or loss of control of scapular movement. Scapular dyskinesis is not considered an injury, itself, however it has been found that scapular dyskinesis is present in nearly all individuals with shoulder injuries. Therefore, clinicians are encouraged to evaluate all patients with shoulder pain for the presence of scapular dyskinesis before implementation of a corrective plan. Currently, the recommended method of testing for scapular function is the visually assessed SDT. The SDT consists of viewing scapular position and motion while the patient performs humeral elevation and lowering in either the sagittal or scapular plane. Scapular dyskinesis is noted present if excessive scapular protraction or elevation are present, the medial border or inferior angle protrudes from the rib cage, or if there is a non-smooth, stuttering motion of the scapula during arm lowering or elevation.

Clinical tests of LPHC function offer time- and cost-efficient methods for identifying kinetic chain abnormalities at multiple segments, and thus are valuable to clinicians during the evaluation process. One commonly used assessment of LPHC function is the SLS. The SLS has been studied extensively and is widely recognized as a valid predictor of lower extremity and LPHC function. Previous literature has displayed that increased trunk, pelvis, hip, and knee motion in the frontal and transverse planes during the SLS is indicative of LPHC dysfunction.

A second test, similar to the SLS in physical demand and overall kinetic chain function is the SLDL. In contrast to the SLS, relatively few studies have described the use of the SLDL explicitly in regard to LPHC function. Instead, the vast majority of these studies have examined the SLDL directly in terms of ACL injury. Despite differences in how these tests have been examined in previous literature, the SLS and SLDL share similar physical requirements of balance, strength, and neuromuscular control while on a single-limb base of support. Accordingly, both tests follow similar kinematic trends, allowing researchers and clinicians to draw parallels between the SLS and SLDL in regard to LPHC function. Additionally, the more dynamic nature of the SLDL may provide additional insight into LPHC dysfunction that is less apparent in the SLS.

Although these tests have been widely studied and utilized to detect lower extremity injury risk, they may also have practical clinical implications for the upper extremity. A growing body of literature has suggested functional assessments of LPHC and kinetic chain function during the evaluation of upper extremity pain and injury, but there are currently no data to support this claim. However, there is evidence to support the association between shoulder injury and quantitative measures of LPHC function, such as hip range of motion and strength. Therefore, the suggestion to utilize clinical tests of LPHC may, in fact, be beneficial during the evaluation of shoulder injuries, but the association between the two is still unclear.

CHAPTER III

METHODOLOGY

The objectives of the current research study were as follows: (1) to examine the association between scapular dyskinesis and kinematics during the SLS and SLDL; and (2) to determine if any movement compensations during the SLS and SLDL have a greater prevalence in individuals with scapular dyskinesis. This chapter describes the methodology to be used to address these objectives. Methodology has been divided into the following subsections: (1) participants, (2) setting, (3) instrumentation, (4) procedures, (5) data analysis and experimental design.

Participants

A power analysis was conducted (effect size = 0.72, alpha = 0.05, power = 0.80) with G*Power v3.1.9.2. for Windows (Ageberg, 2010; Faul, 2007; Nakagawa, 2012). The power analysis indicated that a total of 64 participants (32 per group) would be required to demonstrate significance. In order to qualify for participation in this study, individuals needed to be between the ages of 19-30 years, physically active (at least 30 minutes of moderate to vigorous physical activity 3-5 days per week), have no lower extremity injury within the 6 months prior to data collection, have no shoulder surgery within the past 12 months prior to data collection, and have no limitations that would inhibit them from performing the SDT, SLS, or SLDL assessments. Each participant signed an informed consent document approved by the Auburn University Institutional Review Board prior to any testing or implementation of data collection procedures.

Setting

All testing and data collection procedures took place in a controlled laboratory setting inside the Sports Medicine & Movement Laboratory located on the Auburn University campus. This location contained the necessary space and equipment required to conduct the current study.

Instrumentation

Scapular Dyskinesis Test

The SDT was filmed using a Casio HS EX-FH25 camera (Casio™, Casio Computer Co., Shibuya, Tokyo, Japan) for later analysis by the rater. The camera was placed posterior to the participant at a distance of 2m. The camera lens was adjusted so that the posterior view included the upper trunk, shoulders, and elbows through the full range of motion similar to previously used methods (McClure, 2009).

Single Leg Squat and Single Leg Drop Landing Kinematics

All kinematic data were collected using an electromagnetic tracking system (trakSTAR™, Ascension Technologies, Inc., Burlington, VT, USA) synched with The MotionMonitor™ (Innovative Sports Training, Chicago, IL, USA). (Figures 3, 4, and 5) The electromagnetic tracking system that was used in the current study has been previously validated for measuring trunk, pelvis, hip, and knee kinematics during the SLS and has yielded high reliability (within session intra-class correlation coefficient (ICC): 0.94; minimal detectable change (MDC): 3.4°; between session ICC: 0.91; MDC: 4.3°) (Nakagawa, 2014). Field distortion associated with electromagnetic tracking systems has been shown to be the cause of error in excess of 5° at a distance of 2m from the extended range transmitter (Day, 2000). However, instrument sensitivity increases have reduced this error from approximately 10° prior to system calibration to as low as 2° following calibration (Meskers, 1999; Day, 2000; Perie, 2002). Therefore, prior to data collection, the system was calibrated using previously established techniques (Meskers, 1999; Day, 2000; Perie, 2002; Oliver, 2010; Keely, 2012; Oliver, 2013). All kinematic data describing the position and orientation of electromagnetic sensors was recorded at a sampling rate of 100 Hz (Keely, 2012; Nakagawa, 2012; Nakagawa, 2014; Oliver, 2013). A 40 cm x 60 cm non-conductive Bertec™ force plate (Bertec Corp., Columbus, OH, USA) was built into the surface on which all landings during the SLDL were performed. Force data will only be used to measure the instance of foot contact during the SLDL and will be sampled at a rate of 1000 Hz.

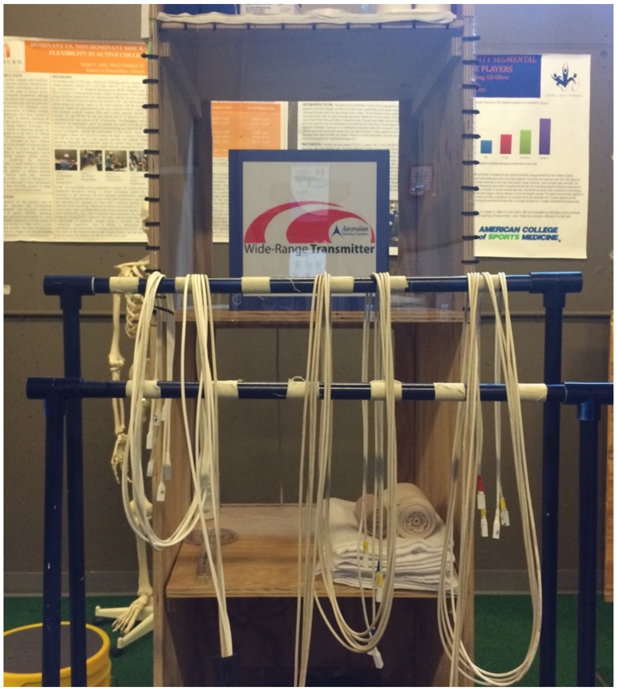

Figure 3: trakSTAR™ electromagnetic tracking system.

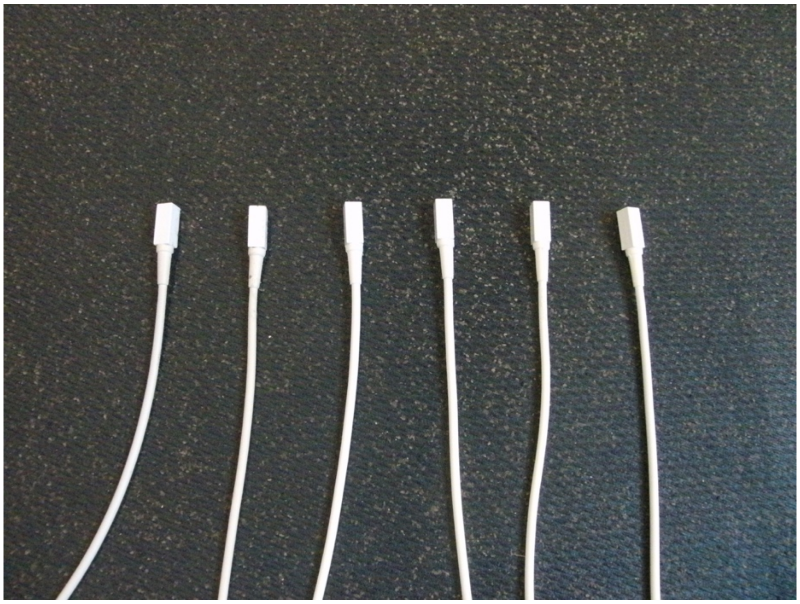

Figure 4: Flock of Birds™ electromagnetic sensors.

Figure 5: The Motion Monitor™ 3D motion capture system.

Procedures

Scapular Dyskinesis Test Protocol

Each participant was filmed from a posterior view while performing 5 weighted repetitions of the SDT (Figure 6). Specifically, participants were instructed to begin in a standing position with their arms at their sides and elbows extended, and perform 5 repetitions of shoulder flexion and return from flexion, at a steady pace (approximately 3 seconds from start to full shoulder flexion, and 3 seconds from full flexion to the starting position without pausing at the end ranges of motion) while holding 3lb weights (Kibler, 2013; Struyf, 2012; Uhl, 2009). The videos were saved on laboratory computer and viewed by a single rater to separate participants two groups: (1) “scapular dyskinesis,” or (2) “no scapular dyskinesis”. Scapular dyskinesis was considered present if there was any visible scapular winging (inferior angle or medial border prominence), excessive superior border elevation, or a non-smooth, stuttering motion of the scapula during arm elevation or lowering of either scapula (Kibler, 2013; Uhl, 2009).

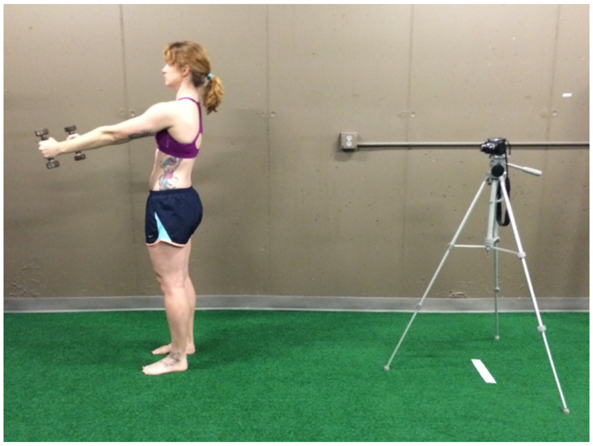

Figure 6: Scapular dyskinesis test protocol

Single Leg Squat and Single Leg Drop Landing Protocols

Participants had a series of 6 electromagnetic sensors (Track Star, Ascension Technologies Inc., Burlington, VT, USA) attached at the following locations: [1] posterior aspect of the torso at the first thoracic vertebra (T1), [2] posterior aspect of the pelvis at sacral vertebra 1 (S1), [3-4] lateral aspect of each femur, centered between the greater trochanter and the lateral condyle of the femur [5-6] lateral aspect of each shank, centered between the head of the fibula and the lateral malleolus (Figures 7 and 8) (Keel,y 2012; Nakagawa, 2012; Oliver, 2010).

Figure 7: Sensor placement.

All sensors were affixed to the participant's skin using PowerFlex cohesive tape (Andover Healthcare, Inc., Salisbury, MA, USA) to ensure secure senor placement throughout testing. Following application of the sensors, a seventh moveable sensor, attached to a plastic stylus, was used for the digitization of bony landmarks. A link segment model (Figure 8) was developed by digitizing joint centers for the ankle, knee, hip, T12-L1, and C7-T1. To guarantee accurate bony landmark identification, participants stood in anatomical neutral during the digitization process. Joint centers were determined by digitizing the medial and lateral aspect of a joint, then calculating the midpoint between those two points; the ankle and knee joints were defined as the midpoint between the digitized medial and lateral malleoli and medial and lateral femoral condyles, respectively; the spinal column was defined as the digitized space between C7-T1 and T12-L1; and a rotation method, validated for providing accurate positional data, was used to estimate the hip joint centers (Huang, 2010; Keely, 2012; Leardini, 1999;

Nakagawa, 2012; Oliver, 2010; Wu, 2002; Wu, 2005). The joint center for the hip was calculated from the rotation of the femur relative to the pelvis, and consisted of the investigator stabilizing the joint, then passively moving the limb into ten different positions in a small, circular pattern (Huang, 2010; Leardini, 1999; Nakagawa, 2012).

Raw data regarding sensor position and orientation was transformed to locally based coordinate systems for each of the respective body segments. The longitudinal axis of each segment was represented by two points, and a third point was used to define the plane of the segment (Holt, 2015; Oliver, 2013). For the global axes, the positive y-axis represented the vertical direction, the positive z-axis was horizontal and to the right of the y-axis, and the positive x-axis was anterior and orthogonal to the plane defined by the y- and z-axes (Figure 8). Position and orientation of the body segments was described using Euler angle decomposition sequences, and kinematic data was obtained using Euler angle sequences consistent with the International Society of Biomechanics standards and joint conventions (Wu, 2002). Specifically, the ZX'Y" sequence was used to describe knee, hip, pelvis, and trunk motion. All raw data were independently filtered along each global axis using a 4th order Butterworth filter with a cutoff frequency of 13.4 Hz (Oliver, 2010; Oliver, 2013). All data were time stamped through The MotionMonitor™ (Innovative Sports Training, Chicago, IL, USA) and passively synchronized using a data acquisition board.

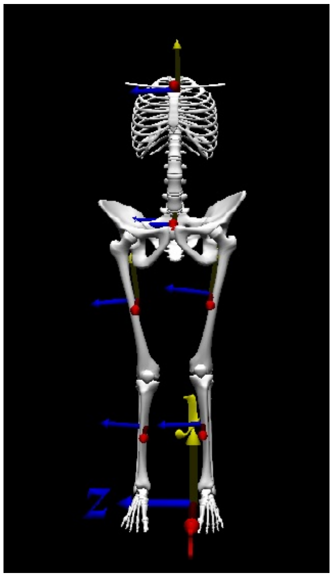

Figure 8: Link segment model created from digitized endpoints and local and global axes.

Following sensor attachment and digitization, participants were given instructions for the SLS and allowed to practice until they were comfortable with performing the task bilaterally. Participants were instructed to stand on a 25cm step positioned directly posterior to the force platform with the test limb aligned with the global coordinate system (marked by a line on the step), cross their arms over their chest, and squat down on the test limb until the heel of the contralateral foot lightly touches the force platform, and return to the upright starting position without pausing at the bottom (Figure 9). The SLS test was performed at a tempo of 1 squat per 3 seconds from a 25cm step to normalize temporal properties and squat depth in a manner that mimicked a clinical situation (Ageberg, 2010; Hollman, 2014; Pantano, 2005; Souza, 2009) A maximum of seven attempts were allowed for each leg. If the participant could not complete three successful repetitions in seven or less attempts, the participant was excluded from the study. Three successful trials were recorded for each leg and saved for subsequent analysis.

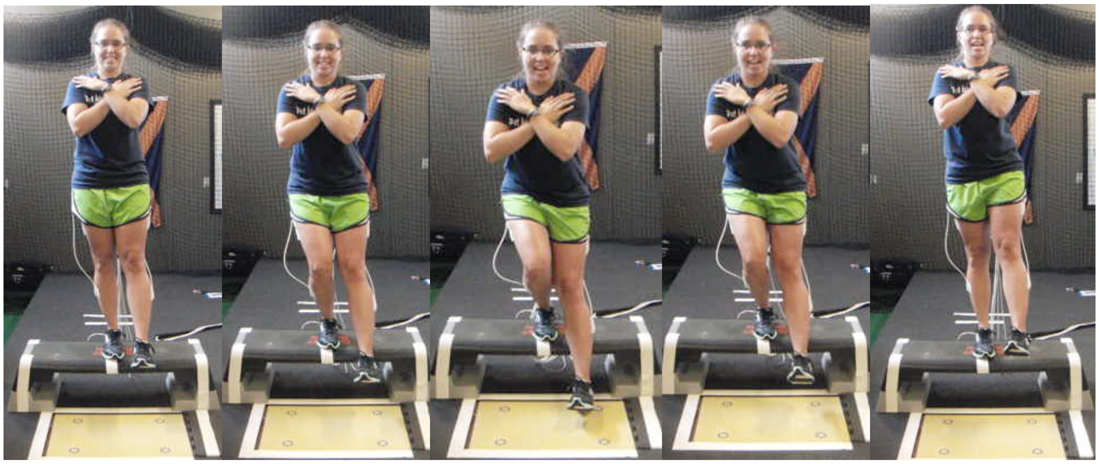

Figure 9: SLS protocol.

For the SLDL, participants were instructed to stand on their left leg on a 33cm step positioned 10cm posterior to the force platform, cross their arms over their chest, and drop land on one leg without jumping (Figure 10) (Kiriyama, 2009). This procedure was performed bilaterally. Participants were allowed to practice the SLDL until they were comfortable with performing the task on each leg. The trial was considered successful when the participant was able to land without having to put the opposite foot down or remove their hands from their chest to regain balance (Kiriyama, 2009; Patrek, 2011). A maximum of seven attempts were allowed for each leg. If the participant could not complete three successful repetitions in seven or less attempts, the participant was excluded from the study. Three successful trials were recorded for each leg and saved for subsequent analysis.

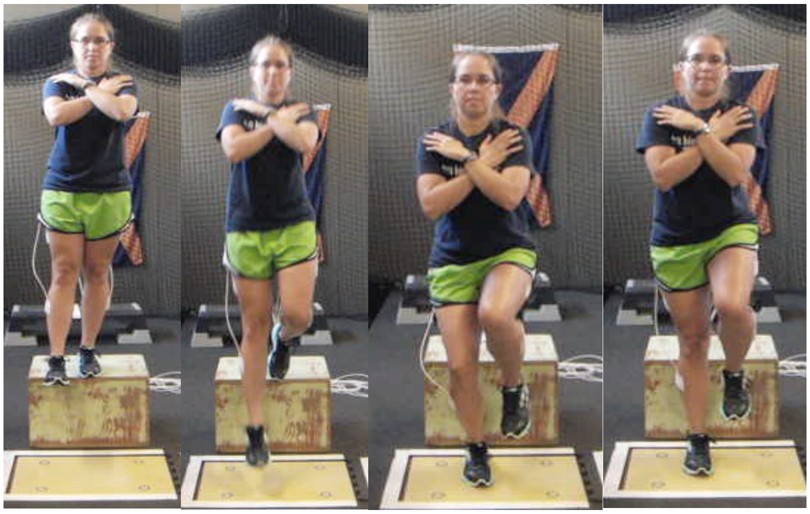

Figure 10: SLDL protocol.

Data Analysis and Experimental Design

All statistical analyses for the current study were performed using IBM SPSS Statistics 24 software (IBM corp., Armonk, NY) with an alpha level set *a priori* at $\alpha = 0.05$. All data were compiled in a spreadsheet using Microsoft Excel to prepare for statistical analysis. Descriptive statistics were calculated for the demographics of all participants. For the SLS, kinematic data were expressed as the maximum excursion throughout the entire movement (from start of descent phase to end of ascent phase when the participant returned to an upright single-leg standing position), and for the SLDL, kinematic data were expressed as the maximum excursion between the time when the participants foot made contact with the force plate and the instant the participant returned to a balanced, upright single-leg standing position. Foot contact was identified as the instant at which the vGRF exceeded 10N (Fong, 2011). Maximum excursion data were averaged across all three trials of the selected leg for the SLS and SLDL. For the "dyskinesis" group, the leg contralateral to the affected scapula was selected for kinematic analysis. In the control group, participants were matched for sex and test limb dominance with participants in the “dyskinesis” group. All kinematic data were reduced using The MotionMonitor™ software, and the kinematic variables examined for the SLS and SLDL were: trunk flexion, lateral flexion, and rotation; pelvis lateral flexion and rotation; hip flexion, adduction/abduction, and rotation; knee flexion and valgus.

To satisfy the first objective (RQ1) of the current study, a series of one-way multivariate analyses of variance (MANOVAs) were employed to determine if the maximum excursion from neutral (absolute value) of trunk, pelvis, hip, and knee kinematics during the SLS and SLDL were significantly different in participants with and without scapular dyskinesis. For all MANOVAs used in the current study, the independent variable was group (“dyskinesis” or “no dyskinesis”), and the dependent variables were kinematic values associated with each functional test. Separate MANOVAs were performed for (1) the trunk (flexion, lateral flexion, and rotation), (2) pelvis (lateral flexion and rotation), (3) hip (flexion, adduction, and rotation), and (4) knee (flexion and valgus) for the SLS and SLDL tasks. For the trunk, two separate 2 (group) x 3 (maximum excursion) designs were used to analyze kinematics of the SLS and SLDL, with trunk flexion, trunk lateral flexion, and trunk rotation used as the dependent variables for each. Two separate 2 (group) x 2 (maximum excursion) designs were used to analyze the pelvis kinematics of the SLS and SLDL, with pelvis lateral flexion and pelvis rotation serving as the dependent variables for each. Two separate 2 (group) x 3 (maximum excursion) designs were used to analyze hip kinematics during the SLS and SLDL, with hip flexion, hip adduction, and hip rotation used as the dependent variables for each. Finally, two separate 2 (group) x 2 (maximum excursion) designs were used to analyze the knee kinematics of the SLS and SLDL, with knee flexion and knee valgus used as the dependent variables for each. In any MANOVA where the independent variable of group had a significant effect on the dependent variables, separate t-tests were conducted on each dependent variable as a follow-up test to MANOVA. Additionally, in any statistical procedure where a dependent variable was significantly different between groups, but violated the assumption of equality of error variances (i.e. $p < .05$ for Levene's Test of Equality of Error Variances), an independent samples t-test with equal variances not assumed was used as a follow-up test to determine whether the dependent variable was in fact significant.

To satisfy the second objective (RQ2) of this study, a series of MANOVAs was conducted to determine whether the common compensations of trunk lateral flexion, trunk rotation, pelvis lateral flexion, hip adduction, and hip rotation were significantly greater in the "dyskinesis" group during the SLS and SLDL. Separate analyses were conducted for the (1) trunk (lateral flexion and rotation), (2) pelvis (lateral flexion and transverse rotation), and (3) hip (adduction and internal rotation). For the trunk, two separate 2 (group) x 2 (positional kinematics) designs were employed to analyze kinematics of the SLS and SLDL, with group as the independent variable and trunk lateral flexion and rotation as the dependent variables. Two separate 2 (group) x 2 (positional kinematics) designs were employed to analyze pelvis kinematics during the SLS and SLDL, with group as the independent variable and pelvis lateral flexion and transverse rotation as the dependent variables. Two separate 2 (group) x 2 (positional kinematics) designs were used to examine differences in pelvis kinematics during the SLS and SLDL, with group as the independent variable and hip adduction and internal rotation as the dependent variables. Finally, two separate one-way analyses of variance (ANOVAs) were employed to examine differences in the degree of knee valgus during the SLS and SLDL, with group as the independent variable and the maximum degree of knee valgus as the dependent variable for each.

In any MANOVA where the independent variable of group had a significant effect on the dependent variables, separate t-tests were conducted on each dependent variable as a follow-up test to MANOVA. Additionally, in any statistical procedure where a dependent variable was significantly different between groups, but violated the assumption of equality of error variances (i.e. $p < .05$ for Levene’s Test of Equality of Error Variances), an independent samples t-test with equal variances not assumed was used as a follow-up test to determine whether the dependent variable was in fact significant.

CHAPTER IV

RESULTS

The purposes of this research were: (1) to examine the association between scapular dyskinesis and maximum excursion of kinematics during the single-leg squat (SLS) and single-leg drop landing (SLDL) (RQ1); and (2) to determine if any of the most common movement compensations during the SLS and SLDL have a greater prevalence in individuals with scapular dyskinesis (RQ2). This chapter presents the result of the current study, and is divided into the following sections: (1) participant demographics, (2) SLS results, and (3) SLDL results.

Participant Demographics

Sixty-seven participants were recruited for the current study. Of the original 67, one was excluded because he could not complete the SLDL task in less than seven attempts, and two were excluded due to their respective group being filled based on SDT test results. In total, 64 participants (32 per group) were included in the study. Separate paired samples t-tests were conducted to determine whether there were any significant differences in age, height, or mass between groups. Results revealed no significant differences between groups. Participant demographics are presented in Table 1.

Table 1: Summary of participant demographics.

Group	n	Age (years)	Height (cm)	Mass (kg)
No Dyskinesis	32	23.03 ± 3.25	174.62 ± 10.40	74.19 ± 16.20
Dyskinesis	32	22.5 ± 3.15	178.37 ± 8.55	74.78 ± 15.95
Total	64	22.77 ± 3.17	176.49 ± 9.59	74.33 ± 15.88

Single-Leg Squat

In attempt to understand differences in SLS kinematics between individuals with and without scapular dyskinesis, a series of one-way MANOVAs was conducted on the different kinematic parameters with an alpha level set *a priori* at α = .05. The first set of statistical procedures aimed to examine differences in maximum excursion of (1) trunk kinematics in all three planes of motion (flexion/extension, lateral flexion, and rotation), (2) pelvis kinematics in the frontal and transverse planes (lateral flexion and rotation), (3) hip kinematics in all three planes of motion (flexion/extension, adduction/abduction, and internal/external rotation), and (4) knee kinematics in the sagittal and frontal planes (flexion/extension and valgus/varus). These results are indicated by the label “RQ1”. The second set of statistical tests aimed to examine differences in the specific kinematic values of (1) trunk lateral flexion and rotation, (2) pelvis lateral flexion and rotation, (3) hip adduction and internal rotation, and (4) knee valgus. For this set of statistical procedures, absolute values were not used in order to examine differences in compensations that are most commonly assessed clinically. These results are indicated in this chapter by the label "RQ2," and are referred to as "positional kinematics". For all statistical procedures, the independent variable *group* consisted of individuals with dyskinesis and individuals without dyskinesis.

SLS Practice and Trial Attempts

Separate paired samples t-tests were conducted to determine whether there were any differences in the number of practice attempts and trial attempts between groups. Results revealed no significant differences between groups. SLS practice and trial attempts are presented in Table 2.

Table 2: Number of practice attempts and trial attempts for each group.

	SLS Practice Right	**SLS Practice Left**	**SLS Trials Right**	**SLS Trials Left**
Control	3.09 ± 1.35	2.84 ± 1.25	3.41 ± .80	3.38 ± .49
Dyskinesis	2.97 ± 1.18	3.09 ± 1.20	3.28 ± .63	3.34 ± .55

Maximum Excursion Trunk Kinematics (RQ1)

A 2 (group) x 3 (maximum excursion trunk kinematics) design was used to analyze maximum excursion trunk kinematics in all three planes of motion. The dependent variables of trunk flexion, lateral flexion, and rotation were obtained as the maximum excursion throughout the entire SLS. The null hypothesis was rejected given the significant interaction of group [Wilks' λ: $F_{(3,60)} = 3.137$, $p = .032$, $\eta^2 = .701$]. Univariate follow-up testing revealed that trunk rotation was significantly greater in the dyskinesis group [$F_{(1,62)} = 6.605$, $p = .013$, $\eta^2 = .716$] Levene's statistic revealed that the error variances were significantly different ($p = .014$). Therefore, a follow-up independent samples t-test was conducted with equal variances not assumed, confirming that trunk rotation was significantly different between groups [$t_{(62)} = -2.570$, $p = .014$]. Means and standard deviations are presented in Table 3. A comprehensive list of statistical results pertaining to trunk kinematics is presented in Appendix C.

Maximum Excursion Pelvis Kinematics (RQ1)

A 2 (group) x 2 (maximum excursion pelvis kinematics) design was used to analyze maximum excursion pelvis kinematics in the frontal and transverse planes. The dependent variables of pelvis lateral flexion and pelvis rotation were obtained as the maximum excursion throughout the entire SLS. MANOVA results indicated that there were no significant differences in pelvis kinematics between groups [Wilks' λ: $F_{(2,61)} = 2.907$, $p = .062$, $\eta^2 = .136$]. These results suggest that the maximum excursion of pelvis lateral flexion and rotation were similar between groups. Means and standard deviations are presented in Table 3. A comprehensive list of statistical results pertaining to pelvis maximum excursion kinematics is presented in Appendix C.

Maximum Excursion Hip Kinematics (RQ1)

A 2 (group) x 3 (maximum excursion hip kinematics) design was used to analyze maximum excursion hip kinematics in all three planes of motion. The dependent variables of hip flexion, adduction/abduction, and internal/external rotation were obtained as the maximum excursion throughout the entire SLS. The null hypothesis was rejected given the significant interaction of group [Wilks' λ: $F_{(3,60)} = 3.137$, $p = .016$, $\eta^2 = .087$]. Levene's statistic revealed that the error variances were significantly different ($p = .004$). Therefore a follow-up independent samples t-test was conducted with equal variances not assumed, and confirmed that hip rotation was significantly different between groups [$t_{(62)} = -2.776$, $p = .008$]. Means and standard deviations are presented in Table 3. A comprehensive list of statistical results pertaining to trunk kinematics is presented in Appendix C.

Maximum Knee Kinematics (RQ1)

A 2 (group) x 2 (maximum excursion knee kinematics) design was used to analyze maximum excursion knee kinematics in the sagittal and frontal planes. The dependent variables of knee flexion and knee valgus/varus were obtained as the maximum excursion throughout the entire SLS. MANOVA results indicated that there were no significant differences in knee kinematics between groups [Wilks' λ: $F_{(2,61)} = 2.399$, $p = .099$, $\eta^2 = .158$]. These results suggest that the maximum excursion of knee flexion and knee valgus/varus were similar between groups. Means and standard deviations are presented in Table 3. A comprehensive list of statistical results pertaining to knee maximum excursion kinematics is presented in Appendix C.

Table 3: Means and (SD) of maximum excursion kinematics for the SLS. Kinematics are expressed in degrees.

SLS (RQ1)	**Dyskinesis**	**Control**
Trunk Flexion	13.08(3.85)	12.05(5.53)
Trunk Lateral Flexion	6.94(2.78)	6.04(2.12)
Trunk Rotation *	11.09(3.28)	9.04(3.09)
Pelvis Lateral Flexion	9.49(2.17)	7.89(3.02)
Pelvis Rotation	13.46(5.73)	13.03(7.13)
Hip Flexion	65.19(13.24)	70.71(12.14)
Hip Adduction/Abduction	22.45(6.12)	20.69(6.94)
Hip Rotation *	9.59(4.40)	6.79(3.02)
Knee Flexion	86.32(7.81)	90.09(6.59)
Knee Valgus/Varus	12.86(6.15)	11.18(4.67)

*Statistical significance ($p<.05$).

Trunk Kinematics (RQ2)

A 2 (group) x 2 (positional trunk kinematics) design was used to analyze positional trunk lateral flexion and rotation kinematics. The dependent variables of trunk lateral flexion and rotation were obtained as the maximum excursion throughout the entire SLS. The null hypothesis was rejected given the significant interaction of group [Wilks' λ: $F_{(2,61)} = 4.478$, $p = .015$, $\eta^2 = .746$]. Univariate follow-up testing revealed that trunk rotation was significantly greater in the dyskinesis group [$t_{(62)} = -2.929$, $p = .005$], and occurred in the direction ipsilateral to the test limb. Means and standard deviations are presented in Table 4. A comprehensive list of statistical results pertaining to trunk kinematics is presented in Appendix C.

Pelvis Kinematics (RQ2)

A 2 (group) x 2 (positional pelvis kinematics) design was used to analyze positional pelvis lateral flexion and rotation kinematics. The dependent variables of pelvis lateral flexion and pelvis rotation were obtained as the maximum excursion throughout the entire SLS. MANOVA results indicated that there were no significant differences in pelvis kinematics between groups [$F_{(2,61)} = 1.040$, $p = .360$, $\eta^2 = .033$]. These results suggest that pelvis lateral flexion and rotation were similar between groups. Means and standard deviations are presented in Table 4. A comprehensive list of statistical results pertaining to pelvis maximum excursion kinematics is presented in Appendix C.

Hip Kinematics (RQ2)

A 2 (group) x 3 (positional hip kinematics) design was used to analyze hip adduction and hip internal rotation in individuals with and without scapular dyskinesis. The dependent variables of hip adduction and hip internal rotation were obtained as the maximum excursion throughout the entire SLS. MANOVA results indicated that there were no significant differences in hip kinematics between groups [Wilks' λ: $F_{(2,61)} = .437$, $p = .648$, $\eta^2 = .014$]. These results suggest the degree of hip adduction and rotation was similar between groups. Means and standard deviations are presented in Table 4. A comprehensive list of statistical results pertaining to trunk kinematics is presented in Appendix C.

Knee Kinematics (RQ2)

ANOVA was used to analyze positional knee valgus during the SLS. The dependent variable of knee valgus was obtained as the maximum excursion throughout the entire SLS. The null hypothesis stated that there was no significant difference in the maximum degree of knee valgus between individuals with scapular dyskinesis and individuals without scapular dyskinesis. Univariate follow-up results indicated that there was a significantly greater degree of knee valgus in the dyskinesis group [$t_{(63)} = 2.146$, $p = .036$]. Means and standard deviations are presented in Table 4. A comprehensive list of statistical results pertaining to knee maximum excursion kinematics is presented in Appendix C.

Table 4: Means and (SD) for positional kinematics during the SLS. Kinematics are expressed in degrees.

SLS (RQ2)	Dyskinesis	Control
Trunk Lateral Flexion	-4.29(6.38)	-4.48(4.38)
Trunk Rotation *	-10.12(6.56)	-6.85(7.77)
Pelvis Lateral Flexion	9.24(2.34)	8.30(3.31)
Pelvis Rotation	-13.46(5.73)	-13.03(7.13)
Hip Adduction	22.45(6.12)	22.93(8.20)
Hip Rotation	-0.10(11.73)	2.14(8.72)
Knee Valgus *	12.49(9.62)	7.07(10.54)

Trunk lateral flexion stance leg (-). Trunk rotation toward stance leg (-). Pelvis rotation toward stance leg (-). Hip external rotation (-).
*Statistical significance (p<.05).

Single-Leg Drop Landing

In attempt to understand differences in SLDL kinematics between individuals with and without scapular dyskinesis, a series of one-way MANOVAs was conducted on the different kinematic parameters with an alpha level set *a priori* at $\alpha = .05$. The first set of statistical procedures aimed to examine differences in maximum excursion (absolute value) from neutral (1) trunk kinematics in all three planes of motion (flexion/extension, lateral flexion, and rotation), (2) pelvis kinematics in the frontal and transverse planes (lateral flexion and rotation), (3) hip kinematics in all three planes of motion (flexion/extension, adduction/abduction, and internal/external rotation), and (4) knee kinematics in the sagittal and frontal planes (flexion/extension and valgus/varus). The second set of statistical tests aimed to examine differences in the specific positional (i.e. not absolute value) kinematic values of (1) trunk lateral flexion and rotation, (2) pelvis lateral flexion and transverse rotation, (3) hip adduction and internal rotation, and (4) knee valgus. For this set of statistical procedures, absolute values were not used in order to examine differences in compensations that are most commonly assessed clinically. For all statistical procedures, the independent variable *group* consisted of individuals with dyskinesis and individuals without dyskinesis.

SLDL Practice and Trial Attempts

Separate paired samples t-tests were conducted to determine whether there were any differences in the number of practice attempts and trial attempts between groups. Results revealed no significant differences between groups. SLDL practice and trial attempts are presented in Table 3.

Table 5: Number of SLDL practice attempts and trial attempts for each group.

	SLDL Practice Right	**SLDL Practice Left**	**SLDL Trials Right**	**SLDL Trials Left**
Control	2.63 ± 1.39	2.66 ± 1.29	3.38 ± .75	3.22 ± .49
Dyskinesis	2.59 ± 1.27	3.25 ± 1.46	3.53 ± .95	3.22 ± .42

Maximum Excursion Trunk Kinematics (RQ1)

A 2 (group) x 3 (maximum excursion trunk kinematics) design was used to analyze maximum excursion trunk kinematics in all three planes of motion. The dependent variables of trunk flexion, lateral flexion, and rotation were obtained as the maximum excursion throughout the entire SLDL (initiated at foot contact). MANOVA results indicated that there were no significant differences in trunk kinematics between groups [Wilks' λ: $F_{(3,60)} = .934$, $p = .430$, $\eta^2 = .045$]. These results suggest that trunk lateral flexion and rotation were similar between groups. Means and standard deviations are presented in Table 5. A comprehensive list of statistical results pertaining to pelvis maximum excursion kinematics is presented in Appendix C.

Maximum Excursion Pelvis Kinematics (RQ1)

A 2 (group) x 2 (maximum excursion pelvis kinematics) design was used to analyze maximum excursion pelvis kinematics in the frontal and transverse planes. The dependent variables of pelvis lateral flexion and pelvis rotation were obtained as the maximum excursion throughout the entire SLDL (initiated at foot contact). MANOVA results indicated that there were no significant differences in pelvis kinematics between groups [Wilks' λ: $F_{(2,61)} = 2.368$, $p = .102$, $\eta^2 = .072$]. These results suggest that pelvis lateral flexion and rotation were similar between groups. Means and standard deviations are presented in Table 5. A comprehensive list of statistical results pertaining to pelvis maximum excursion kinematics is presented in Appendix C.

Maximum Excursion Hip Kinematics (RQ1)

A 2 (group) x 3 (maximum excursion hip kinematics) design was used to analyze maximum excursion of hip kinematics in all three planes of motion. The dependent variables of hip flexion, hip adduction/abduction, and internal/external rotation were obtained as the maximum excursion throughout the entire SLDL (initiated at foot contact). MANOVA results indicated that there were no significant differences in pelvis kinematics between groups [Wilks' λ: $F_{(3,60)} = .860$, $p = .467$, $\eta^2 = .041$]. These results suggest that hip flexion, adduction/abduction, and internal/external rotation were similar between groups. Means and standard deviations are presented in Table 5. A comprehensive list of statistical results pertaining to hip maximum excursion kinematics is presented in Appendix C.

Maximum Excursion Knee Kinematics (RQ1)

A 2 (group) x 2 (maximum excursion knee kinematics) design was used to analyze absolute knee kinematics in the sagittal and frontal planes. The dependent variables of knee flexion and valgus/varus were obtained as the maximum excursion throughout the entire SLDL (initiated at foot contact). MANOVA results indicated that there were no significant differences in knee kinematics between groups [Wilks' λ: $F_{(2,61)} = .064$, $p = .938$, $\eta^2 = .002$]. These results suggest that the maximum excursions of knee flexion and valgus/varus were similar between groups. Means and standard deviations are presented in Table 5. A comprehensive list of statistical results pertaining to knee maximum excursion kinematics is presented in Appendix C.

Table 6: Means and (SD) for maximum excursion kinematics during the SLDL. Kinematics are expressed in degrees.

SLDL (RQ1)	**Dyskinesis**	**Control**
Trunk Flexion	7.81(4.13)	6.45(3.61)
Trunk Lateral Flexion	3.81(2.14)	3.53(2.45)
Trunk Rotation	7.39(4.32)	6.35(3.18)
Pelvis Lateral Flexion	7.03(3.44)	7.00(2.99)
Pelvis Rotation	8.64(3.62)	6.22(2.98)
Hip Flexion	32.04(11.67)	30.63(10.54)
Hip Adduction/Abduction	9.63(3.64)	10.25(4.03)
Hip Rotation	10.32(4.48)	8.95(4.60)
Knee Flexion	49.45(11.31)	50.09(9.28)
Knee Valgus/Varus	7.58(3.84)	7.69(3.34)

Trunk Kinematics (RQ2)

A 2 (group) x 2 (positional trunk kinematics) design was used to analyze positional trunk lateral flexion and rotation kinematics during the SLDL. The dependent variables of trunk lateral flexion and rotation were obtained as the maximum excursion throughout the entire SLDL (initiated at foot contact). MANOVA results indicated that there were no significant differences in trunk kinematics [Wilks' λ: $F_{(2,61)} = .183$, $p = .833$, $\eta^2 = .006$]. These results suggest that trunk lateral flexion and rotation were similar between groups. Means and standard deviations are presented in Table 6. A comprehensive list of statistical results pertaining to trunk kinematics is presented in Appendix C.

Pelvis Kinematics (RQ2)

A 2 (group) x 2 (positional pelvis kinematics) design was used to analyze positional pelvis kinematics in the frontal and transverse planes during the SLDL. The dependent variables of pelvis lateral flexion and pelvis rotation were obtained as the maximum excursion throughout the entire SLDL (initiated at foot contact). MANOVA results indicated no significant differences in pelvis kinematics between groups [$F_{(2,61)} = 2.793$, $p = .058$, $\eta^2 = .047$]. Means and standard deviations are presented in Table 6. A comprehensive list of statistical results pertaining to trunk kinematics is presented in Appendix C.

Hip Kinematics (RQ2)

A 2 (group) x 2 (positional hip kinematics) design was used to analyze hip adduction and hip internal rotation in individuals with and without scapular dyskinesis. The dependent variables of hip adduction and hip internal rotation were obtained as the maximum excursion throughout the entire SLDL (initiated at foot contact). MANOVA results revealed that there were no significant differences in hip kinematics [Wilks' λ: $F_{(2,61)} = .728$, $p = .487$, $\eta^2 = .023$]. These results suggest the degree of hip adduction and internal rotation was similar between groups. Means and standard deviations are presented in Table 6. A comprehensive list of statistical results pertaining to trunk kinematics is presented in Appendix C.

Knee Kinematics (RQ2)

A one-way ANOVA was used to analyze knee kinematics in the frontal plane during the SLDL. The dependent variable of knee valgus was obtained as the maximum excursion throughout the entire SLDL (initiated at foot contact). ANOVA results indicated that there were no significant differences in knee valgus between groups [$F_{(1,63)} = .036$, $p = .851$]. Means and standard deviations are presented in Table 6. A comprehensive list of statistical results pertaining to knee maximum excursion kinematics is presented in Appendix C.

Table 7: Means and (SD) for positional kinematics during the SLDL. Kinematics are expressed in degrees.

SLDL (RQ2)	**Dyskinesis**	**Control**
Trunk Lateral Flexion	.-1.53(4.44)	.-1.40(4.50)
Trunk Rotation	.-7.23(4.22)	.-6.67(3.06)
Pelvis Lateral Flexion	7.03(3.44)	6.38(3.79)
Pelvis Rotation	.-8.58(3.48)	.-6.36(3.04)
Hip Adduction	7.08(6.26)	7.33(6.23)
Hip Rotation	7.68(6.13)	6.06(4.43)
Knee Valgus	1.32(9.23)	1.76(9.40)

Trunk lateral flexion stance leg (-). Trunk rotation toward stance leg (-). Pelvis rotation toward stance leg (-). Hip external rotation (-).

CHAPTER V

DISCUSSION

The objectives of this research study were to examine the associations between scapular dyskinesis and clinical tests of lumbo-pelvic-hip complex stability. This chapter presents the discussion and conclusions drawn from the current study and is divided into the following subsections: (1) the association between single-leg squat (SLS) kinematics and scapular dyskinesis, (2) the association between single-leg drop landing (SLDL) kinematics and scapular dyskinesis, and (3) conclusions and directions for future research.

Single-Leg Squat

The SLS is commonly used to assess LPHC function, and has been suggested as a test to examine multiple points of the kinetic chain during the evaluation of shoulder dysfunction (Beckett, 2014; Kibler, 2006; Kibler, 2016; Sciascia, 2012; Wilk, 2016). While the SLS has been studied extensively in the realm of lower extremity injury and LPHC dysfunction, no prior studies have examined SLS kinematics in regard to upper extremity dysfunction. Previous studies on SLS kinematics have revealed that individuals with LPHC weakness or lower extremity dysfunction tend to exhibit decreased flexion at the trunk, hip, and knee coupled with increased frontal and transverse plane motion at the trunk (lateral flexion and rotation), pelvis (lateral flexion and rotation), hip (adduction/abduction and internal/external rotation), and knee (valgus/varus) (Ageberg, 2010; Claiborne, 2006; Crossley, 2011; Dwyer, 2010; Graci, 2015; Hollman, 2014; Kulas, 2012; Nakagawa, 2012; Willson, 2006). Due to the known relationship between the kinetic chain and upper extremity function (Beckett, 2014; Burkhart, 2000; Kibler, 2006), the current research study aimed to examine the association between SLS kinematics and scapular function.

Trunk Kinematics

The trunk and upper extremities comprise approximately 60% of total body mass. (Hewett 2009) Therefore, motions of the trunk have been studied extensively in regard to its effect on other kinetic chain segments during functional athletic movements. While a relatively small amount of SLS literature has examined 3D kinematics of the trunk, previous research has suggested that increased trunk flexion produces concomitant increases in hip and knee flexion, coupled with decreased anterior shear forces at the knee and decreased ground reaction force (GRF) during the SLS, cutting maneuvers, and drop landing tasks (Blackburn, 2008; Blackburn, 2009; Kulas, 2012). Additionally, it has been reported that decreases in hip flexion are associated with decreased hip extensor strength and activation (Nakagawa, 2012). Therefore, it is likely that decreased trunk flexion is indicative of LPHC instability. Trunk lateral flexion and rotation have also been studied minimally in the SLS, however previous studies have found increased trunk lateral flexion and rotation in individuals with LPHC weakness and lower extremity injury (Bolgla, 2008; Crossley, 2011; Graci, 2012; Graci, 2015; Nakagawa, 2012).

Furthermore, increased trunk lateral flexion and rotation have been related to decreased gluteus maximus and gluteus medius activation and strength during the SLS and stair ascent/descent (Blackburn, 2009; Bolgla, 2008; Cowan, 2009; Nakagawa, 2012). Therefore, increased trunk lateral flexion and rotation during the SLS indicate LPHC weakness.

The results of this study revealed that trunk rotation was significantly different between groups. The maximum excursion kinematic data from this study suggest that the dyskinesis group displayed greater trunk rotation (11.09° ± 3.28) than the control group (9.04° ± 3.09) (Figure 11). Similarly, when examining the positional trunk rotation kinematics, the dyskinesis group displayed greater trunk rotation (-10.12° ± 6.56) than the control group (-6.85° ± 7.77) (Figure 12). These data suggest that maximum trunk rotation during the SLS occurred toward the test limb, but are higher than the values previously observed by both studies published by Graci and colleagues. (Graci, 2012; Graci 2015). It is speculated that differences in trunk rotation kinematics between the current and previous studies were likely due to differences in methodology. In the previous studies, trunk rotation kinematics were extracted at the instant of maximum knee flexion, as opposed to the maximum degree of trunk rotation throughout the entire SLS motion assessed in the current study (Graci, 2012; Graci, 2015). Nonetheless, the results from this study suggest that individuals with scapular dyskinesis tend to have increased trunk rotation during the SLS.

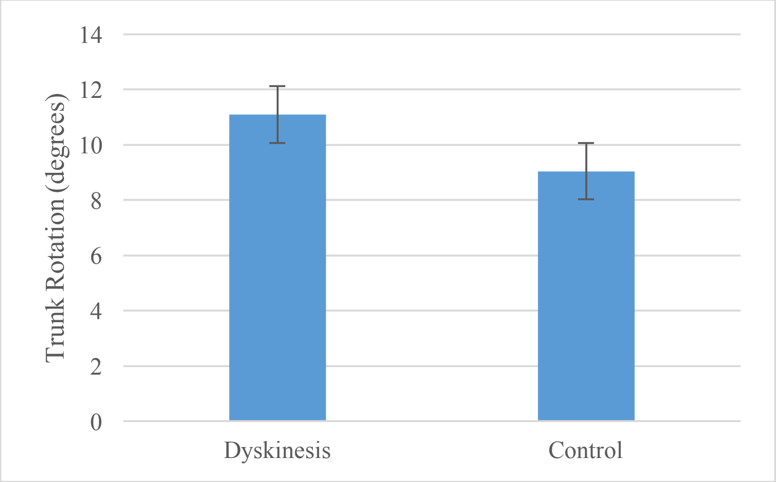

Figure 11: Means and standard error for maximum excursion trunk rotation kinematics.

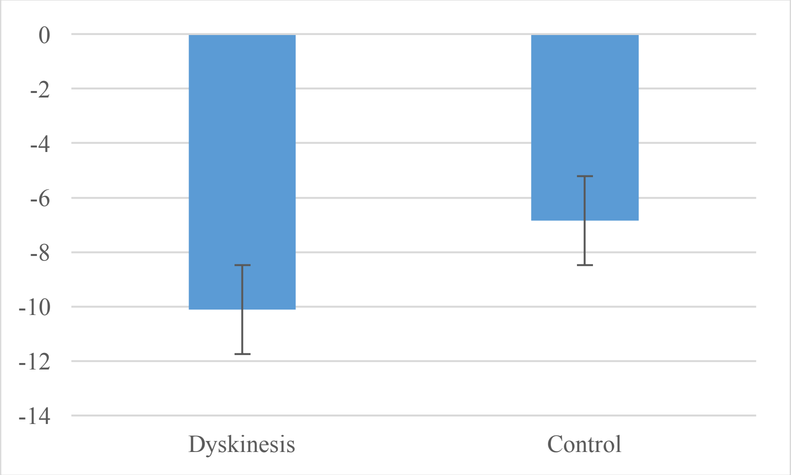

Figure 12: Means and standard error for positional trunk rotation kinematics.

Despite differences in methodology, trunk flexion values observed in the current study were similar to those presented by Graci et al. (2012) and Kulas et al. (2012), and were similar between groups (dyskinesis: 13.08° ± 3.85; control: 12.05° ± 5.53). Graci et al. (2012) observed trunk flexion values at peak knee flexion, and found significant differences between sexes. The authors theorized that the more upright posture in females during the SLS may have been the result of inadequate hip extensor strength to control the forward displacement of the center of mass during the descent phase of the SLS

(Graci, 2012). In contrast to this study, the current study did not separate groups by sex, and resulted in trunk flexion values similar to those reported by Graci et al. (2012). It is possible that separating the groups in the current study by sex may have yielded different results, however this was not done for the sake of applying the results of this study to the general population.

Trunk lateral flexion was also similar between groups, and closely resembled previously reported values in a healthy population (Nakagawa, 2012). Trunk lateral flexion values in the current study were -4.29° ± 6.38 for the dyskinesis group, and -4.48° ± 4.38 for the control group. These values suggest that trunk lateral flexion occurred in the direction of the test limb. This has been reported previously, and it has been suggested that laterally flexing the trunk in the direction of the test limb reduces the demand placed on the gluteus by moving the center of mass over the base of support (Nakagawa, 2012; Zeller, 2003).

The maximum excursion kinematics in this study yielded a slightly higher degree of trunk lateral flexion compared to the positional kinematics (dyskinesis: 6.94° ± 2.78; control: 6.04° ± 2.12). The differences between the maximum excursion and positional trunk lateral flexion kinematics observed in the current study suggest that while the majority of participants laterally flexed the trunk toward the test limb, some exhibited maximum trunk lateral flexion toward the side contralateral to the test limb. It is possible that including both sexes in the two groups had an effect on the findings of the current study, as Nakagawa et al. (2012) found significantly greater trunk lateral flexion toward the stance leg in females compared males. Furthermore, Graci et al. (2012) stated that at 45° knee flexion, males tend to laterally flex the trunk in the direction of the non-test limb before moving back toward the test limb at peak knee flexion. These sex differences in movement strategies during the SLS could explain the differences in maximum excursion and positional trunk lateral flexion kinematics observed in the current study. Further investigation between males and females with and without scapular dyskinesis may be necessary.

The data from the current study provide valuable information for clinicians regarding trunk motion during the SLS in individuals with scapular dysfunction. Previous authors who have suggested the SLS as a method for testing LPHC strength during the shoulder evaluation process have used the term “corkscrewing” to describe excessive motion of the trunk in the frontal and transverse planes (Beckett, 2014; Kibler, 2006; Sciascia, 2012). While these authors relied on observation in a clinical setting versus kinematic data, the current study substantiate previous observations of trunk rotation in individuals with shoulder dysfunction.

Trunk stability is achieved by adequate function of the intrinsic core stabilizing musculature (i.e. multifidi, internal obliques, transverse abdominis, diaphragm, and pelvic floor muscles) as well as muscles such as the quadratus lumborum, latissimus dorsi, and the gluteals. Collectively, these muscles increase trunk stability preceding movement of the upper limbs, and failure of these muscles to appropriately activate decreases the ability of the trunk to act as a stable base for efficient upper extremity function (Cholewiski, 1999; Daggfeldt, 1997; Kibler, 2006). The effect of trunk position and stability on scapular function has also been evidenced by studies examining scapular motion and stabilizer activity when trunk position is altered. Yamauchi et al. (2015) reported an increase of scapular external rotation and posterior tilt coupled with an increase in LT activity and a decrease in UT activity when performing scapular retraction exercises with ipsilateral trunk rotation (Yamauchi, 2015). Similarly, authors have suggested altering trunk rotation during scapular rehabilitation exercises to improve scapular stability (Sciascia, 2012). Therefore, function of the scapula depends greatly on the trunk, further necessitating assessment of trunk stability during the clinical evaluation process of shoulder dysfunction.

While the results of the current study cannot be extended to individuals with specific shoulder injuries, they indicate that individuals with improper scapular positions or motions (i.e. scapular dyskinesis) tend to display increased trunk rotation during the SLS, and subsequently, decreased LPHC stability. These results have multiple implications for clinical use. In addition to exercises targeting the GH and scapular stabilizers, exercises incorporating a trunk stability component are likely warranted. Furthermore, the results from this study may have implications for detecting future upper extremity injury risk in individuals who have decreased LPHC stability. SLS performance indicates an increased risk of injury of the upper extremity, similar to how the SLS has been used to detect lower extremity injury risk (Ugalde, 2015). However, longitudinal studies examining SLS performance in uninjured individuals who later sustain shoulder injuries would have to be conducted to confirm this hypothesis. Furthermore, future research should examine the association between upper extremity dysfunction and trunk kinematics between sexes, as previous studies have shown differences in trunk kinematics between males and females performing the SLS.

Pelvis Kinematics

The pelvis is the center of the kinetic chain, serving as a crucial link between the lower extremity and the trunk and upper extremity. The muscles that attach to the pelvis serve to stabilize the trunk and lower extremity and to generate power during dynamic upper extremity movements (Kibler, 2006). Specifically, gluteus maximus and gluteus medius work to help control the trunk, pelvis, and legs during functional and athletic maneuvers. Weakness or failure of these muscles to activate appropriately has been associated with dysfunction at proximal and distal segments of the kinetic chain (Bolgla, 2008; Burkhart, 2000; Kibler, 2006). The common compensations of pelvis lateral flexion toward the non-test limb (also referred to as "contralateral pelvic drop") and pelvis rotation are thought to indicate hip muscle weakness during the SLS (Graci, 2012; Graci, 2015; Nakagawa, 2012). Nakagawa et al. (2012) reported significantly greater pelvis lateral flexion toward the non-test limb in participants with PFPS compared to healthy controls, coupled with decreased eccentric hip abductor strength. Furthermore, it has been reported that while both males and females tend to rotate the pelvis toward the non-test limb, females rotate the pelvis toward the test limb at 45° of knee flexion, then rotate back toward the non-test limb at peak knee flexion (Graci, 2012). Graci et al. (2012) speculated that this oscillatory motion of the pelvis may play a role in the increased incidence of ACL injury in females.

In addition to being a point of attachment for major muscles of the lower extremity, the pelvis is also the attachment site for muscles that control the trunk and upper extremity such as the abdominals, erector spinae, and the latissimus dorsi via the thoracolumbar fascia. Therefore, pelvic instability can have detrimental effects at the upper extremity. It has been suggested that Trendelenburg posture (frontal plane pelvic rotation toward the non-stance limb) during single-leg stance or the SLS indicates weakness in the LPHC, and may lead to shoulder dysfunction (Burkhart, 2000; Kibler, 2006; Kibler, 2008). Therefore, it was hypothesized that the dyskinesis group in the current study would display significantly greater pelvis lateral flexion than the control group.

Results of the current study revealed no significant differences in maximum excursion or positional kinematics of pelvis lateral flexion. In terms of positional kinematics, the dyskinesis and control groups displayed -9.24° ± 2.34 and -8.30° ± 3.31 of pelvis lateral flexion toward the non-test limb. These values are similar to previously published data in the healthy population by Nakagawa et al. (2012), but much higher than those reported in other studies (Graci, 2012; Olson, 2011; Willy, 2011). Maximum excursion kinematics of pelvis lateral flexion were similar to the positional kinematic values (dyskinesis: 9.49° ± 2.17; control: 7.89° ± 3.02), indicating that maximum frontal plane motion of the pelvis also occurred in the direction of the non-test limb. It has been reported that lateral trunk flexion toward the ipsilateral side is a compensation for contralateral pelvic drop (Nakagawa, 2012). Therefore, lateral flexion of the pelvis during the SLS affects the trunk, possibly reducing the ability of the trunk to act as a stable base for the scapular stabilizing musculature.

Based on previous studies that reported decreased hip abductor strength in individuals with shoulder injury, it was expected that the control group would display less pelvis lateral flexion than the dyskinesis group during the SLS (Burkhart, 2000). There are two possible explanations for why pelvis lateral flexion values were much higher than previous studies, and were not different between groups. First, because participants performed the SLS from a 25cm platform and were instructed to tap the heel of the non-test limb on the floor, it is possible that participants were attempting to reach for the floor by laterally flexing the pelvis toward the non-test limb. Second, it is possible that some individuals in the dyskinesis group may have had other causes of scapular dyskinesis than LPHC weakness (e.g. pectoralis minor tightness or repetitive unilateral loads above shoulder height). However, this would not explain why the pelvis lateral flexion values from the current study were much higher than most other studies using similar methodologies. Therefore, it is more likely that the high and nearly identical pelvis lateral flexion values in the current study were a result of participants laterally flexing to reach the ground.

As in the case of frontal plane pelvis motion, there were no significant differences in pelvis transverse rotation in the current study. Positional kinematic values for the control and dyskinesis groups were -13.03° ± 7.13 and -13.46° ± 5.73, respectively, and occurred in the direction of the test limb. Again, maximum excursion kinematics for trunk rotation were identical to the positional kinematics (dyskinesis: 13.46° ± 5.73; control: 13.03° ± 7.13), indicating that trunk rotation tended to be in the same direction for all participants. These values were much higher than previously reported transverse plane pelvis kinematics in healthy participants and participants with PFPS (Graci, 2012; Graci, 2015; Olson, 2011). As with pelvis lateral flexion, it is probable that the higher and nearly identical values between groups may have been a result of participants performing the SLS from a raised platform and attempting to reach forward to tap the heel of the non-test limb on the ground. This may be supported by previous studies that required participants to perform the SLS on the ground, and further evidenced by reported pelvis transverse rotation which occurred toward the non-test limb (Graci, 2012). Although the results of the current study suggested that there were no differences in pelvis kinematics between individuals with and without dyskinesis, additional research may be necessary to explain the cause for the contradictory motions observed at the pelvis compared to previous studies.

Hip Kinematics

Due to the ball-and-socket configuration of the hip joint and its multidirectional range of motion, performance of the SLS relies greatly on eccentric control of the hip extensors, abductors, and external rotators during the descent phase, and concentric control of these muscles during the ascent phase. Weakness or dysfunction in any of these muscle groups results in decreased stabilization of the femur, pelvis, or trunk in any or all planes of motion. As many of the muscles that act on the hip joint contribute largely to force production and pelvic stabilization, the hip has been one of the most commonly examined segments in SLS literature. In addition to studies assessing hip kinematics in healthy populations, a vast majority of SLS studies have examined hip kinematics, muscle activation, and strength in individuals with lower extremity injury or dysfunction.

A large range of hip flexion values during the SLS has been previously reported (Dwyer, 2010; Graci, 2012; Graci 2015, Hollman, 2014; Kulas, 2012; Weeks, 2012; Whatman, 2011; Yamazaki, 2010; Zeller, 2003). Generally, it has been reported that decreased hip flexion during the SLS is likely indicative of decreased hip extensor strength and neuromuscular control during the eccentric phase of the squat (Dwyer, 2010;

Graci, 2012). This difference has been found between sexes (with females displaying decreased hip flexion), and between healthy and injured populations (Dwyer, 2010; Graci, 2012; Graci, 2015; Weeks 2012). Results from the current study yielded maximum hip flexion values of 70.71° ± 12.14 for the control group, and 65.19° ± 13.24 for the dyskinesis group. The hip flexion values observed in the current study were similar to those observed by Zeller et al. (2003) and Weeks et al. (2012) in healthy participants. Although a non-significant, data from the current study trended toward the expected result of decreased hip flexion in the dyskinesis group. It is possible that the similarity in hip flexion values was a result of a fixed height from which participants performed the task. However, a previous study by Hollman et al. (2014) also required participants to perform the SLS from a raised platform (20cm), and reported significant differences in hip flexion between "good" and "bad" performers of the SLS. Therefore, the notion that hip flexion was similar between groups due to the fixed squat depth used in the current study cannot be entirely justified. A more reasonable explanation for the similarity between groups observed in the current study is the inclusion of both sexes, as previous literature has found decreased hip flexion coupled with decreased activation and strength of the gluteus maximus in females (Dwyer, 2010). Thus, future research should examine potential group differences with sex as an additional factor.

Previous studies examining hip adduction/abduction during the SLS have suggested that increased adduction indicates difficulty controlling the hip abductors, specifically gluteus medius, during dynamic movement (Dwyer, 2010; Nakagawa, 2012; Weeks, 2012; Zeller, 2003). Significantly greater hip adduction has been reported in females and in individuals with lower extremity pain or injury, with both of these populations displaying decreased eccentric and isometric hip abduction strength and decreased activation or delayed onset of gluteus medius (Bolgla, 2008; Brindle, 2003; Dwyer, 2010; Graci, 2012; Levinger, 2007; Nakagawa, 2012; Souza, 2009; Souz,a 2009; Weeks, 2012; Yamazaki, 2010). In terms of upper extremity dysfunction, it was reported that nearly half of patients who had sustained a labral tear of the shoulder had significantly decreased hip abduction strength (Burkhart, 2000). Based on the association between scapular dyskinesis and injuries such as labral tears (Kibler, 2016), and the findings by Burkhart et al. (2000), it was hypothesized that individuals in the dyskinesis group would display increased frontal plane hip motion during the SLS.

The current study revealed no significant differences between groups in maximum excursion kinematics or positional kinematics of hip adduction/abduction. First, the maximum excursion kinematics, which aimed to examine total adduction/abduction motion away from the neutral position, yielded 22.45° ± 6.12 for the dyskinesis group, and 20.69° ± 6.94 for the control group. While non-significant, a trend of more frontal plane hip motion was observed in the dyskinesis group. When examining the positional kinematic values for maximum hip adduction/abduction, the dyskinesis and control groups had similar degrees of hip adduction (control: 22.93° ± 8.20; dyskinesis: 22.45° ± 6.12), and were similar to data reported by previous authors in female participants who tend to display increased hip adduction compared to males (Dwyer, 2010; Hollman, 2014; Weeks, 2012; Zeller, 2003). While the inclusion of both sexes may be a possible explanation for these high hip adduction values, another possible contributing factor was the pelvis lateral flexion kinematics observed in the current study. As previously hypothesized, the participants may have laterally flexed the pelvis in attempt to touch the floor with the heel of the non-test limb. Since motion of the hip was described relative to the pelvis, the increased pelvis lateral flexion may have caused increased hip adduction. If this were the case, the hip adduction values in the current study likely would have been lower, as seen in previous research (Bolgla, 2008; Graci, 2012; Hollman, 2014; Nakagawa, 2012; Souza, 2009; Weeks, 2012; Zeller 2003).

Hip rotation has been reported in numerous studies and has ranged from 16.04° of external rotation to 9.7° of internal rotation in healthy participants (Dwyer, 2010; Nakagawa, 2012). This wide range of previously reported hip rotation is likely due to the nature of the SLS task. Unlike bilateral weight-bearing tasks, such as two-leg squat or drop landings, the pelvis is not constrained within the transverse plane during the SLS. Therefore, even if the hip were to internally rotate with respect to a global axis, external rotation of the hip may be observed if the pelvis is rotated away from the stance leg, and vice-versa. Because most studies report hip rotation relative to the pelvis, a distinction of actual hip rotation kinematics is hard to make and readers should be cautious when attempting to understand these data. Furthermore, the majority of SLS research (including the current study) has examined maximum movement deviation of hip rotation from neutral (as opposed to extracting kinematic values from one specific point in time), making it impossible to make a clear distinction of precisely how much pelvis transverse rotation may have impacted hip rotation kinematics. Nonetheless, increased hip internal rotation has been found in females as well as individuals with PFPS and previous ACL injury, and is often observed in individuals who also display increased knee valgus (Ageberg, 2010; Graci, 2015; Hollman, 2014; Nakagawa, 2012; Weeks, 2012).

Results of the current study revealed a significant difference in maximum excursion hip rotation kinematics (dyskinesis: 9.59° ± 4.40; control: 6.97° ± 3.02), but not in positional hip rotation kinematics (dyskinesis: -0.10 ° ± 11.73; control: 2.14 ° ± 8.72; negative values reflect external rotation) (Figure 13). The observed values of positional hip rotation kinematics fall within the range of previously reported data and closely resemble data reported by Graci et al. (2012) and Weeks et al. (2012). Although the positional hip rotation kinematics in the current study were not significant, the most important conclusion that may be drawn from the current study regarding hip rotation lie in the maximum excursion kinematics. The differences in maximum excursion and positional hip rotation kinematics imply that individuals with scapular dyskinesis exhibit increased transverse plane motion of the hip, but not necessarily in the direction of internal rotation, which contradicts the majority of previous research regarding SLS performance and LPHC function. It has been suggested that rotation of the pelvis and trunk away from the test limb (resulting in hip external rotation) during the SLS is indicative of an overactive (tight) piriformis, and underactivity of gluteus medius and gluteus maximus (Clark 2014). This may partially help explain why Burkhart et al. (2000) observed decreased hip rotation range of motion coupled with decreased hip abduction strength in individuals who had sustained a shoulder injury.

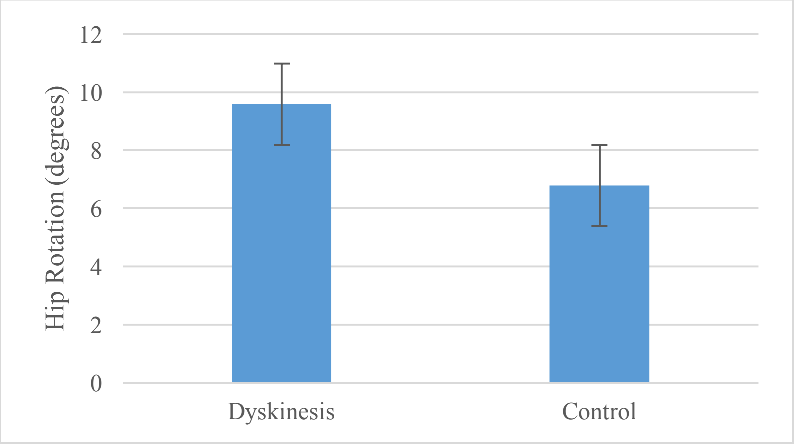

Figure 13: Means and standard error for maximum excursion hip rotation kinematics.

Knee Kinematics

The SLS has been studied extensively as a means of understanding knee pathologies, such as AKP, PFPS, and ACL injury (Dwyer, 2010; Hollman, 2014; Kulas, 2012; Yamazaki, 2010; Zeller, 2003). Furthermore, many studies have compared knee kinematics between sexes, due to ACL injuries being more prevalent in females versus males (Cowan, 2009; Graci, 2012; Hewett, 2009; Mendiguchia, 2011). The majority of these studies have found that females tend to display decreased knee flexion and increased knee valgus during the SLS, which is commonly present in non-contact ACL injury (Graci, 2012; Munkh-Erdene, 2011; Munro, 2012; Nakagawa, 2012; Zeller 2003.) While several studies have found decreased strength and activation of the hip extensors and abductors in females, another possible explanation for these kinematic differences at the knee is the more upright posture observed in females during the SLS (Graci, 2012; Powers, 2003; Nakagawa, 2012). It has been argued that this upright trunk posture may expose females to the risk of ACL injury by increasing the demand on the quadriceps to maintain control of the center of mass, and that the degree of trunk flexion is related to the degree of hip and knee flexion during the SLS (Graci, 2012; Griffin, 2000; Kulas, 2012; Padua, 2012; Vesci, 2007; Zazulak, 2005). Due to the associations between hip muscle strength, LPHC dysfunction, and shoulder injury, it was hypothesized that the dyskinesis group would display a decreased amount of knee flexion and an increased amount of knee valgus than the control group.

Results from the current study revealed significantly greater knee valgus in the dyskinesis group (12.49° ± 9.62) than in the control group (7.07° ± 10.54) (Figure 14), but not in maximum excursion knee valgus/varus kinematics. The positional knee valgus/varus kinematic findings in this study were similar to most previously reported values of knee valgus during the SLS (Ageberg, 2010; Bittencourt, 2012; Dwyer, 2010; Munro, 2012; Nakagawa, 2012; Zeller, 2003). Furthermore, the difference between the two groups in the current study is similar to kinematics reported by Nakagawa et al. (2012) when comparing healthy controls with individuals with PFPS. Differences in strength and neuromuscular control of proximal and local stabilizing musculature have been previously reported, with hip abduction, knee flexion, and knee extension strength being significant predictors of knee medio-lateral motion during the SLS (Claiborne, 2006). However, because the quadriceps and hamstrings have small abduction and adduction moments at the knee, it has been suggested that these muscles may reduce frontal plane knee motion primarily by increasing joint compression and stiffness (Claiborne, 2006; Hewett, 1996). Therefore, it is more likely that hip abduction strength is the primary predictor of frontal plane knee motion (Claiborne, 2006; Crossley, 2011).

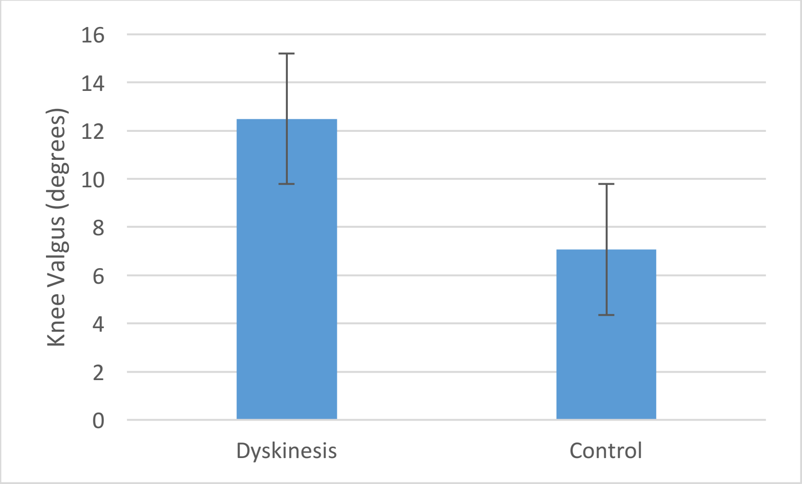

Figure 14: Means and standard error for positional knee valgus kinematics.

The maximum excursion valgus/varus kinematics observed in the current study suggest that while individuals with dyskinesis may have greater knee valgus than the controls, the amount of total movement deviation of the knee away from neutral was similar between groups. The dyskinesis group displayed 12.86° ± 6.15 of frontal plane knee motion, while the control group displayed 11.18° ± 4.67. Examination of these results, along with the positional kinematics reported above, indicate that participants in the control group likely displayed greater varus compared to the dyskinesis group. This finding is supported by previous research that reported greater knee varus in males versus females, as well as in healthy populations compared to those with lower extremity injury or dysfunction (Bolgla, 2008; Claiborne, 2006; Graci, 2012; Yamazaki, 2010; Zeller, 2003).

Finally, there was no significant difference in maximum knee flexion between the dyskinesis group (86.32° ± 7.81) and control group (90.09° ± 6.59). Although the current study did not require participants to reach a specific knee flexion angle, it is postulated that the lack of differences between groups may have resulted from participants performing the SLS from a specific height. Hollman et al. (2014) used a similar methodology, and found no differences in peak knee flexion when participants who were “good” and “bad” performers of the SLS when performing the task from a 20cm platform. In previous research examining differences in knee flexion, authors have neglected normalize squat depth between participants in order to mimic a clinical situation (Ageberg, 2010; Graci, 2012; Weeks, 2012; Yamazaki, 2010; Zeller, 2003). Therefore, while the current study cannot conclude that individuals with scapular dyskinesis display less knee flexion than those without, further investigation may be necessary to examine knee flexion between these groups without the normalization of squat depth.

Summary

The SLS is a controlled functional task that resembles activities of daily living as well as athletic movements. It is a valuable test for clinicians, due to its ability to detect dysfunction at multiple segments and in multiple planes with little cost, time, space, or equipment. While the majority of the literature has focused on lower extremity injury, the association between kinetic chain function and the upper extremity has led some authors to suggest the use of the SLS during the shoulder examination process (Beckett, 2014; Kibler, 2006; Kibler, 2008; Sciascia, 2012). Only one study has examined the relationship between SLS performance and shoulder function (Beckett, 2014). The authors of this study reported a universally poor performance of the SLS coupled with a high incidence of scapular dyskinesis in youth and adolescent baseball players. However, these authors relied on visual analysis of the SLS, as opposed to kinematic data.

Therefore, the current study aimed to examine the relationship between the presence of scapular dyskinesis and SLS kinematics of the trunk, pelvis, knee, and hip.

The primary findings from the current study revealed significantly greater trunk rotation, hip rotation, and knee valgus in individuals with scapular dyskinesis compared to a control group. Each of these findings corresponded with previously described aspects of LPHC dysfunction related to shoulder function. First, the increased degree of trunk rotation present in the dyskinesis group lends support to the observation of "corkscrewing" (excessive movement of the trunk and pelvis in the frontal and transverse planes during the SLS) previously described by Kibler and Sciascia (Kibler, 2006; Kibler, 2008; Sciascia, 2012). These authors postulated that LPHC weakness, represented by the observation of a corkscrewing motion during the SLS, could contribute to shoulder injury. While scapular dyskinesis is not considered an injury, the results of the current study support this theory.

Burkhart et al. (2000) reported that nearly half of patients who had sustained a labral tear in the shoulder exhibited significantly decreased hip rotation range of motion, hip abduction strength, and displayed Trendelenburg posture during single leg stance. The results of the current study partially reflect these findings with the significant findings of increased knee valgus and hip rotation. The gluteus medius is responsible for controlling frontal plane motion of the femur, and failure of this muscle to meet its demands can result in a valgus position of the knee. In this study, the dyskinesis group displayed a greater degree of knee valgus, and like the patients described by Burkart et al. (2000), individuals with scapular dyskinesis also had hip abductor weakness that was detectable by the SLS.

Finally, perhaps the most interesting finding of the current study in regard to the SLS was the significant difference in maximum excursion hip rotation, but not in positional hip rotation kinematics. Most SLS research has suggested that LPHC dysfunction is often associated with internal rotation of the hip. Results of the current study suggest that individuals with scapular dyskinesis have more hip rotation, but not always in the direction of internal rotation. It has been suggested that trunk and pelvis rotation away from the stance leg (resulting in hip external rotation) indicates possible piriformis tightness and weakness of gluteus medius and gluteus maximus (Clark, 2014). Therefore, the findings of decreased hip abductor strength and hip rotation range of motion by Burkhart et al. (2000) were also likely present in the current study.

Single-Leg Drop Landing

The SLDL is commonly used by clinicians and researchers to examine lower extremity and LPHC function due to its likeness to athletic movements known to be associated with ACL injury. Like the SLS, the SLDL requires adequate balance, neuromuscular control, and LPHC stability on a single-limb base of support. Although much of the SLDL literature has focused on ACL injury and rehabilitation, many of the same kinematic variables examined in SLS literature have been examined in the SLDL. Decreased sagittal plane motion of the trunk (flexion), hip (flexion), and knee (flexion), as well as increased frontal and transverse plane motion of the trunk (lateral flexion and rotation), pelvis (lateral flexion and rotation), hip (adduction/abduction), and knee (valgus/varus) indicate LPHC dysfunction as well as possible lower extremity injury risk.

Therefore, the current study aimed to examine potential differences in SLDL kinematics in individuals with and without dyskinesis, to see if the SLDL may be more revealing of LPHC dysfunction than the SLS.

Trunk Kinematics

Trunk kinematics have been studied less extensively in SLDL literature than in SLS literature. To the author's knowledge, only one study has examined trunk kinematics of the SLDL and in only the sagittal plane (Ali, 2013). In this study, the authors reported trunk flexion to range from 17.63° ± 6.80 to 21.88° ± 9.30 in healthy participants. While this is the only SLDL study that has reported trunk kinematics, previous research on bilateral drop landings and cutting maneuvers has suggested that trunk position during landing tasks has a great influence on the lower extremity and can indicate LPHC function (Mendiguchia, 2011).

Safe landing techniques typically involve increased sagittal plane movements (i.e. trunk, hip, and knee flexion) to dissipate high impact forces. Blackburn and Padua reported that increasing the degree of trunk flexion during a bilateral drop landing by 47% produced concomitant increases in hip (31°) and knee flexion angles (22°), and that increasing trunk flexion also increased hip extensor activity (Blackburn, 2008; Blackburn, 2009). Contrarily, it has been reported that excessive trunk flexion and concomitant hip flexion may influence the gluteus medius and gluteus maximus muscles, resulting in decreased hip abduction and extension strength (Kulas, 2006). However, the excessive trunk flexion angles studied by Kulas et al. (2006) do not typically correspond with angles observed in most athletic maneuvers, and increased trunk flexion is generally advantageous during landing (Mendiguchia, 2011).

The results of the current study revealed no significant differences in trunk flexion between the dyskinesis group (7.81° ± 4.13) and control group (6.45° ± 3.61). Although the current study only examined maximum excursion trunk flexion kinematics, these results suggest that both groups displayed much less forward trunk flexion than that reported by Ali and colleagues (Ali, 2013). It is plausible that differences in vertical drop height and horizontal distance from the landing surface between the current and previous study had an effect on trunk flexion. In the previous study by Ali et al. (2013), the authors examined trunk flexion angles from drop heights of 20cm, 40cm, and 50cm, with horizontal distances of 30cm, 50cm, and 70cm. The current study used a drop height of 33cm and a horizontal distance of 10cm. Though not completely linear, trunk flexion angles in the previous study generally increased with increased horizontal distance (Ali, 2013). Therefore, it is possible that the short horizontal distance used in the current study did not place a large demand on the trunk and hip extensors, resulting in the generally erect trunk posture observed across all participants.

The current study also revealed no significant differences in trunk lateral flexion. Maximum excursion kinematics suggest that the dyskinesis group (3.81° ± 2.14) and control group (3.53° ± 2.45) display similar total amounts of lateral trunk motion during the SLDL. Further examination of positional trunk lateral flexion kinematics revealed that both groups slightly flexed the trunk laterally toward the test limb, yet trunk posture was generally erect (dyskinesis group: -1.53° ± 4.44; control group -1.40° ± 4.50). While it was hypothesized that the dyskinesis group would display more frontal plane trunk motion (maximum excursion and positional kinematics) than the control group, it was also expected that both groups would display more lateral trunk motion (similar to the values found in the SLS). Similarly, there were no differences in maximum excursion kinematics (dyskinesis: 7.39° ± 4.32; control: 6.35° ± 3.18) or positional trunk rotation kinematics (dyskinesis: -7.23° ± 4.22; control: -6.67° ± 3.06). These data suggest that trunk rotation tended to occur in the direction of the test limb for both groups, as reported in previous SLS research (Graci, 2012; Graci, 2015).

During single-leg landing, the entire body mass must be balanced over one limb. Because the trunk, head, and arms comprise over half of the body's mass, it was expected that trunk lateral flexion and rotation would be greater across all participants due to the more dynamic nature of the SLDL task. It has been reported that increased trunk lateral flexion and rotation during unilateral lower extremity tasks indicates LPHC weakness. (Bolgla, 2008; Dempsey, 2007; Mendiguchia, 2011). Specifically, it has been stated that trunk lateral flexion toward the plant leg leads to increased knee valgus during the weight acceptance phase of cutting maneuvers, and indicates weakness of the gluteus medius (Dempsey, 2007); and increased trunk rotation has been related to decreased gluteus maximus and gluteus medius activation and strength during stair descent (Bolgla, 2008). Compared to the SLS results observed in the current study, both groups displayed generally decreased motion of the trunk, pelvis, hip, and knee in all three planes of motion. However, because no previous studies have examined these variables in the SLDL, it is difficult to explain this occurrence. It is possible that the SLDL, while a more dynamic task than the SLS, does not place the expected (greater) demand on the frontal plane trunk stabilizing musculature. Therefore, trunk motion during the SLDL observed in the current study is likely not an appropriate indicator of LPHC stability as it relates to upper extremity function.

Pelvis Kinematics

The current study aimed to distinguish possible differences in pelvis lateral flexion and rotation kinematics due to the association between LPHC function, pelvic stability during dynamic movements, and upper extremity function (Burkhart, 2000; Crossley, 2011; Graci, 2012; Kibler, 1998; Kibler, 2006; Nakagawa, 2012; Sciascia, 2006). Pelvis position and motion has been studied extensively in previous research regarding walking and running, LPHC muscle strength and activation, and overhead athletic maneuvers (Burkhart, 2000; Claiborne, 2006; De Mey, 2013; Elliott, 2003; Nakagawa, 2012; Whatman, 2013). In contrast, this information is virtually non-existent in the currently available SLDL literature. Given the association between hip abductor strength and ACL injury risk, it would seem that pelvic contributions to single-leg landing mechanics would be studied more frequently (Leetun, 2004). Contrarily, the vast majority of SLDL research has focused on motions of the knee, and to the author's knowledge, only one study has examined pelvis kinematics, and only in the frontal plane (Patrek 2011).

The current study revealed no significant differences in positional or maximum excursion pelvis kinematics. The control and dyskinesis groups displayed 7.00° ± 2.99 and 7.03° ± 3.44 of maximum excursion of pelvis lateral flexion, respectively. Similarly, positional kinematic values of pelvis lateral flexion revealed 6.83° ± 3.79 and 7.04° ± 3.44 for the control and dyskinesis groups, respectively. These data suggest that pelvis lateral flexion occurred toward the contralateral side, as expected, but was not significantly associated with scapular dyskinesis. Patrek, et al. (2011) examined effect of a hip abductor fatiguing protocol on pelvis lateral flexion toward the dominant leg during a SLDL in females. The authors reported that pre-fatigue pelvis lateral flexion at the instant of foot contact was 12.5° ± 6.1, and 60ms after foot contact, pelvis lateral flexion was 13.9° ± 6.5. After completing a hip abductor fatiguing protocol, the authors reported no change in pelvis lateral flexion. Additionally, the authors reported no change in peak EMG amplitude of the hip abductors during the first 60ms of the SLDL. It was postulated that although participants completed the post-fatigue SLDL within 1 minute of the fatigue protocol, their data could indicate signs of recovery from completion of the fatigue protocol to completion of the post-fatigue landing trials (supported by an 89% increase in average EMG activity of the hip abductors during the fatigue protocol, but no differences in peak EMG during the pre- and post-fatigue SLDL trials) (Patrek, 2011).

Pelvis rotation kinematics revealed non-significant differences between groups in maximum excursion kinematics (control: 6.22° ± 2.98; dyskinesis: 8.64° ± 3.62) and positional kinematics (control: -6.36° ± 3.04; dyskinesis: -8.58° ± 3.48). This suggests that pelvis rotation occurred in the direction of the test limb in nearly all participants. However, a possible limitation in the methodology of the current study exists. Because the participants were required to step forward (without jumping) to drop-land onto the force plate, the pelvis was typically rotated toward the non-test limb at the instant of foot contact. Following foot contact, the pelvis then rotated forward toward the test limb as a result of the forward motion of the body. Thus it is questionable whether maximum movement deviation of the pelvis in the frontal plane observed in this study was an authentic representation of a truly vertical SLDL. An alternate method for examining transverse pelvis rotation during the SLDL, which would better represent a strictly vertical drop landing, is to have participants perform the SLDL by hanging from a bar and drop landing onto one leg. This method has been used in two previous studies examining SLDL kinematics, however neither study included the pelvis in the analyses (Coventry, 2006; Durall, 2011). Therefore, future research regarding transverse plane pelvis kinematics during the SLDL (whether in relation to scapular function or not) may necessitate a similar drop landing protocol.

Hip Kinematics

Control of the hip and its associated musculature is crucial for safe landing mechanics (Mendiguchia, 2011). Because the hip allows motion in all three planes and also supports the trunk and upper extremity, strength and neuromuscular control of the muscles surrounding the hip joint play an important role in single-limb landing. Due to the interest in ACL injury, hip kinematics have been studied extensively in regard to proximal control of the knee (Ali, 2013; Coventry, 2006; Jacobs, 2007; Myer, 2015; Orishimo, 2006; Kerzonek, 2008; Schmitz, 2007; Yeow, 2011). Previous studies have mainly examined sex differences in hip kinematics during the SLDL to determine why females display a greater incidence of ACL injury. However, proximal control of the knee depends greatly on LPHC function (Kibler, 2006; Mendiguchia, 2011). Therefore, it was expected that the SLDL would be an appropriate test of LPHC function, and individuals with scapular dyskinesis would exhibit different sagittal, frontal, and transverse plane hip kinematics compared to a control group.

Hip flexion has been previously reported to range from 21.3° ± 15.0 to 61.2° ± 6.4 in healthy participants, with the majority of those studies reporting hip flexion angles on the lower end of this spectrum (Coventry, 2006; Jacobs, 2007; Kerzonek, 2008; Myer, 2015; Oritz, 2008; Orishimo, 2009). Results of previous studies have been mixed, with two studies reporting significantly greater peak hip flexion in females (Kerzonek, 2008; Orishimo, 2009), and one with significantly greater hip flexion in males (Jacobs, 2007). While these differences are likely a result of differences in methodology (i.e. vertical drop height), it has been generally acknowledged that relatively increased hip flexion during landing contributes to decreased joint reaction forces in the ankle, knee, and hip, and is therefore advantageous (Blackburn, 2008; Kerzonek, 2008; Mendiguchia, 2011).

As in the case of the trunk, hip flexion during landing is primarily controlled eccentrically by the gluteus maximus and, in part, by gluteus medius (Blackburn, 2009). Therefore it was hypothesized that the dyskinesis group would display less hip flexion during the SLDL, due to the relationship between LPHC and scapular function (Beckett, 2014; Burkhart, 2000; Kibler, 2006; Sciascia, 2012). Results of the current study revealed no significant differences in hip flexion between the dyskinesis group (32.04° ± 11.67) and control group (30.63° ± 10.54). There are two possible explanations for this finding. First, it is possible that there are no differences in hip extensor and abductor strength between the two groups. However, this is unlikely based on previous research finding significant differences in hip strength between those with and without shoulder dysfunction (Beckett, 2014; Burkhart, 2000), as well as the significant differences in SLS performance observed in the current study. Thus, it is more reasonable to conclude that hip flexion during the SLDL are not a significant predictor of scapular dysfunction due to the nature of the task.

Hip flexion kinematics in the current study were similar to those observed in previous studies (Coventry, 2006; Myer, 2015). While non-significant, these results suggest that the dyskinesis group trended toward slightly greater hip flexion than the control group. Although it has been suggested that increased trunk, hip, and knee flexion during landing likely indicate increased neuromuscular control of gluteus maximus and gluteus medius (Blackburn, 2009), some authors have also speculated that increased hip flexion may shift the center of gravity forward and negatively affect neuromuscular control of the knee (Jacobs, 2007; Kerzonek, 2008). Based on conflicting results regarding hip flexion during single-limb landing, it is difficult to determine exactly how much hip flexion is considered "excessive". It is possible that increased hip flexion may be advantageous if the trunk remains in a more erect position, and vice-versa. However, no previous SLDL studies have examined this relationship.

Hip adduction/abduction kinematics of the SLDL have been studied predominantly due to the association between hip adduction and knee valgus, the primary mechanism of non-contact ACL injury. Peak hip adduction angles have ranged from 3.9° ± 5.6 to 12.49° ± 6.93, with females exhibiting slightly greater peak hip adduction (Jacobs, 2007; Myer, 2015; Oritz, 2008; Orishimo, 2009; Yeow, 2011). It has been suggested that the increased degree of hip adduction in females, coupled with decreased hip abductor strength, are partially to blame for the high incidence of ACL injuries in females. Furthermore, Kerzonek et al. (2008) reported greater peak hip abduction in females (6.44° ± 4.92) compared to males (1.22° ± 6.95). Therefore, it was hypothesized that the dyskinesis group in the current study would display significantly greater total (maximum excursion) frontal plane movement of the hip, specifically in the direction of adduction.

The current study revealed no significant differences in maximum excursion or positional kinematics of hip adduction/abduction. In terms of maximum excursion kinematics, the control group displayed 10.25° ± 4.03, while the dyskinesis group displayed 9.63° ± 3.64. Further investigation of positional kinematics (control: 7.33° ± 6.23; dyskinesis: 7.08° ± 6.26) suggests that the majority of participants exhibited hip adduction, while a smaller proportion of participants displayed hip abduction. The failure of the current study to find any differences in frontal plane hip motion between groups may be due to the inclusion of both sexes, as females have typically displayed greater hip adduction than males as well as decreased hip abductor strength (Jacobs, 2007; Kerzonek, 2008; Nakagawa, 2012). Therefore, future research may aim to examine the relationship between scapular function and hip adduction during the SLDL with sex as a factor.

Although few studies have reported hip rotation kinematics during the SLDL, previous authors have reported values ranging from 6.6° ± 6.9 of external rotation to 13.4° ± 5.5 of internal rotation. Differences have been observed between sexes, with females exhibiting generally increased internal rotation coupled with decreased hip abduction and rotation strength (Jacobs, 2007); between healthy and ACL injured populations, with ACL injured individuals displaying greater hip internal rotation (Oritz, 2008); and between dominant and non-dominant sides, with the dominant leg displaying greater external rotation (Myer, 2015) Due to these differences relating to LPHC function, it was hypothesized that differences in maximum excursion and positional hip rotation kinematics would exist between groups. Furthermore, it was hypothesized that maximum deviation of hip rotation would occur in the direction of internal rotation and be greater in the dyskinesis group.

The current study revealed no significant differences in maximum excursion hip rotation kinematics (control: 8.95° ± 4.60; dyskinesis: 10.32° ± 4.48) or positional hip rotation kinematics (control: 6.06° ± 4.43; dyskinesis 7.68° ± 6.13). These data suggest that the majority of hip rotation was in the direction of internal rotation, however some participants displayed peak transverse plane hip motion in the direction of external rotation. Although non-significant, this is similar to the trend observed in hip rotation kinematics during the SLS in the current study. The lack of significant differences between groups in the current study could possibly be due to the inclusion of both sexes, whose differences were previously described. Therefore, while the current study was unable to conclude that hip rotation during the SLDL is significantly related to upper extremity function, it may be worth examining this variable in the future with sex as an additional factor.

Knee Kinematics

The knee has been studied more extensively in SLDL literature than any other segment of the body due to the association between landing mechanics and non-contact ACL injury (Brazen, 2010; Coventry, 2006; Jacobs, 2007; Kerzonek, 2008; Kiriyama, 2009; Myer, 2015; Nagano, 2007; Orishimo, 2006; Oritz, 2008; Russell, 2006; Wikstrom, 2006). Previous studies have examined the effects of sex, fatigue, muscle strength, and proximal segment contribution on knee kinematics during single-leg landing. Authors have suggested that decreased knee flexion and increased valgus/varus indicate dysfunction that may lead to lower extremity injury (Brazen, 2010; Jacobs, 2007; Kerzonek, 2008; Oritz ,2008; Russell, 2006).

Although no SLDL studies have examined this task with implications for upper extremity injury risk, it has been reported that alterations in knee flexion can affect stresses in the arm. Elliott et al. (2003) reported that tennis players who had decreased knee flexion during a serve had 23-27% increased loads in horizontal adduction and rotation at the shoulder and valgus load at the elbow. The authors suggested that decreasing knee flexion during the tennis serve resulted in a break in the kinetic chain, thereby decreasing the contribution of the hip and trunk. Furthermore, alterations in hip muscle (i.e. gluteus maximus, gluteus medius, hip external rotators) activity and strength have been associated with increased knee valgus during landing maneuvers, as well as an increased incidence of shoulder injury (Burkhart, 2000; Kibler, 2006; Leetun, 2004). This implies that compensatory motions of the knee can be manifested in the shoulder complex. Thus, it was hypothesized that individuals with scapular dyskinesis would exhibit decreased knee flexion and increased valgus/varus motion, specifically in the direction of valgus, compared to controls.

The current study revealed no significant differences in knee flexion between groups. The dyskinesis group displayed 49.45° ± 11.31, while the control group displayed 50.09° ± 9.28 of knee flexion. These values are similar to those reported in previous literature (Coventry, 2006; Kiriyama, 2009; Myer, 2015; Nagai, 2013; Nyland, 2011; Schmitz, 2007), but suggest that knee flexion during the SLDL is not a predictor for scapular dyskinesis. It is worth noting that the contribution of the knee to total energy dissipation during a SLDL is only 11.4% (Yeow, 2011). Therefore, the body likely relies on more proximal segments to contribute to safe landing techniques, and future SLDL research may require a more multidimensional approach to understand dysfunction holistically.

Control of knee valgus is important to researchers and clinicians. This motion places stress on passive structures, and combined with anterior translation of the tibia, induces strain on the ACL. Although it has been reported that knee extensor and flexor strength are significant correlates of knee valgus, these muscle groups have small adduction and abduction moments at the knee and likely contribute to frontal plane stabilization of the knee via co-contraction and increases in joint compression and stiffness (Hewett, 1996). It has also been reported that the lateral hip musculature plays a significant role in controlling knee valgus, and altered activity or strength deficits of the gluteus medius leads to increased knee valgus (Bolgla, 2008; Claiborne, 2006; Crossley, 2011).

The results of the current study yielded no significant differences in positional or maximum excursion kinematics of knee valgus/varus motion. In terms of maximum excursion kinematics, the control and dyskinesis groups exhibited 7.69° ± 3.34 and 7.85° ± 3.84 of valgus/varus motion, respectively. Further inspection of positional kinematics revealed that the control and dyskinesis groups displayed 1.76° ± 9.40 and 1.32° ± 9.23, respectively. This implies that as a whole, both groups displayed similar degrees of valgus/varus motion. Furthermore, while the mean values suggest that motion occurred slightly in the direction of valgus, participants in both groups exhibited nearly equal amounts of valgus and varus. Because previous studies have reported significantly greater valgus in females and varus in males (Jacobs, 2007; Kerzonek, 2008; Russell, 2006), one may be inclined to propose that the inclusion of both sexes had a canceling effect on the knee valgus values observed in the current study. However, this is highly unlikely, given that the maximum excursion kinematics presented in the current study were also nearly identical. Therefore, it is more reasonable to conclude that frontal plane knee motion during the SLDL is not an appropriate predictor of scapular function and is not suitable for clinical use.

Summary

The SLDL was examined as a secondary test to the SLS due to its similarity in demand for balance, LPHC stability, and neuromuscular control on a single base of support. It was originally thought that the more dynamic nature of the test may expose possible LPHC dysfunction that was not observed in the SLS. The SLDL has been studied almost unanimously in terms of the ACL due to its likeness to motions associated with non-contact ACL injury. Although previous research has focused primarily on ACL injury mechanisms, SLDL mechanics have been largely related to LPHC function (Oritz, 2008; Patrek, 2011; Zazulak, 2005). Optimal performance of the SLDL consists of adequate sagittal plane biomechanics and eccentric control of the hip and knee musculature, combined with decreased frontal and transverse plane motion of the trunk, pelvis, hip, and knee.

Based on previously reported associations between LPHC stability and upper extremity function, it was hypothesized that individuals with scapular dyskinesis would display greater frontal and transverse motion of the trunk (lateral flexion and rotation), pelvis (lateral flexion and rotation), hip (adduction/abduction and internal/external rotation), and knee (valgus/varus) coupled with decreased sagittal plane motion of the trunk (flexion), hip (flexion), and knee (flexion) (Beckett, 2014; Burkhart, 2000; Elliott, 2003; Kibler, 2006; Oliver 2013). The results of the current study indicated that there were no significant differences in SLDL kinematics between the dyskinesis and control groups. This finding may suggest one of two things. First, it is possible that individuals with scapular dyskinesis do not have differences in LPHC function compared to those without dyskinesis. However, based on previous research regarding upper extremity injury and LPHC function (Beckett, 2014; Burkhart, 2000), as well as the SLS results observed in the current study, this assumption cannot be made with confidence. Therefore, it is more likely that the SLDL used in the current study is not an appropriate test of LPHC function as it pertains to scapular dyskinesis.

In addition to the lack of significance found in the current study, there is also a lack of literature regarding SLDL kinematics not focused primarily on the knee. While this is understandable to some extent, it should also be borne in mind that the knee only contributes to 11.4% of total energy dissipation during single-leg landing (Yeow, 2011) Moreover, it is surprising that more studies examining the upper body's influence on SLDL biomechanics do not exist, considering the trunk, arms, and head make up over half of the body's mass (Hewett, 1996) This gap in the literature made it difficult to establish relationships between findings of the current study and past research, and therefore necessitated inclusion and comparison of research on other activities such as plant and cut maneuvers and bilateral drop landings.

Conclusions and Directions for Future Research

The current study indicated that trunk rotation, hip rotation, and knee valgus during the single-leg squat were significantly greater in the dyskinesis group compared to the control group. These findings are valuable for clinicians during the evaluation process, as well as for the development of corrective exercise strategies for patients with shoulder injuries. There were some limitations to the current study. First, although scapular dyskinesis is associated with shoulder pain/injury, it is not considered an injury in and of itself. Therefore, the scapular dyskinesis group included participants with and without injury. Second, although previous research has highlighted some sex differences in single-leg squat and single-leg drop landing performance, both sexes were included in the current study in attempt to generalize findings across sexes.

Future research should consider examining single-leg squat and single-leg drop landing kinematics in individuals with and without shoulder dysfunction with sex as an additional factor. Furthermore, there is an apparent gap in the literature concerning SLDL kinematics related to the pelvis and trunk. Due to its similarity with the mechanism of injury for non-contact ACL ruptures, the SLDL has been studied extensively in terms of hip and knee kinematics. Because the upper body contributes to over half the body’s mass, it would likely be advantageous to examine pelvis and trunk mechanics to give a more global sense of SLDL performance.

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APPENDIX A

Participant ID: _______________

Age: ___________ Sex: ___________ Height: ___________ Weight: _________

Hand Dominance: RIGHT LEFT

Leg Dominance: RIGHT LEFT

Scapular Dyskinesis Test: YES NO

Affected Shoulder: RIGHT LEFT

Test Leg: RIGHT LEFT

# SLS Practice Trials:	Right: __________	Left: __________
# SLS Trials Attempted:	Right: __________	Left: __________
# SLDL Practice Trials:	Right: __________	Left: __________
# SLDL Trials Attempted:	Right: __________	Left: __________

Previous Shoulder Injury/Pain (Include date):

____

____

Previous Lower Extremity Injury/Pain (Include date):

____

____

APPENDIX B

AUBURN UNIVERSITY
COLLEGE OF EDUCATION

SCHOOL OF KINESIOLOGY

301 Wire Road
Auburn, AL 36849
(334) 884-4483

(NOTE: DO NOT SIGN THIS DOCUMENT UNLESS AN IRB APPROVAL STAMP WITH CURRENT DATES HAS BEEN APPLIED TO THIS DOCUMENT.)

INFORMED CONSENT for a Research Study entitled

Clinical Tests of Lumbopelvic-Hip Complex Function in Individuals with Scapular Dyskinesis: Implications for Identifying Individuals at Risk for Upper Extremity Injury

Explanation and Purpose of the Research

You are being asked to participate in a research study for the Sports Medicine & Movement Laboratory in the School of Kinesiology. Before agreeing to participate in this study, it is vital that you understand certain aspects of what might occur. This statement describes the purpose, methodology, benefits, risks, discomforts, and precautions of this research. This statement describes your right to confidentiality and your right to discontinue your participation at any time during the course of this research without penalty or prejudice. No assurances or guarantees can be made concerning the results of this study.

This study is designed to examine the association between shoulder function and performance on the single-leg squat and single-leg drop landing assessments. To investigate this, kinematic data during the single-leg squat and single-leg drop landing assessments, as well as the results of a scapular dyskinesis test, will be collected.

Research Procedures

To be considered for this study, you must be between the ages of 19-30 years old, and partake in at least 30 minutes moderate to vigorous physical activity 3-5 days per week. You must also be free of lower extremity injury for the last 6 months, and no shoulder surgery within the past 1 year, have no neurological or musculoskeletal conditions that make the lower extremity weak, and no dizziness or health conditions that would lead to dizziness. Additionally, you must not have an allergy to adhesive tape. Total time for testing is approximately 30 minutes.

Testing will require the evaluation of height, body mass, and age, as well as scapular function and performance of the single-leg squat and single-leg drop landing assessments. Age will be determined from this consent form and will be recorded to the nearest month. The presence of scapular dyskinesis will be determined by video analysis of the scapular dyskinesis test. Single-leg squat and single-leg drop landing performance will be measured with a 3D Motion Capture system.

The Auburn University Institutional
Review Board has approved this
Document for use from
07/19/2016 to 07/18/2017
Protocol # 16-252 EP 1607

Once all preliminary paperwork has been completed, you will need to be dressed in only a pair of shorts, sports bra or bathing suit top, t-shirt, socks, and tennis shoes for testing. You will be allotted an unlimited time to perform any stretches or warm-up you deem necessary. Once properly dressed and ready for testing, scapular function will be assessed by filming the scapular dyskinesis test. A digital camera will be placed behind you to film your scapulae during the scapular dyskinesis test. The scapular dyskinesis test consists of five repetitions of shoulder flexion while holding 3-pound weights.

After the scapular dyskinesis test, electromagnetic sensors will be placed on your legs, torso, and neck. Placement of the sensors at these locations will allow the joints to be properly monitored during testing. Following the placement of the sensors, you will will be asked to perform 3 repetitions of the single-leg squat and single-leg drop landing assessments on each leg. The single-leg squat test will consist of standing on a 25cm platform with your arms crossed over your chest, and slowly squatting down on one leg until the heel of the opposite foot touches the ground before returning to an upright standing position. The single-leg drop landing will consist of you standing on a 33cm platform with your arms crossed over your chest, and stepping forward with one foot and landing on the foot with which you stepped forward. At the completion of testing, water will be provided to you and you will be asked to perform your own specified post-physical activity cool-down.

Potential Risks

As with any movement research, certain risks and discomforts may arise. The possible risks and discomforts associated with this study are no greater than those involved in activities of daily life and light physical activity, and may include: injury from falling, muscle strain, muscle soreness, and ligament and tendon damage. Every effort will be made to minimize these risks and discomforts by selecting participants who are physically active. It is your responsibility, as a participant, to inform the investigators if you notice any indications of injury or fatigue, or feel symptoms of any other possible complications that might occur during testing or the intervention.

To reduce the risk of injury, certain precautions will be taken. During testing, two board certified athletic trainers will be present to monitor participants during testing. Ample warm-up and cool-down periods will be allowed, and water will be provided to you as needed.

Confidentiality

All information gathered in completing this study will remain confidential. Your individual performance will not be made available for public use, and will not be disclosed to any person(s) outside of the research team. The results of this study will primarily be written as a dissertation to satisfy the degree requirements for a PhD in the School of Kinesiology at Auburn University. Additionally, supplemental results may be published or presented as scientific research. No participant's name or identity shall be revealed should such publication occur.

The researcher will try to prevent any problem that could occur because of this research. If at any time there is a problem, you should let the researcher know and he or she will help you. Should an emergency arise, we will call 911 and follow our Emergency Action Plan. You are responsible for any cost associated with medical assistance.

Participation and Benefits

Participation in this research is strictly voluntary, and refusal to participate will result in no penalty. You will be allowed to withdraw consent and discontinue your participation in this research at any time without bias or prejudice from Auburn University, the School of Kinesiology, or the Sports Medicine & Movement group.

Participants will potentially benefit from this research study by verbal notification of the results of the scapular dyskinesis test, single-leg squat test, and single-leg drop landing test immediately after testing is complete. This information will let you know if you have any potential weakness in your core or scapular stabilizing musculature that may lead to potential injury. Knowledge of your performance on these tests will give insight on core strength and scapular function, thereby informing you of future potential injury risk.

Questions Regarding the Study

If you have any questions about your rights as a research participant, you may contact the Auburn University Office of Research Compliance or the Institutional Review Board by phone (334)-884-5966 or email at irbadmin@auburn.edu or IRBChair@auburn.edu.

HAVING READ THE INFORMATION PROVIDED, YOU MUST DECIDE WHETHER OR NOT YOU WISH TO PARTICIPATE IN THIS RESEARCH STUDY. YOUR SIGNATURE INDICATES YOUR WILLINGNESS TO PARTICIPATE.

____ ______ years ______ months

Printed Name of Participant Age

____ _________________

Signature of Participant Date

The above consent form was read, discussed, and signed in my presence. In my opinion, the person signing said consent form did so freely and with full knowledge of its contents.

____ _________________

Signature of Investigator Date

The Auburn University Institutional
Review Board has approved this
Document for use from
07/19/2016 to 07/18/2017
Protocol # 16-252 EP 1607

APPENDIX C

Summary of Statistical Results for the SLS.

MANOVA	Degrees of Freedom	F Statistic	Significance	Partial Eta Squared
Trunk (RQ1)	(3,60)	3.137	0.032	0.136
Pelvis (RQ1)	(2,61)	2.907	0.062	0.087
Hip (RQ1)	(3,60)	3.742	0.016	0.158
Knee (RQ1)	(2,61)	2.399	0.099	0.073
Trunk (RQ2)	(2,61)	4.478	0.015	0.128
Pelvis (RQ2)	(2,61)	1.040	0.360	0.033
Hip (RQ2)	(2,61)	0.437	0.648	0.014
ANOVA				
Knee (RQ2)	(1,63)	4.606	0.036	-

Summary of Follow-Up Statistical Results for Significant SLS Variables.

t-test	Degrees of Freedom	t-statistic	Significance	Mean(SD) Dyskinesis	Mean(SD) Control
Trunk Rotation (RQ1)*	(63)	-2.570	.013	11.09(3.28)	9.04(3.09)
Trunk Rotation(RQ2)	(63)	-2.929	.005	-10.12(6.56)	-6.85(7.77)
Hip Rotation (RQ1)*	(63)	-2.776	.008	9.59(4.40)	6.79(3.02)
Knee Valgus (RQ2)	(63)	-2.146	.036	12.49(9.62)	7.07(10.54)

*Equal variances not assumed.

Summary of Statistical Results for the SLDL.

MANOVA	**Degrees of Freedom**	**F Statistic**	**Significance**	**Partial Eta Squared**
Trunk (RQ1)	(3,60)	0.934	0.430	0.045
Pelvis (RQ1)	(2,61)	2.368	0.102	0.072
Hip (RQ1)	(3,60)	0.86	0.467	0.041
Knee (RQ1)	(2,61)	0.064	0.938	0.002
Trunk (RQ2)	(2,61)	0.183	0.833	0.006
Pelvis (RQ2)	(2,61)	3.793	0.058	0.047
Hip (RQ2)	(2,61)	0.728	0.487	0.023
ANOVA				
Knee (RQ2)	(1,63)	0.036	0.851	-