The Effect of an Isometric Strength Training Protocol on Valgus Angle During a Drop-Jump Landing in Elite Female Volleyball Players

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The Effect of an Isometric Strength Training Protocol on Valgus Angle During a Drop-Jump Landing in Elite Female Volleyball Players

By

Kaitlin Jackson

A Thesis
Submitted to the Faculty of Graduate Studies through the Department of Kinesiology in Partial Fulfillment of the Requirements for the Degree of Master of Human Kinetics at the University of Windsor

Windsor, Ontario, Canada

2014

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The Effect of an Isometric Strength Training Protocol on Valgus Angle During a Drop-Jump Landing in Elite Female Volleyball Players

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DECLARATION OF ORIGINALITY

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ABSTRACT

The purposes of this study were to a) strengthen the gluteal and hamstring muscles of 14 elite female volleyball players via a six week isometric strength training program to b) determine changes in peak knee valgus angle, c) determine any changes in tibial acceleration, and d) determine changes in vertical ground reaction forces at peak valgus angle during a drop-jump landing task. Significant strength increases were seen in hip extension (20.5%), abduction (27.5%), and knee flexion (23.5%) in the training group. No significant group changes were observed for knee valgus angle, tibial acceleration, or ground reaction forces. Notable significant individual changes were found for knee valgus angle, knee flexion angle, peak vertical ground reaction forces, and tibial accelerations. A trend of decreased knee flexion in the training group was also observed. Isometric strength training increases strength, and could potentially decrease knee valgus in certain individuals.
DEDICATION

I dedicate this thesis to my coaches and teachers, who continue to inspire and challenge me to ask questions and seek answers.
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GLOSSARY

ACL (anterior cruciate ligament): a cruciate ligament of each knee that is attached in front to the medial aspect of the tibia, that passes upward, backward, and laterally through the middle of the knee, crossing the posterior cruciate ligament to attach to the lateral condyle of the femur. The ACL functions to prevent hyperextension of the knee and to keep the tibia from sliding forward in relation to the femur.

AS (acceleration slope): slope of the acceleration waveform calculated using the points 30% and 70% between the base of the curve (slope=0) just prior to the change in slope towards the peak, and peak axial acceleration amplitude.

ASIS (anterior superior iliac spine): the anterior extremity of the iliac crest, which provides attachment for the inguinal ligament and the sartorius muscle.

ATT (anterior tibial translation): anterior movement of the tibia relative to the femur.

EMG (electromyography): a technique used to evaluate and record the electrical activity of a muscle.

FMA (femoral mechanical axis): the line connecting the centre of the femoral head to the mid-condylar point between the cruciate ligaments of the knee.

GRF (ground reaction force): the force of the ground on the body that is equal in magnitude and opposite in direction to the force the body exerts on the ground.

HKA (hip knee angle): the angle formed between the femoral mechanical axis and the tibial mechanical axis in the frontal plane.

Kinematics: the study of the motion of a body without consideration given to its mass or the internal and external forces acting on it.

Kinetics: the study of the motion of masses in relation to the forces acting on them.

LAS (linear tibial acceleration): the rate of increase of tibial axial acceleration measured linearly between the 30% and 70% points on the acceleration curve; where 0% is the base of the curve just before the slope begins to increase, and 100% is the peak amplitude.

LBA (load-bearing axis): the line that is perpendicular to the ground and runs upward through the body when the feet are in contact with the ground.

LCL (lateral collateral ligament): a ligament that connects the lateral epicondyle of the femur with the lateral side of the head of the fibula and that helps to stabilize the knee by preventing lateral dislocation.
LTT (lateral tibial translation): movement of the tibia in the frontal plane relative to the femur.

MCL (medial collateral ligament): a ligament that connects the medial epicondyle of the femur with the medial condyle and medial surface of the tibia and that helps to stabilize the knee by preventing medial dislocation.

MVIC (maximal voluntary isometric contraction): the peak force produced by a muscle as it contracts while pulling against an immovable object.

NCAA (National Collegiate Athletic Association): Organization that administers U.S. intercollegiate athletics. It was formed in 1906 but did not acquire significant powers to enforce its rules until 1942. Headquartered at Indianapolis, Ind., it functions as a general legislative and administrative authority, formulating and enforcing rules of play for various sports and eligibility criteria for athletes. It has about 1,200 member schools and conducts about 80 national championships in a total of about 20 sports.

PA (peak acceleration): the maximal tibial acceleration measured parallel with the long axis of the tibia segment.

PAS (peak acceleration slope): the maximum rate of increase of tibial axial acceleration that occurs between 30% and 70%; where 0% is the base of the curve just before the slope begins to increase, and 100% is the peak amplitude.

PCL (posterior cruciate ligament): a cruciate ligament of each knee that is attached in back between the condyles of the tibia, that passes upward and forward through the middle of the knee, crossing the anterior cruciate ligament to attach to the medial condyle of the femur. The PCL functions to prevent hyperflexion of the knee and to keep the tibia from sliding backward in relation to the femur when the knee is flexed.

PFPS (patellofemoral pain syndrome): refers to pain in the front of the knee due to inflammation. It sometimes is due to the wearing down, roughening, or softening of the cartilage under the kneecap due to misaligned tracking of the patella when the knee flexes and extends.

PV (peak value): the maximum value of a kinetic and/or kinematic variable measure.

Q-angle (quadriceps angle): the angle between a line drawn from the anterior superior iliac spine (ASIS) to the centre of the patella and the extension of a second line drawn from the tibial tuberosity through the centre of the patella.

TA (tibial acceleration): the acceleration of the tibia after impact measured just medial to the tibial tuberosity at the proximal end of the tibia.
TMA (tibial mechanical axis): the line connecting the centre of the tibial plateau at the proximal end to the centre of the tibial plafond at the distal end.

TTP (time to peak): time between the base of the curve just prior to the change in slope towards the peak, and peak axial acceleration amplitude.

Valgus: the medial shift of the femoral and tibial mechanical axes, observed as the knee joint shifting towards the midline of the body, relative to the hip and ankle joints.
1. INTRODUCTION

Preventing anterior cruciate ligament (ACL) injuries in female athletes has been heavily researched in recent decades due to high injury rates. Female athletes have twice as many ACL injuries (de Loes et al., 2000) and require surgery for ligamentous knee injuries almost twice as often as males (Fernandez et al., 2007). Approximately one third of all sports injury surgeries involve the ACL (Powell et al., 1999; Rishiraj et al., 2009), making them the most costly procedures when all surgery and rehabilitation expenses are considered (de Loes et al., 2000; Louw et al., 2008). The significantly higher number of ACL injuries among female (compared to male) athletes has prompted a focus on exercise interventions in an attempt to reduce the risk of injury for females (Cammarata et al., 2010; Ford et al., 2003; Howard et al., 2011; Jacobs et al., 2007; Joseph et al., 2011; Myer et al., 2005b).

Studies show that 70%-90% of sports injuries occur in non-contact situations (no contact with any other object or person except for the ground) (Griffin et al., 2000; McNair et al., 1990; Mykelbust et al., 1997). Female athlete knee injuries predominantly occur during maneuvers such as deceleration, pivoting, or landing tasks that are associated with high external loads at the knee joint (Besier et al., 2001; Boden et al., 2000). There has been a particular focus on sports-related non-contact injuries sustained during landing activities due to the high forces and high risk biomechanical strategies used (Chappell et al., 2008; Ford et al., 2003; Hewett et al., 2005; Jacobs et al., 2007; Joseph et al., 2008; Myer et al., 2006). During landing, valgus deviation (also referred to as knee adduction or tibial
abduction) – the degree to which the tibia angles laterally relative to the femur – strains passive knee tissues, such as the ACL, that maintain the structural integrity of the tibiofemoral joint, thereby increasing the risk for injury (Hewett et al., 2005; Cooke et al., 2007). The ACL’s primary role in knee stabilization is to resist anterior movement of the tibia relative to the femur, as well as resist tibial internal rotation (Butler et al., 1980; Ellison et al., 1985). It is the association of valgus angle with the occurrence of this anterior tibial translation that links larger valgus angles with excessive strain on the ligaments of the knee, which is thought to lead to injury (Powers et al., 2010; Myer et al., 2005b). In non-contact landing maneuvers, tibial abduction (valgus) has been found to be a primary link to ACL injury (Hewett et al., 2005; Levine et al., 2013). These non-contact maneuvers happen frequently in volleyball. Injury data for NCAA women’s volleyball collected between the 1988/1989 and 2003/2004 seasons showed that 57.3% of injuries were to the lower extremity, with 32.7% of those during games and 54% of those during practices caused by non-contact mechanisms. The most common non-contact mechanism involved a drop-jump landing, such as would be experienced when a player jumps immediately after landing (usually on two feet) after a block or attack jump (Agel et al., 2007). During this maneuver, dynamic stability of the knee through adequate muscle and ligament restraints is crucial for injury prevention, with muscle actions being the primary defense in all planes of movement.

In addition to higher valgus angles, female athletes demonstrate lower knee and hip flexion during landing compared to their male counterparts. Lower flexion angles result in more rigid lower extremities and are associated with higher
anterior tibial force and ACL injury (Berns et al., 1992; Ford et al., 2003; Hewett et al., 2005; Howard et al., 2011; Hughes et al., 2008; Hughes et al., 2010; Kirkendall et al., 2000; Markolf et al., 1995; Withrow et al., 2006a; Withrow et al., 2006b). The increased rigidity results in a stiffer landing and therefore higher foot-ground vertical impact forces and higher tibial acceleration (a measure of shock wave attenuation at the proximal tibia), which is directly proportional to impact-induced ACL strain (McLean et al., 2011). In the sagittal plane, higher hip and knee flexion could decrease the tibial acceleration and impact forces absorbed at the knee through a less rigid landing technique. In the frontal plane, however, it is unknown if an improved alignment of the knee joint will change these factors, as a more aligned system may theoretically increase the tibial acceleration. The impact forces in this scenario could be more attenuated by the decrease in the medial/lateral movement at the knee.

Recent research in this area has focused on the effectiveness of various exercise interventions to improve the biomechanics of the knee (increase sagittal flexion and decrease knee valgus angles) through strengthening muscles surrounding the hip (Anwer & Alghadir, 2014; Earl et al., 2011; Herman et al., 2008). This is because the hip is the most proximal joint of the lower extremity closed-kinetic-chain, and attaining adequate control of this joint is beneficial for controlling movement mechanics at the more distal joints, most importantly the knee. During landing, muscle weakness in abduction, external rotation, and extension of the hip is associated with instability at the knee as it leads to high adduction and internal rotation of the hip, resulting in a higher valgus angle (Hewett et al., 2006; Myer et al.,
Therefore, proximal control of the femur is crucial to be able to maintain a neutral alignment of the distal femur with the tibia at the knee to prevent excessive valgus deviation.

Several injury prevention exercise protocols have been used in clinical and research settings to increase hip muscle strength and/or activation to improve knee kinematics. Dynamic resistance, neuromuscular (plyometrics, agility, balance), and isometric resistance (static contractions) training programs have been studied in an attempt to alter the biomechanics of the lower extremity joints. Neuromuscular strengthening programs commonly consist of a combination of balance and plyometric exercises involving gross multi-joint body movements and/or sport-specific maneuvers (Hewett et al., 2005; Myer et al., 2005b). Some success has been seen with neuromuscular training in controlled settings; however, injury rates have not declined (Agel et al., 2007). The exercises used in each neuromuscular training study vary, thereby making the results associated with general neuromuscular training inconsistent. In addition, other neuromuscular training programs, despite showing improvements in strength, have failed to decrease the peak valgus angle during landing tasks (Chappell et al., 2008; Chimera et al., 2004). Dynamic resistance training targets a specific muscle or muscle group in a weight and speed controlled manor (i.e. a bicep curl, squat). Ferber et al. (2011) used this type of training to strengthen the hip abductor muscles to improve biomechanical function in the frontal plane, but found no kinematic change, despite improvements in strength and lower reported pain levels. This suggests that strengthening hip musculature in all planes of movement (i.e. tri-planar) may be necessary for
controlling the knee in the frontal plane (Joseph et al., 2011; Nadler et al., 2002), as weakness in hip abduction (Jacobs et al., 2007; Nadler et al., 2002), external rotation (Howard et al., 2011; Khayambashi et al., 2012), and extension (Nadler et al., 2002) are all associated with higher valgus angles.

Isometric resistance training involves a static muscle contraction that typically targets the muscles surrounding one joint at a time, with the focus being on the muscle/muscle group in which the directional force is applied (i.e. gluteus medius targeted with isometric hip abduction at 0° hip flexion). Studies show that isometric resistance training produces larger strength gains than dynamic resistance training, higher muscle activation levels (Duchateau et al., 1984; Folland et al., 2005), and faster muscle activation timing (Cowan et al., 2003; Tsao et al., 2010). Despite these findings, the majority of resistance training protocols investigated in the literature to date have used dynamic exercises to try and manipulate lower extremity biomechanics with inconsistent results. Considering all the research completed to date, no study has assessed the effectiveness of an isometric tri-planar hip-strengthening program to control frontal plane movement at the knee during a drop-jump landing task.

Therefore, the purpose of this study was to determine if a tri-planar isometric hip strengthening program decreases the valgus angle of female volleyball athletes during a drop-jump landing task. The program focused on strengthening the hip abductors, extensors, and external rotators, with the intention of decreasing the valgus angle, thereby decreasing the risk for injury by improving the alignment
of the knee in the frontal plane. There are two landings associated with a drop-jump task. The initial landing occurs after the participant jumps off the 30 cm box onto the ground and then proceeds to perform a block jump. The second landing is the athlete returning to the ground from the block jump. The primary focus of this study, as studied previously, was the initial jump (Chappell et al., 2008; Hewett et al., 2005). The specific aims of this study were to:

1) determine if there were any improvements in hip abduction and extension strength (joint moments) after the isometric strengthening protocol
2) quantify changes in the peak valgus angle of the initial landing during a drop-jump task after an isometric strengthening protocol
3) determine any changes in tibial acceleration upon initial landing
4) determine any changes in vertical ground reaction forces upon initial landing at the peak knee valgus angle

It was hypothesized that an isometric strengthening protocol would result in:

1) an increase in the maximum voluntary hip abduction and extension moment-generating capacity
2) a decrease in the peak valgus angle during the initial landing in a drop-jump landing task
3) an increase in tibial acceleration upon initial landing
4) a decrease in vertical ground reaction force magnitudes upon initial landing at the peak valgus angle
2. REVIEW OF THE LITERATURE

2.1 Lower Extremity Anatomy and Function

2.1.1 Hip Joint

The hip joint is the most proximal end of the lower extremity kinetic chain. It is the articulation between the rounded head (ball) of the femur and the acetabulum, a concave socket on the inferior lateral aspects of the pelvis (Figure 1).

Figure 1: A frontal view of the ball and socket joint of the right hip (modified from The Food and Drug Administration, The Hip Joint).

The hip joints allow angular movements of the femurs (abduction/adduction, flexion/extension, internal/external rotation) in all three primary planes (frontal, sagittal, transverse) (Figure 2), which occur about their corresponding perpendicular axes (antero-posterior, medio-lateral, longitudinal). Circumduction, a movement characterized by a circular motion created by sequential flexion/extension and abduction/adduction movements, is also possible at the hip.
The three primary planes of movement: sagittal (flexion/extension about a medio-lateral axis), frontal (abduction/adduction about an antero-posterior axis), and transverse (rotation about a longitudinal axis) (image modified from www.interactive-biology.com).

(Sutton, 1995). The range of motion allowed by the hip joint is second only to the shoulder.

The hip is structurally very stable due to the depth of the acetabulum and the strength of the capsular ligaments that surround the joint. The capsular ligaments of the hip joint include the iliofemoral, pubofemoral, and ishiofemoral ligament (Figure 3) (Kelly et al, 2003).
The muscles of the hip originate on or superior to the pelvis, and insert on or inferior to the pelvis; in doing so, they act to stabilize the hip joint and help to control movements of the most proximal segment(s) of the lower extremity. The hip muscles that originate at or above the pelvis and insert at or below the knee are biarticular, controlling movements at the hip as well as the knee. The importance of the endurance and strength capacity of these muscles in preventing injury lies in maintaining the integrity of the joint(s) they surround. The hip is a weight-bearing joint, therefore the muscles of the hip function to move the thigh through its range of motion as well as protect the hip joint by holding it firmly in place to maintain joint integrity during a wide variety of maneuvers of various intensities and speeds.

Muscles that coordinate movement about the hip are generally categorized in two groups: deep stabilizer muscles and prime mover muscles. The deep stabilizer
muscles hold the joint in place by pulling the femoral head into the acetabulum. They are smaller in size and located deeper relative to the prime mover muscles. Their movements are primarily reflexive and do not require conscious thought to move. They do not produce as much force as the prime mover muscles; however, they typically have great endurance and are continuously activated to stabilize the joint. The prime mover muscles are located more superficially and are primarily responsible for the gross motor movements of the thigh about the hip.

Various movement patterns of the thigh about the hip require the activation of the deep stabilizers and various combinations of the prime mover muscles that cross the hip joint. Movements in the frontal plane are made by the abductors (e.g. gluteus medius, gluteus minimus) and adductors (e.g. adductor magnus, adductor longus, adductor brevis, pectineus, gracilis). Movements in the sagittal plane are made by hip flexors (e.g. psoas major, iliacus, rectus femoris) and extensors (e.g. semitendinosus, semimembranosus, biceps femoris, gluteus maximus). Lastly, internal and external rotation about the hip joint (transverse plane) are executed by the gluteus medius, gluteus minimus, and tensor fascia latae, and piriformis, gemelli (gemellus superior and inferior), obturator internus and externus, and quadratus femoris, respectively (Fernandez, 2004; Kay, 2011) (Figure 4).
Figure 4: Muscles of the hip shown in lateral (A) and posterior (B) views (modified from Muscolino, 2011).
The gluteal muscles (gluteus maximus, medius, and minimus - Figure 4) are major contributors to hip movement and stability in all planes (Ferrell et al., 2001). The primary concentric roles of the gluteal muscles are hip extension and abduction. Eccentrically, the gluteal muscles control deceleration of the trunk during hip and knee flexion while the feet are in contact with the ground during a landing task. Eccentric muscle strength is crucial for effective deceleration, and the activation level required for the same body deceleration control increases with greater hip and knee flexion angles. The gluteal muscles also control lateral stability in static and dynamic semi- and full-squat positions, such as those observed in a two-footed landing task (Delp et al., 1999; Zazulak et al., 2005).

An improper movement pattern leading to a misalignment of the lower extremity during a weight bearing position can have more severe consequences in terms of injury risk than a similar movement of a non-weight bearing joint, due to the load placed on the joint by external forces (e.g. ground reaction forces) and internal forces (e.g. muscle forces). Repetitive landings experienced by jumping athletes can cause acute or chronic knee injuries such as an ACL tear or patellofemoral pain syndrome (PFPS), potentially due to the kinematic function of the knee joint that is compromised partly due to muscle weakness, muscle strength imbalances, or poor muscle firing patterns (Zazulak et al., 2005). Utilizing improper mechanics on a regular basis can create muscle strength imbalances across a joint, as more active muscles become stronger, and relatively inactive muscles become weaker. Female athletes have been found to elicit lower gluteus medius activation (Jacobs et al., 2007) and higher rectus femoris activation (DeMorat et al., 2004) in
landing tasks compared to males; muscle firing patterns which have been associated with an increase in knee injury among female athletes (DeMorat et al., 2004; Hashemi et al., 2011). Additionally, strong positive correlations have been found between increased injury and low hip external rotator strength (Leetun et al., 2004) and low hip extensor strength (Nadler et al., 2002).

As indicated above, optimal control of the knee joint has been shown to require adequate hip abduction, external rotation, and extension strength in order to stabilize the joint and absorb mechanical energy during landing tasks. Therefore, the gluteal muscles will be the primary focus of this thesis (in terms of strengthening).

2.1.2 Knee Joint

The knee joint consists of two primary articulations that occur between the femoral condyles and the tibial condyles at the distal end of the femur and proximal end of the tibia, respectively. The patella also articulates with the femoral condyles at the patellar surface on the anterior, distal end of the femur (Figure 5) (Goldblatt et al., 2003).

The knee joint is a modified hinge joint, predominantly allowing angular movements to occur in the sagittal plane (i.e. flexion, extension). Minor rotation movements in the transverse plane can also occur, but excessive rotation typically results in an injury to the joint, mainly to the ligaments holding the joint together.
The structural integrity of the knee joint is maintained by surrounding ligaments and muscles. The deepest and strongest stabilizing ligaments of the knee are the anterior and posterior cruciate ligaments (ACL, PCL), which stabilize the knee primarily in the sagittal plane. The ACL attaches superiorly to the posteromedial aspect of the lateral femoral condyle and inferiorly to the anterior aspect of the intercondylar region of the tibial plateau. This orientation allows the ACL to protect against hyperextension of the knee and excessive forward displacement of the tibia relative to the femur. The PCL attaches superiorly to the anterolateral surface of the medial femoral condyle and inferiorly to the posterior aspect of the intercondylar region of the tibial plateau, thereby allowing it to protect against excessive posterior displacement of the tibia relative to the femur (or anterior movement of the femur relative to the tibia), which can occur when the knee is in a flexed position. The medial and lateral collateral ligaments (MCL, LCL) support the knee in the frontal plane. The LCL is attached superiorly to the lateral femoral condyle and inferiorly to the head of the fibula. The MCL is attached superiorly and inferiorly to the medial condyles of the femur and tibia, respectively. The medial and lateral menisci, C-and O-shaped discs of fibrocartilage, provide shock absorption and help to improve the fit between the femoral and tibial condyles (Figure 5) (Goldplatt et al., 2003).
The patellofemoral joints occur between the anterior surfaces of the distal femoral condyles and the corresponding articular surfaces on the posterior aspect of the patella. The position of the patella is maintained via its connection to the quadriceps tendon above and the tibial tuberosity below, via the patellar ligament. The patella slides superiorly when the knee extends, and inferiorly when the knee flexes. Given its anterior location, the patella provides protection and stability to the front of the knee joint (Tecklenburg et al., 2006) and improves the mechanical advantage of the quadriceps femoris muscle (Kaufer et al., 1979).

The muscles that control flexion and extension of the leg at the knee originate superiorly to the knee and insert at or inferiorly to the knee. It is important to note
that some of the muscles of the knee are biarticular, and also enable movement at the hip as they cross the hip joint. On the anterior aspect of the thigh is the quadriceps muscle group, consisting of the rectus femoris, vastus lateralis, vastus intermedius, and vastus medialis (Figure 6A). At the knee, this muscle group functions in extension. The rectus femoris originates at the anterior inferior iliac spine and inserts at the base of the patella. Due to its origin on the ilium, rectus femoris is also a hip flexor. The vastus lateralis originates at the lateral surface of the femur, the vastus intermedius originates at the anterior surface of the femur, and the vastus medialis originates at the medial surface of the femur. All three vastus muscles insert at the base of the patella with rectus femoris (Muscolino, 2011).

On the posterior aspect of the thigh are the hamstring muscles: semitendinosus, semimembranosus, and biceps femoris (long head and short head) (Figure 6B). Originating at the ischial tuberosity (exception: biceps femoris short head originates on the lateral condylar ridge of the femur) and inserting on the head of the fibula and medial condyle of the tibia, the hamstrings cross both the knee and the hip joints and are responsible for knee flexion, knee internal and external rotation, and hip extension when the trunk is in a fixed position (Muscolino, 2011).
Figure 6: Anterior (A) and posterior (B) views of muscles that cross the knee. (modified from Muscolino, 2011).
2.2 Kinematics of the Lower Extremity

2.2.1 Knee Alignment in the Frontal Plane

The lower extremity alignment measurement in the frontal plane of primary interest in this study is the valgus angle (Figure 7C). The degree of knee movement in the frontal plane is measured as the angle between the mechanical axes of the femur and the tibia. The femoral mechanical axis (FM) is the line connecting the centre of the femoral head to the mid-condylar point between the cruciate ligaments of the knee (Yoshioka et al., 1987). The tibial mechanical axis (TM) is the line connecting the centre of the tibial plateau at the proximal end to the centre of the tibial plafond at the distal end (Yoshioka et al., 1989). The angle formed between the FM and TM lines is referred to as the Hip Knee Angle (HKA) (Cooke et al., 2003). The HKA coincides with the load-bearing axis (LBA) that runs perpendicularly from the ground to the hip (Figure 7B). Therefore, when the FM and TM are not in alignment with the LBA, excessive load is placed either medially (Figure 8A) or laterally (Figure 7C) on the knee, which can cause damage (Cooke et al., 2007). Cooke et al. (2007) have associated a positive HKA value with valgus deviations.
Figure 7: This diagram displays the femoral (FM) and tibial (TM) axes in relation to the load-bearing axis (LBA). Deviation of the FM and TM alignment is measured via the Hip Knee Angle (HKA). Lateral deviation of the knee is represented by a negative HKA value and is known as knee varus (A). No deviation of the FM or TM results in alignment with the LBA (B). Medial deviation of the knee is represented by a positive HKA value and is known as knee valgus (C) (from Cooke et al., 2007).

The valgus angle measurement used in this thesis is a reflection of the degree to which the FM and TM shift medially away from neutral alignment. Valgus deviation, characterized by medial movement of the knee joint in the frontal plane (Figure 7C), is due to one or a combination of internal rotation and adduction at the hip joint (Howard et al., 2011; Zeller et al., 2003). Olsen et al. (2004) used video analysis to determine two specific knee valgus conditions linked to an increased risk...
for injury; 1) a valgus angle of 10°-20° with flexion of the knee between 5°-20° and tibial internal rotation of 5°-15°, or 2) a valgus deviation of 5°-20° with knee flexion of 5°-25° and tibial external rotation of 5°-15°. In other words, a high valgus angle combined with tibial rotation when the knee is bent, is a primary condition for injury. For example, under high valgus conditions, the risk for ACL injury significantly increases. Hewett et al. (2005) agree with this correlation, as they define dynamic knee valgus as the adduction of the distal femur and the abduction of the distal tibia (Figure 8).

Figure 8: Dynamic knee valgus via medial movement of the distal femur and lateral movement of the distal tibia (modified from Hewett et al., 2005).
Notably, there is a direct relationship between valgus angle and knee anterior and lateral tibial translation (ATT and LTT) during drop landings (Torry et al., 2011). As previously stated, females have a higher peak valgus angle during landing tasks compared to their male counterparts (Hughes et al., 2008). It is the association of valgus angle with tibial translation that links larger valgus angles with excessive strain on the ligaments of the knee, which is thought to lead to injury. It is primarily hypothesized that the increase in medial deviation of the knee joint is due to muscle weakness of the hip abductors (Hewett et al., 2005; Howard et al., 2011), extensors (Nadler et al., 2002), and external rotators (Hewett et al., 2005; Howard et al., 2011; Nadler et al., 2002).

2.2.2 Role of Hip Musculature in Hip and Knee Kinematics

The articulations of the femur at the hip and knee joints make the thigh a key link in the lower extremity kinetic chain. The majority of the muscles that dynamically stabilize the hip in all planes insert on the femur. If the femur is inadequately controlled at the proximal end (hip) it will directly affect movement at the distal end (knee), thereby potentially compromising the stability of the knee joint. Consequently, the strength and coordinative function of the hip muscles dictates the movement of the thigh (Zajac et al., 2003). Weaknesses in hip abduction (Ford et al., 2003; Homan et al., 2013; Hughes et al., 2010; MacLean et al., 2005), external rotation (Homan et al., 2013), and extension cause the femur to adduct and internally rotate beyond normal ranges when in a load-bearing posture (with one or
both feet on the ground), creating a larger valgus angle (Homan et al., 2013; Nadler et al., 2002). The gluteus maximus is predominantly responsible for hip extension, but also assists in external rotation of the thigh. The gluteus medius and minimus are the prime movers for hip abduction. Gluteal muscle weakness is commonly reported in the female population after the onset of puberty (Quatman et al., 2006) and therefore, females tend to exhibit less control of the lower extremity during landing tasks and display high risk kinematics at the knee joint (Hewett et al., 2006; Nadler et al., 2002).

Hip muscle function significantly influences body mechanics during landing maneuvers, and dictates how the body absorbs impact-induced ground reaction forces to a significant degree (DeMorat et al., 2004; Lindstedt et al., 2001). When performing a task such as landing from a block or an attack jump in volleyball, the body absorbs ground reaction forces mainly through eccentric muscle contractions, predominantly in the sagittal plane (i.e. flexion/extension). Female athletes tend to have different lower extremity biomechanics than male athletes in landing maneuvers, including decreased abduction (Earl et al., 2011; Hewett et al., 2004), external rotation and flexion at the hip; all actions which increase the risk for knee injury (Chappell et al., 2007). In the sagittal plane, increased flexion of the trunk leads to increased hip and knee flexion compared to landing with an erect trunk position (Griffin et al., 2000; Blackburn et al., 2008). A more flexed trunk also results in higher hip extensor eccentric activation and energy absorption, leading to lower shear forces and reduced ground reaction force absorption at the knee (Decker et al., 2003, Kulas et al., 2008, Oddsson et al., 1986). The gluteus maximus is
a primary trunk and hip extensor, thereby contributing considerably to energy absorption at the hip during landing maneuvers (Decker et al., 2003).

Females tend to land in a more erect posture than males (Decker et al., 2003; Delp et al., 1999; Krosshaug et al., 2007), and also show significantly lower gluteus maximus strength and hip extensor activation (Cahalan et al., 1989; Claiborne et al., 2006; Kernozek et al., 2005; Schmitz et al., 2002; Wilson et al., 2006) during landing tasks. The combination of poor landing posture and weak extensors can result in females shifting over 20% of the mechanical energy normally absorbed at the hip through eccentric hip extensor action to the knee via eccentric activity of the quadriceps, thereby significantly increasing the ground reaction forces absorbed at the knee (De Vita et al., 1992). Therefore, weakness in the gluteus maximus can lead to increased knee loading during landing and increase the risk for injury. Among volleyball players, females showed significantly lower hip and knee flexion in block and attack landings compared to males (Salci et al., 2004). With less flexion of the hip and knees, females land more stiffly and show more of a reliance on quadriceps activation to absorb the impact of the landing as they decelerate their body. Higher quadriceps activation, combined with lower relative hamstring activation (activation levels too low to properly stabilize the joint by pulling the tibia posteriorly), generates higher tibial anterior translation as the contraction pulls the tibia forward via the quadriceps tendon, thereby increasing the load on the ACL (Cerulli et al., 2003; DeMorat et al., 2004; Durselen et al., 1995; Fleming et al., 2004; Markolf et al., 1995; Renstrom et al., 1986).
In the frontal plane, females demonstrate decreased hip abduction, in conjunction with weakness in the gluteus medius, which can result in higher valgus angles at the knee (Jacobs et al., 2007). A positive correlation has also been found between combined weakness of the gluteus medius and gluteus maximus muscles and a higher peak valgus angle during a drop-jump landing task in females (Padua et al., 2005). In the transverse plane, a low external to internal rotation strength ratio has been suggested to lead to poor kinematic control of the knee, specifically increased medial deviation (Howard et al., 2011). If opposing muscles in each plane about the hip are not activating properly, medial deviation of the knee joint can result during landing activities. Ground reaction forces experienced during landing tasks, under high valgus angles and low hip and knee flexion angles, place excessive and repetitive stress on the knee joint via anterior tibial translation. In this way, the chance for injury to the ACL increases as the aggressiveness and frequency of landing impacts increases.

2.2.3 Sex Differences in the Lower Extremity Structure

Anatomical studies of the lower extremity have shown that females typically have a wider pelvis, increased femoral anteversion (the femoral neck leans forward relative to the rest of the femur, causing the lower extremity to rotate inward – commonly seen as being “pigeon toed”), a larger Q-angle (see below), greater tibial torsion, and greater subtalar pronation compared to a typical male (Nguyen et al., 2009).
Pelvic width influences the orientation of the acetabulum on the pelvic bone. A wider pelvis will increase the distance between the acetabulum and the midline of the body, compared to a narrower pelvis. Pelvic width also significantly affects the angle at which the femur is oriented relative to the midline of the body in the frontal plane. The angle between a line drawn from the anterior superior iliac spine (ASIS) to the central patella and the extension of a second line drawn from the tibial tuberosity through the central patella, is known as the quadriceps angle (Q-angle) (Figure 9).

Figure 9: A schematic depiction of the Q-angle (from Calbach et al., 2003).

The Q-angle is positively correlated to the ratio of the pelvis width to femoral length (Pantano et al., 2005). At full maturation, female pelvises are wider due to
the evolutionary demand for parturition. Females are also shorter than males on average, resulting in shorter femoral length compared to males. This increases the pelvis width to femoral length ratio, resulting in a Q-angle that is 4.4˚ larger (on average) than their male counterparts (Tillman et al., 2005).

The difference in pelvic bone width and shape translates into differences in the lines of action of the muscles that surround the pelvis and therefore the resulting movement about the hip joint. The biomechanical sex differences in dynamic hip movements during gait and landing activities have been extensively studied (Cammarata et al., 2010; Decker et al., 2003; Howard et al., 2011; Hughes et al., 2008; Hughes et al., 2010; Jacobs et al., 2007; Kernozek et al., 2005; Nadler et al., 2002; Russell et al., 2006; Schmitz et al., 2006; Zazulak et al., 2005), and sex-related muscle activation levels have been consistently shown (Schmitz et al., 2002; Withrow et al., 2006b; Zazulak et al., 2005). Zazulak et al. (2005) found that during a single-leg landing task, female athletes had increased biceps femoris and decreased gluteus maximus activity compared to males. This demonstrated a decreased dependency for females to utilize the gluteus muscles, thereby decreasing the ground reaction forces (GRFs) absorbed at the hip through eccentric gluteus maximus activation. Jacobs et al. (2007) demonstrated a positive link between increased valgus angle in single-leg landing tasks and abductor weakness. This strongly suggests that the hip abductors also influence knee movement and stability in the frontal plane.
Landing mechanics observed in female athletes increase the risk for injury as the ground reaction forces absorbed at the knee joint is generally higher than their male counterparts. The ligaments of the knee which provide passive stability to joint structures are further disadvantaged in females, as their ACLs are smaller in length, cross-sectional area, and volume than male ACLs on average (Chandrasheker et al., 2005). In addition, the female ACL is less stiff and fails at a lower normalized force level (Chandrasheker et al., 2006).

2.2.4 Non-Contact ACL Injury Mechanisms

The ACL provides passive stability to the knee joint by resisting anterior tibial movement relative to the femur, absorbing 90% of anterior tibial shear forces (Butler et al., 1980). An injury to the ACL is typically the result of an acute event in which the amount of anterior tibial force exceeds the strength of the ligament. The majority of ACL injuries occur during a landing task or attempting to change direction while decelerating (Boden et al., 2000). The precise mechanism causing an ACL injury is not known. The ACL primarily resists anterior tibial translation, as well as limits tibial internal rotation, thus these movements produce the highest stress on the ligament (Butler et al., 1980; Ellison et al., 1985). There is a large body of evidence showing strong correlations between ACL injury risk and lower extremity biomechanics that increase anterior tibial translation and internal rotation. Specifically, higher knee valgus angles, tibial internal rotation, decreased hip and knee flexion angles, and various combinations of these kinematics during a
drop-jump landing task have been linked to increased anterior tibial shear force and ACL injury (Berns et al., 1992; Ford et al., 2003; Hewett et al., 2005; Howard et al., 2011; Hughes et al., 2008; Hughes et al., 2010; Kirkendall et al., 2000; Markolf et al., 1995; Withrow et al., 2006a; Withrow et al., 2006b).

It is strongly suggested that a higher peak valgus angle upon landing is predictive of an ACL injury in female athletes (Ford et al., 2003; Hewett et al., 2005; Howard et al., 2011; Hughes et al., 2008; Hughes et al., 2010), as higher valgus angles are associated with increased anterior tibial shear force (Withrow et al., 2006a). A study by Hewett et al. (2005) linked higher valgus angles upon landing with ACL rupture in female athletes, finding that ACL-injured athletes (measured before injury occurred) had a valgus angle that averaged 8.4° greater at initial ground contact and 7.6° greater at maximum displacement during a drop-jump task compared to non-injured athletes. The injured athletes also showed a 2.5 times greater knee abduction moment and 20% higher ground reaction force. The valgus measures taken were shown to have a predictive $r^2$ value of 0.88 for ACL injury status among the participants and predicted injury status with 73% specificity and 78% sensitivity (Hewett et al., 2005).

In the sagittal plane, female athletes tend to display reduced hip and knee flexion, high eccentric quadriceps activity and low relative hamstring activation during deceleration from a landing task (Withrow et al., 2006b). The relatively high activity of the quadriceps combined with decreased hamstring activation during landing can cause anterior shear forces on the tibia via the pulling action of the
quadriceps on the tibia via the patellar tendon (Kirkendall et al., 2000) and the failure of the hamstring muscle group to provide an adequate counterbalancing posterior shear force on the tibia (Laible et al., 2014; Li et al., 1999; Withrow et al., 2006b). The load experienced at the ACL is partially due to this anterior force, and is positively correlated to lower knee flexion angles, as landing with less knee flexion is an indicator of higher quadriceps activity (Figure 10) (DeMorat et al., 2004). In addition to the relatively low hamstring activation level during a drop-jump landing task, decreased knee flexion further lowers the hamstrings ability to produce posterior tibial shear force (Li et al., 1999).
Figure 10: Rectus femoris forces in the sagittal plane, which result from activating the muscle, are illustrated. Anterior tibial shear force ($F_{Q,x}$) increases with higher quadriceps activity and is positively associated with ACL injury. Due to the positive correlation between higher quadriceps activation and decreased knee flexion during a landing task, there is an inverse relationship between force generated from the patellar tendon through quadriceps activation ($F_Q$) and knee flexion angle ($\theta$) (from DeMorat et al., 2004).

Despite the evidence for low knee flexion, high knee valgus, tibial internal rotation, high vertical ground reaction forces, and various combinations of these factors being mechanisms of ACL injury, the precise cause is still unknown. Hashemi et al. (2011) proposed a new mechanism of ACL injury that involves the convergence of the following factors: 1) delayed or slow co-activation of quadriceps and hamstring muscles, 2) very low knee flexion when a GRF is applied in a dynamic
movement, 3) a shallow medial tibial plateau and a steep posterior tibial slope, and 4) mismatched hip and knee flexion velocities resulting in a stiff landing. It is suggested that increased knee flexion would balance the body in the sagittal plane and decrease the strain at the knee joint. However, instead of higher knee flexion, higher quadriceps activity is seen, thereby increasing the anterior tibial shear force. This mechanism is referred to as the relative hip extension-knee flexion paradox (Hashemi et al., 2011). Under this biomechanical mechanism, the highlighted risk factors significantly increase the chance for injury.

2.2.5 Joint Energy Absorption Upon Ground Impact

The risk of injury associated with ground reaction forces generated during a landing task is lowest when the absorbed energy is distributed throughout the body’s tissues. In a landing task, the majority of the impact energy is absorbed by the ankle, knee and hip joints. The energy absorbed at a joint is characterized by the eccentric activity of the extensor muscles surrounding that joint (McNitt-Gray et al., 1993). Imbalances in energy absorption at certain joints may result in the absorption capacity at that joint being exceeded, which may result in injury (Lindstedt et al., 2001). Eccentric contraction of the gluteus maximus at the hip and the quadriceps at the knee increases the relative amount of energy absorbed at the hip and knee joint during a landing task (Schmitz et al., 2010), respectively. Energy absorption capacity is lowered when muscular strength (specifically lower eccentric activation) around the joint is inadequate, as this puts higher demand on the passive
tissues (ligaments) to maintain the integrity of the joint, which have a much lower absorption capacity than the muscles.

In a drop-jump landing task, the level of energy absorption at the knee is 69% higher in females versus males and is predicted by a greater knee extensor to knee flexor strength ratio (quadriceps to hamstrings), as well as lower hip and knee flexion angles characteristic of females (Schmitz et al., 2010); in other words, females display a more erect posture during landing in drop-jump tasks due to weaknesses in the gluteal muscles and excessive activation of the quadriceps relative to the hamstrings (Decker et al., 2003; Houck et al., 2006; Pollard et al., 2007; Schmitz et al., 2007). It is important to note that muscle activation does not necessarily equate to muscular strength; it has been observed that higher muscle activation levels around the hip joint (gluteus maximus and gluteus medius) during a landing task are actually linked to lower strength of those muscle actions (hip abduction and external rotation) (Homan et al., 2013). Therefore, excessive activation of the quadriceps relative to the hamstrings as stated above does not necessarily equate to higher muscular strength of the quadriceps. The ground reaction force absorbed at the knee is an important component of non-contact ACL injuries related to jump landings (Sell et al., 2007). Consequently, there is a strong association between females with low hip flexion who demonstrate high load absorption at the knee, as well as higher valgus angles at the knee (frontal plane) (Hewett et al., 2005).
The frontal and sagittal plane alignment of the knee joint influences the magnitude and location of the ground reaction forces acting relative to the joint. Large ground reaction forces, valgus (medial) deviation, and decreased knee and hip flexion are all ACL injury risk factors (Fong et al., 2011) as they increase the load on the ACL through mechanisms previously discussed. Pertaining to the proposed study, higher valgus angles are associated with higher ground reaction forces attenuated at the knee joint (Fong et al., 2011; Hewett et al., 2005), specifically those that are laterally directed (Sigward & Powers, 2007).

2.2.6 Shock Absorption and Tibial Acceleration

The tissues of the body also absorb the shock energy from a landing impact. Tibial acceleration is a measurement used to assess the impact experienced at the knee joint through externally applied accelerometers, typically attached on the bony area medial to the tibial tuberosity. Tibial acceleration is an indicator of shock attenuation – the body absorbing impact energy from foot-ground contact (Mercer et al., 2003) – at the knee. The position of a joint upon impact partly influences the force attenuated at that joint (Hamill et al., 1995). Additional influences of the level of shock attenuated at a given joint include dynamic body kinematics and the activation level of the surrounding muscles (Cholewicki & McGill, 1995). Measures of tibial acceleration have been shown to be associated with muscle activation level, as higher muscle activation may increase the stiffness of the segment and decrease the amount of shock attenuated by the muscle tissue (Holmes & Andrews, 2006). Increased segment stiffness may be reflected in an increase in tibial acceleration
(wave attenuation) at the proximal tibia. However, the link between tibial acceleration and body kinematics is unknown.

It has been found that the ground reaction forces attenuated at the knee are positively correlated to anterior tibial acceleration (Elvin, 2007). Therefore, higher ground reaction forces and anterior tibial acceleration are directly proportional to impact-induced ACL strain (McLean et al., 2011). A landing technique with a more neutrally aligned knee in the frontal plane (Chaudhari et al., 2006), and higher hip and knee flexion angles (DeMorat et al., 2004) may decrease the ground reaction forces attenuated at the knee joint (Hewett et al., 2005), and potentially decrease the tibial acceleration.

2.3 Injury Prevention Strategies

2.3.1 Neuromuscular Training

Athletes who are at risk for an ACL injury may lack the neuromuscular control to perform proper movements to minimize their risk for injury (Chappell et al., 2008; Hewett et al., 2006; Hewett et al., 2004; Myer et al., 2005b; Olson et al., 2011). Neuromuscular control is the subconscious “activation of the dynamic restraints surrounding a joint in response to sensory stimuli” (Laible et al., 2014). The literature generally defines neuromuscular training as a multi-intervention program that incorporates a combination of agility, plyometric (muscle lengthening immediately followed by muscle shortening; stretch-shortening cycle (Chmielewski et al., 2006)), strength, balance, and sport-specific exercises. These various
programs attempt to teach/re-teach proper movement patterns that become automatic (subconscious activation). The exercise components tend to be more gross body movements, fast-paced impact maneuvers, or dynamic positions that challenge the body's balance/control. It is important to note that each neuromuscular training study varies by a great deal in the exercise components, frequency, duration, and intensity of the training. Therefore, it remains unclear precisely which exercise or combination of exercises are effective, or even necessary, to produce kinematic changes linked to reducing the risk for injury.

The implementation of a neuromuscular training program has been shown to decrease the risk of ACL injuries by improving knee kinematics in the frontal and sagittal planes (decreased valgus angles and increased knee flexion) upon landing (Hewett et al., 2006; Myer et al., 2006). Myer et al. (2006) compared the kinematic changes in the lower extremity in the frontal and sagittal planes following plyometric and dynamic stabilization exercise protocols. In the sagittal plane, plyometric and balance training improved two-footed and single-leg landing kinematics, respectively. Both exercise programs were found to decrease the valgus angle by an average of 28% (Myer et al., 2006). No other study has found an improvement in valgus angle after a neuromuscular training program.

Despite these findings showing improvements after neuromuscular training, rates of injury have not decreased over the years (Agel et al., 2007). There is a disconnection between successful research studies and the lack of improvement to injury rates, which could arguably be related to several factors. Firstly, the design
(length, frequency, and intensity) of the program(s) used is inconsistent, thereby making it difficult to accurately compare the success of the program(s). Secondly, the supervision of a qualified trainer and time commitment required is extensive due to the multi-component nature of a neuromuscular program, resulting in low compliance. Lastly, the frequency and intensity of joint impacts during this additional training could increase susceptibility for overuse injuries.

2.3.2 Dynamic Resistance Training

Dynamic resistance training is widely thought to be a vital part of any performance or injury prevention program through its effectiveness in increasing the strength and hypertrophy of the training muscle(s) (Atha et al., 1981; Komi et al., 1991). Typically, a dynamic resistance exercise is one fluid movement that targets one or more joints at a time while controlling the weight and speed of the movement (i.e. a squat). This differs from neuromuscular training (as it is used in the literature) in two ways. First, the movement of a dynamic resistance exercise is one fluid motion where the resistance and pace are controlled, typically moving in one plane at a time (i.e. deadlift, squat, bicep curl) in a stabilized position, whereas a neuromuscular exercise can be a multi-planar, multi-component movement where the speed and resistance are not completely controlled, and balance is also challenged (i.e. agility steps, a jump-cutting task). Second, the primary goal/function of a dynamic resistance exercise is to increase the strength of the
target muscles, whereas the goal of neuromuscular retraining is to improve or alter movement kinematics.

Several recent studies have attempted to use dynamic resistance training programs to increase muscular strength to determine if this increase translates into kinematic changes (Cochrane et al., 2010; McCurdy et al., 2012). The two most common methods of dynamic muscle strengthening utilize external resistance (e.g. free weights, weight machines, resistance bands, body weight), or accommodating resistance (e.g. isokinetic machines that alter resistance at various degrees of movement based on muscle strength) (Wernbom et al., 2007). Neither method has consistently emerged as superior in terms of correcting high risk kinematic movements at the knee and few studies have attempted to directly evaluate the various methods of strengthening at comparable intensity, volume and frequency levels (Wernbom et al., 2007). A protocol using resistance bands targeting the quadriceps, hamstrings, gluteus maximus and gluteus medius resulted in significant increases in strength (P<0.001), but no biomechanical changes of the lower extremity (Herman et al., 2008). An 8-week dynamic resistance training program targeting the muscle groups surrounding the hip and knee (squat, Romanian deadlift, lunge, step-up, unilateral squat) found an increase in the knee flexion angle of a bilateral drop-jump (60 cm), but no change in knee valgus angle (McCurdy et al., 2012). A recent study by Cochrane et al. (2010) found detrimental effects of dynamic resistance training (using both machine and free weights – two groups) on knee kinematics; an increase in knee joint loading, and lower knee flexion angles during running and cutting maneuvers, which both increase ACL strain.
Performing a dynamic resistance movement requires proper technique to target the appropriate muscle/muscle group as well as to avoid injury. The effect of fatigue on joint biomechanics during any type of training is important to consider as technique has been shown to breakdown, thereby increasing the risk for injury (Hooper et al., 2013).

2.3.3 Isometric Resistance Training

Isometric resistance (also referred to as static resistance) training involves the contraction of a muscle or muscle group with no length change during the contraction (as opposed to lengthening and shortening of the muscle as seen in dynamic exercises) (Wernbom et al., 2007). This differs from other training methods by allowing individual target muscles to be isolated and strengthened in a specified direction without activating surrounding muscles/muscle groups that may already be compensating for the weaker target muscle(s) through modifying the exact joint direction of a dynamic movement. These compensations are typically seen in dynamic movements, as slight variation in technique (i.e. stance), weight, stability (free weight versus a machine) (Anderson et al., 2005; Clark et al., 2012), and fatigue (Hooper et al., 2013) result in different (and unintended) muscles being activated at undesired levels (having a more agonistic role versus a stabilizing or inactive role) in order to carry out the exercise. These compensatory activation patterns used to maintain dynamic joint stability have been associated with increased joint laxity and an increased time to sense joint motion (specifically knee extension) in female athletes, thereby increasing the risk for injury (Rozzi et al., 1999). There is very limited research on the effects of isometric strengthening in
altering lower extremity biomechanics, thereby leaving a large hole in the literature related to using isometrics as a potential training tool. The major benefits to investigating the effectiveness of isometric resistance training are: 1) non-impact exercise, which may significantly reduce acute or overuse injuries due to high and/or repetitive impacts from other forms of training, 2) no external weight placed on the joints, 3) high controlled body position and target muscle contraction, and 4) little to no equipment necessary. These factors allow isometric exercises to be performed easily and safely with little to no injury risk. Since isometric resistance training does not involve impact and no external weights are needed, the chance for injury while exercising is minimized as there is no additional stress added to the active joints during an exercise (Burges et al., 2007). With no movement, the focus of isometric resistance training is geared towards positional precision, as the joint position needed to isolate the muscle is specific (Crow et al., 2011). Positional accuracy (more commonly referred to as ‘form’ or ‘technique’) is important in dynamic exercises as well, but is significantly more difficult to control, requiring proper supervision and practice to perform properly versus a controlled isometric exercise. In addition, if the exerciser does not possess the necessary strength levels to perform the movement, proper form may not even be possible. Joint position could be consistently controlled in an isometric exercise with appropriate equipment that would allow the exerciser to reproduce the position accurately (i.e. hip abduction at 30° controlled by lying a fixed distance from a wall/object).

It has been hypothesized that greater changes are seen in central movement control adaptations during isolated muscle training compared to training methods
involving multiple muscle contractions across multiple joints at once (Boudreau et al., 2010). These greater changes in movement control are thought to translate to larger improvements in activation levels of the targeted muscle(s) (Tsao et al., 2008; Tsao et al., 2010).

Clear benefits of isometric exercises as opposed to dynamic (Folland et al., 2005) or plyometric (Burgess et al., 2007) have been shown when looking at muscle strength and activation timing. Significantly greater gains in strength have been shown with isometric resistance training versus dynamic resistance training at comparable intensities for a 9-week (three sessions per week) program. Targeting the quadriceps through knee extension, the isometric training group performed four sets of ten repetitions, each held for two seconds at 75% maximum force production, while the dynamic group performed four sets of ten repetitions at 75% maximum effort (Cybex VR2) (Folland et al., 2005). A 5-week, 5 days/week isometric strengthening program also targeting the quadriceps with three positions (isometric contraction while leg is neutral, 10cm hip flexion, and hip adduction) resulted in a strength increase of approximately 34% (Anwer et al., 2014). It has been observed that isometric resistance training demonstrates the highest strength gains at the trained angles (Weir et al, 1995). It has also been found that when observing the isometric and isokinetic strength gains of the quadriceps using isometric versus dynamic training at four angles of knee flexion (0.87, 1.22, 1.57 & 1.92 rad), isometric training increased the isometric strength of the quadriceps muscle across several angles, not just the trained angles (Folland et al., 2005). This study showed a comparable improvement in isokinetic strength for both isometric
and dynamic training (Folland et al., 2005). However, the effect that isolated muscle training has on dynamic conditions, such as landing knee kinematics, where dysfunctional muscle activation exists, is unknown (Crow et al., 2011), and is the primary research question of this project. What still remains to be determined are the potential transference effects of isometric training to dynamic movement. There is evidence to support this potential, as Burgees et al. (2007) directly compared isometric and plyometric training with a 6-week program (2-3 sessions per week, 3-4 sets of 15-20 repetitions at maximal effort) targeting the plantar flexors (isometric plantar flexion vs. one-legged drop-jump), seeing a dynamic performance (jump height) improvement of 64.3% increase with isometrics versus a 58.6% increase with plyometrics. With fairly equal performance increases, without the high impact loads of the joint seen with plyometric training, isometrics could be an ideal training option to minimize the load as well as the number of impacts experienced by athletes.

Ideally, a high level athlete does additional training to improve their strength and performance in a shorter rather than longer timeframe. Significant strength improvements have been demonstrated in as little as three weeks via a combined isometric and dynamic resistance strengthening program (Yilmaz et al., 2010), and other studies have found significant strength improvements in 4-week (Hicks et al., 1993; Yue & Cole, 1992) and 5-week (Anwer et al., 2014) isometric resistance training programs. The majority of research strength training protocols are six to eight weeks in length. Therefore, based on the time it will likely take to see if the isometric training produces significant strength gains, a 6-week isometric
strengthening protocol will be used for this study. The significance of the timeframe is important as this study aims to minimize the exercise program length while still achieving significant strength improvements, thereby reducing the chance for participant dropout due to a lengthy program that may interfere with the athletes' sport and academic commitments. The greater improvements seen in previous studies in muscle strength, activation, and performance (jump height) with equal or less exercise time would be more beneficial to all populations, and could minimize injury and improve compliance to maximize its potential to alter the kinematic control of a maneuver (i.e. drop-jump landing task).

Poor kinematic control of the knee is often characterized by high peak valgus angles during sport maneuvers such as a drop-jump landing, and is linked to hip abductor, extensor, and external rotator weakness (Ford et al., 2003; Hewett et al., 2005; Hughes et al., 2008; Hughes et al., 2010). To date, no study has exclusively used a tri-planar (hip abduction, extension, and external rotation) isolated isometric resistance program to alter the frontal plane kinematics of the knee, specifically the valgus angle, during landing tasks. An efficient and effective training protocol targeting these kinematic risk factors appears warranted for injury prevention programs. It may be that with equal gains in dynamic strength, superior gains in isometric strength, and potential for larger improvements in sport-maneuvers (jump height – Burgees et al., 2007), an isometric program would better strengthen and stabilize the hip joint, which may result in improved kinematics at the knee, and reduce the associated risks for ACL injury. In addition, isolated isometric exercise allows participants to control the contraction of specific target muscles that might
otherwise be less activated in a dynamic exercise (Boudreau et al., 2010) due to other muscles being recruited to compensate for the weak target muscle (Comerford et al., 2001). This is illustrated in studies where participants perform compound dynamic movements such as single-leg step-downs, and their muscle activation levels (as measured using electromyography-EMG) show muscle activations that are associated with injury due to improper kinematic movement (Holland & Lynch-Ellerington, 2009). Holland & Lynch-Ellerington (2009) state that the gluteus maximus and medius muscles of healthy women with higher valgus angles showed decreased activation while performing a single-leg step down task. This suggests that when performing a landing task, the appropriate hip muscles may not be recruited to adequately absorb the impact, resulting in excessive hip adduction and internal rotation, reduced hip and knee flexion, and higher impact forces absorbed at the knee. These findings demonstrate the need for an isolated tri-planar strengthening program to be investigated in an attempt to change kinematic patterns at the knee, as strengthening programs isolating muscles in only one or two planes did not result in any significant changes. Utilizing the superior strength gains seen with isometric training, this study will be the first to isolate the hip abductors, extensors, and external rotators in an isometric strengthening program in an attempt to alter lower extremity kinematics during a drop-jump landing task with a primary focus of decreasing the peak knee valgus angle that is associated with ACL injury.
3. METHODOLOGY

3.1 Participants

3.1.1 Recruitment

Fourteen female volleyball players (20-26 years of age) were recruited from the University of Toronto Women’s varsity volleyball team as well as college and club level volleyball teams in the Greater Toronto Area (GTA). All athletes had at least 2 years of experience participating at the college/university or club level. Each participant played in a front row position and demonstrated a peak valgus (knee adduction) angle of 9° or greater during drop landings, as determined through a pre-screening protocol detailed below. The angle of 9° is based on findings showing that this angle was associated with injurious knee populations (healthy population angle was 4° on average) (Hewett et al., 2005).

A mass email (Appendix A) was sent to all coaches of women’s varsity volleyball teams in the GTA (club, college, and university level). The email included a brief description of the purpose of this study and the protocol. As well, it highlighted the potential value of the results for future training and injury prevention. In addition, individual players were contacted through word of mouth and personal relationships for additional recruitment. The value of the research pertaining to them as female athletes was highlighted in a basic script (Appendix B).

A total of twelve teams received an information session, and 109 athletes were put through the pre-screen protocol. Forty-one athletes demonstrated a knee valgus angle of 9° of greater. Only 7 athletes were able to commit to a 6-week
training program, therefore 7 additional athletes were subsequently assigned to the control group.

3.1.2 Exclusion Criteria

Participants were excluded from the study if they had: 1) a history of lower extremity surgery, 2) any lower extremity injury within the last 3 months that limited athletic participation (resulted in treatment and three or more consecutive missed days of training), and 3) had a valgus angle of less than 9° in the pre-screen test. This was determined through a short series of verbal questions asked prior to participation.

3.1.3 Consent

Participants in the control and training groups were informed of the procedures of the study both verbally and in written form (letter of information Appendices E and F) and were asked to sign a consent form (consent form Appendices C and D) approved by the Research Ethics Boards (REBs) of the University of Windsor and the University of Toronto, prior to participation in any session of the study (see Study Design section below).
3.2 Study Design and Setting

This thesis is part of a larger project, and as such, only some of the data collected has been reported.

3.2.1 Pre-Screen Test

All potential participants underwent a pre-screening process to determine their peak valgus angle. As described previously, to be included in this study, participants had to have a peak valgus angle of 9° or greater during the pre-screening session. Participants were required to wear spandex shorts, a t-shirt, and the shoes that they typically wear during volleyball participation. Red (to maximize visibility) markers made of paper were attached using double-sided tape on the right and left anterior superior iliac spines (marker LH for the left side and RH for the right side), the tibial tuberosity (marker LK for the left side and RK for the right side), and the middle of the ankle joint (marker LA for the left side and RA for the right side). 2D video analysis (frontal plane view) was used to determine the valgus angle during the drop-jump landing task. The frame that corresponded with the highest valgus angle observed during the landing task (peak medial deviation) was used to assess the valgus angle. The valgus angle of the left and right lower limbs was determined by first marking overlapping LH to LK (and RH to RK) and LK to LA (and RK to RA) lines using a straight edge (to mimic Figure 8). The angle made between the LK-LA/RK-RA lines and the inferiorly extended LH-LK/RH-RK lines was measured using a protractor to represent the valgus angle. The above approach
for measuring the valgus angle was only used for the pre-screening session in order to determine if the potential participants met the inclusion criterion (valgus angle equal to or greater than 9°).

Each potential participant performed a minimum of three practice trials to familiarize herself with the task. Following the practice trials, three test trials were recorded with a minimum of 30 seconds rest in between each trial. Participants were eligible to be included in the study if two of the three trials resulted in knee valgus angles greater than 9°.

3.2.2 Drop-Jump Landing Task

The drop-jump landing task began with participants atop a box 30 cm high, standing upright with their feet shoulder-width apart. Participants were instructed to drop down (the stepping foot was not specified) with each foot landing on one of the two force platforms placed directly in front of the box. Immediately following the landing, participants executed a full vertical jump with their shoulders fully extended for maximum reach as if they were performing a maximal block jump (Figure 1). Participants were instructed prior to dropping down to “drop down on the force platforms, then immediately jump up as if you are performing a maximal block jump. Focus on pressing your hands over a net and land back on the force platforms”. The focus for the participant was directed to upper body block jump technique in order to simulate a practice/game situation, as well as to redirect their
focus away from their lower body mechanics. The primary focus of this study was the initial landing from the box onto the force platforms.

Figure 11: Visual representation of a drop-jump landing task (modified from Hewett et al., 2005).
3.2.3 Target Muscles for Strengthening Protocol

The superficial muscles that produce the majority of the force generated at the hip joint during hip extension, hip abduction, and hip external rotation are the gluteus maximus (extension, external rotation), gluteus medius (abduction), and biceps femoris (extension). These muscles were targeted because of the primary movement control they contribute about the hip joint associated with poor knee kinematics and high valgus angles. The rectus femoris muscle was included in the data collection, but was not trained, as the strength of this muscle has not been positively correlated with lower knee valgus angle. The reasons for including rectus femoris was a) to serve as a control muscle for each training group participant, and b) to have comparative data between the quadriceps and the hamstrings for force production, as this information (H:Q ratio) is frequently discussed in the literature as a factor that predicts ACL injury risk (Bulluck, 2010; Noonan & Wojtys, 2012).

3.2.4 Design, Setting, and Variables

The study consisted of a pre-screening session followed by a 6-week training study between pre- and post-test data collection sessions. Each participant in the training group began their training within 3 days after their pre-test data collection, thereby creating a waterfall effect in terms of the training and testing schedules for the participant pool. The total time from the start of the first pre-screen to the end of the last post-test data collection was approximately 8 weeks, with each participant following their own 6-week protocol timeframe (Table 1).
Table 1: A description and timeframe for each session of the study for each participant.

<table>
<thead>
<tr>
<th>Session</th>
<th>Description</th>
<th>Timeframe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Screening Session</td>
<td>2D video analysis of the valgus angle during a drop-jump landing task. The valgus angle was measured in the frontal plane from the video frame containing the peak valgus angle. See procedures for detailed description.</td>
<td>Week 1: Day 1</td>
</tr>
<tr>
<td>Pre-Test Data Collection</td>
<td>15 trials of the drop-jump landing task while analyzing 3D motion capture, ground reaction force, and tibial acceleration. See procedures for detailed description.</td>
<td>Week 2: Day 1</td>
</tr>
<tr>
<td>Training Sessions</td>
<td>All exercises were performed 2-3 days per week supervised and 2-3 days per week unsupervised (5 total sessions per week) for 6 consecutive weeks by the isometric strength training (TG) group. See procedures for detailed description.</td>
<td>Weeks 2-6</td>
</tr>
<tr>
<td>Post-Test Data Collection</td>
<td>Identical to the Pre-Test Data Collection. See procedures for detailed description.</td>
<td>Week 7: Day 1</td>
</tr>
</tbody>
</table>

Based on previous hip muscle strengthening programs, a 6-week protocol is the shortest timeframe that demonstrated significant strength gains in the target muscles (Davies et al., 1988; Snyder et al., 2009) as well as changes in lower extremity biomechanics due to strength increases (Snyder et al., 2009). The shortest possible timeframe is preferred in order to minimize dropout rates as well as maximize compliance of other populations by introducing the shortest possible program to produce significant results. All participants completed the full study. A pre-screening session was used to determine if each potential participant fulfilled the minimum valgus angle requirement of 9° for inclusion in the study. Those females who met the valgus angle inclusion criterion were randomly assigned to one of two groups: the isometric strength training group (TG) or the control group (CG).
(see more below). The pre-screening session and the pre- and post-test data
collection sessions for each participant were conducted in the Biomechanics
Laboratory at the University of Toronto. Two to three of the five weekly training
sessions were supervised and were held either at a private gym or at Striation6
Exercise and Performance Centre in Toronto.

The two independent variables for this study were: 1) group: isometric
strength training (TG) group, who underwent the isometric strength training
program, and a control group (CG), who did not partake in any isometric strength
training program; and 2) time: participants were tested before and after the 6-week
training program (TG). Both TG and CG groups continued volleyball participation
and exercise regimes as usual during the 6-week training period. The reason for
continuing usual exercise activity levels was a) to eliminate any changes in muscle
strength due to reduced, sport-specific activity, and b) athletes playing at a high
level of sport are typically already participating in a team exercise program. All
observed changes in strength could therefore be attributed to the isometric strength
training protocol.

The primary dependent variable for this study was the peak knee valgus
angle that occurred between the times of first foot contact with the force platforms
and when the feet first left the force platforms, during the drop jump landing task.
Medial/lateral movement of the knee was assessed in four ways to identify any
kinematic change in the frontal plane to compare these findings with the literature
based on their methodology of knee frontal plane (valgus) kinematic assessment.
The four assessments were the knee to toe width ratio, valgus angle (angle of the tibia relative to the global vertical line - a positive value for the left shank and a negative value for the right shank indicate knee adduction/tibial abduction; medial movement of the superior end of the tibia), and knee deviation (the distance between the knee joint centre and a body-fixed plane that passed through the hip, ankle, and toe).

Additional dependent variables include the following: 1) force output of each target muscle, 2) peak tibial acceleration, 3) tibial acceleration slope, 4) time to peak tibial acceleration, 5) the vertical ground reaction force at the peak valgus angle of the initial landing, and 6) the vertical ground reaction forces at peak knee flexion for the initial landing.

3.3 Instrumentation

3.3.1 Motion Capture

A Qualisys motion capture system (Gothenburg, Sweden) with eight Oqus 100 (0.3 MP, 250 fps) cameras (Gothenburg, Sweden) was used to collect 3D movement data during the pre- and post-training data collection sessions. The motion capture system (including analog acquisition) was controlled with Qualisys Track Manager (QTM) software. CalTester (Germantown, MD) was used to spatially locate force platforms, and Visual3D (Germantown, MD) was used to calculate joint angles and compute summary/descriptive statistics, etc. A total of 45 14.0 mm spherical reflective markers (B&L Engineering) were placed bilaterally on each
participant during the pre- and post-test evaluations as outlined in Table 2. Once
the static calibration trial was collected, the medial knee markers were removed
from both sides to prevent interference during the drop-jump trials, leaving 43
markers for the remaining trials.

Table 2: Bilateral optical marker placements and placement instructions for motion
capture movement tracking for the upper body (A) and lower body (B). Marker
locations that are italicized indicates bilateral placement.

A: Upper Body

<table>
<thead>
<tr>
<th>Joint/Segment</th>
<th>Marker Locations</th>
<th>Placement instructions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Thorax Region</td>
<td>Top of Head</td>
<td>Attached to a plastic headband and placed at the apex of the head.</td>
</tr>
<tr>
<td></td>
<td>Cervical Spine 7 (C7)</td>
<td>Placed on C7 (the most prominent bone at the base of the neck when the neck is flexed).</td>
</tr>
<tr>
<td></td>
<td>Suprasternal Notch</td>
<td>Placed at the most superior aspect of the sternum, between the clavicles.</td>
</tr>
<tr>
<td></td>
<td>Xiphoid Process</td>
<td>Placed on the most inferior bony process of the sternum.</td>
</tr>
<tr>
<td>Shoulder</td>
<td>Acromion Process (2)</td>
<td>Placed on the superior aspect of the acromion processes.</td>
</tr>
<tr>
<td>Mid Thorax</td>
<td>4 Skin Markers on the Posterior Mid Thorax</td>
<td>Placed individually in a square-like pattern on the back, just above the inferior edge of the ribcage.</td>
</tr>
</tbody>
</table>
## B: Lower Body

<table>
<thead>
<tr>
<th>Joint/Segment</th>
<th>Marker Locations</th>
<th>Placement instructions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pelvis</td>
<td><strong>Iliac Crest (2)</strong></td>
<td>Placed on the superior aspect of the iliac crest, while remaining vertically parallel to the greater trochanter marker.</td>
</tr>
<tr>
<td></td>
<td><strong>3 Skin Markers: Lateral Pelvis (2)</strong></td>
<td>Placed in an angled line formation outside the line between the crest and greater trochanter markers. The three markers were arranged non-collinearly.</td>
</tr>
<tr>
<td>Femur</td>
<td><strong>Greater Trochanter (2)</strong></td>
<td>Placed on the greater trochanter (can be found by instructing participant to rotate their hip while keeping their foot on the ground – “squish a bug”).</td>
</tr>
<tr>
<td></td>
<td><strong>Lateral Thigh (2)</strong></td>
<td>Placed approximately 1/3 the distance and slightly anterior to the line between the greater trochanter marker and the lateral knee marker.</td>
</tr>
<tr>
<td></td>
<td><strong>Frontal Thigh (2)</strong></td>
<td>Placed on the anterior surface of the midpoint of the thigh.</td>
</tr>
<tr>
<td>Knee</td>
<td><strong>Medial (2)</strong></td>
<td>Placed on the medial epicondyle of the knee.</td>
</tr>
<tr>
<td></td>
<td><strong>Lateral (2)</strong></td>
<td>Placed on the lateral epicondyle of the knee.</td>
</tr>
<tr>
<td>Tibia</td>
<td><strong>Tibial Tuberosity (2)</strong></td>
<td>Placed on the prominent bony landmark of the frontal proximal tibia located just inferior to the patella.</td>
</tr>
<tr>
<td></td>
<td><strong>Lateral (2)</strong></td>
<td>Placed on the lateral tibia approximately 7-10 cm below the lateral epicondyle of the knee.</td>
</tr>
<tr>
<td></td>
<td><strong>Frontal (2)</strong></td>
<td>Placed at the midpoint of the anterior tibia.</td>
</tr>
<tr>
<td>Ankle</td>
<td><strong>Medial (2)</strong></td>
<td>Placed on the medial malleolus.</td>
</tr>
<tr>
<td></td>
<td><strong>Lateral (2)</strong></td>
<td>Placed on the lateral malleolus.</td>
</tr>
<tr>
<td>Foot</td>
<td><strong>1st Metatarsal (2)</strong></td>
<td>Placed on the medial surface of the shoe at the 1st metatarsal joint.</td>
</tr>
<tr>
<td></td>
<td><strong>5th Metatarsal (2)</strong></td>
<td>Placed on the lateral surface of the shoe at the 5th metatarsal joint.</td>
</tr>
<tr>
<td></td>
<td><strong>Cuneiform (2)</strong></td>
<td>Placed on the top of the shoe over the 2nd (middle) cuneiform bony landmark located in the middle of the superior surface of the foot.</td>
</tr>
<tr>
<td></td>
<td><strong>Calcaneus (2)</strong></td>
<td>Placed on the calcaneus at the same height above the plantar surface of the foot as the toe marker.</td>
</tr>
</tbody>
</table>
3.3.2 Force Platforms

For the drop-jump landing task, two force platforms (AMTI-OR6-6-1000, A-Tech Instruments Ltd, Scarborough ON, Canada), each bolted to 2 cm thick steel plates (56 cm x 61 cm), and placed on the lab floor (basement lab built on concrete), were used to collect ground reaction forces (for each foot separately). The platforms were connected to an AMTI amplifier, which was connected to the AD converter through BNC cables all close to the source.

3.3.3 Accelerometers

Acceleration of the proximal tibia was measured to determine the transient force effects of the ground reaction forces along the shaft of the tibia. Two surface-mounted tri-axial accelerometers (MMA3201D, Freescale Semiconductor, Inc, Ottawa, ON, Canada; range of +/- 50 G) were used (one for each leg) with a sensitive axis on each accelerometer visually aligned parallel to the long axis of each tibia. The accelerometers were placed over the bony area medial to the tibial tuberosity of both legs and secured to the skin using double-sided tape. The accelerometers were secured tightly to the bone with a thick tape-like strap.

3.3.4 2D Video Camera

For the pre-screening protocol, an iPad (Apple, Inc.) was placed approximately 2 m in front of the participant at knee height to capture the peak valgus angle during several trials of a drop-jump task (see description below).
3.3.5 Digital Force Gauge

A digital force gauge (Manual Muscle Testing System, Lafayette Instrument Company, Lafayette, IN) (Figure 13) was used during the pre- and post-test evaluations to assess the joint moment produced in each of the strength assessments (Table 3). The force gauge was secured to a MotionBlock ™ table on built-in adjustable lever arms (Figure 14) where it served as a rigid structure to resist motion in each movement (described in Table 3) in order to obtain accurate force data.

Figure 12: Lafayette Manual Muscle Testing System digital force gauge that was used to assess joint moment through measuring force produced by the participant at the hip joint in specific positions. It was secured in the appropriate position on the MotionBlock™ table using industrial metal clamps.
Figure 13: MotionBlock ™ table that was used for MVIC and isometric strength assessments in the pre- and post-testing sessions. The force gauge was attached to the middle of the adjustable lever arm using clamps and thick elastic tensor straps.
3.4 Procedures

3.4.1 Pre-Screening Session

Participants underwent a pre-screen test as described in the study design (section 3.2.1) to determine inclusion in the study. Following a minimum of three practice trials, three test trials were recorded with a minimum of 30 seconds rest in between each trial. The peak valgus angle from the three trials was taken to determine inclusion in the study, where two of the three trials had to have valgus angles equal or greater than 9°.

3.4.2 Pre-Test Data Collection

Participants were asked to wear athletic shoes that they would normally play volleyball in, a sports bra, and spandex shorts to minimize clothing interference for motion capture. Upon arrival to the laboratory, the participant’s body mass (kg) and height (m) were measured by the participant standing on a force platform with a reflective marker placed at the apex of their head. Their mass was converted from Newtons of force to kilograms and their height was calculated as the distance between the location of the force platform on which they are standing, and the reflective marker location on their head.

Each participant performed three maximum voluntary isometric contraction (MVIC) trials for each muscle against a force gauge anchored to the MotionBlock™ table (Figure 14). Each trial involved a brief ramp up to a maximal effort contraction (held for 5 seconds), followed by a return to rest. A minimum of 60
seconds rest occurred between trials. The researcher provided verbal motivation to maximize the effort level of each participant. The standardized positions of each force measurement for each muscle are outlined in Table 3.

Table 3: The standardized positions that participants were placed in to perform the maximum isometric strength test for each target muscle or muscle group during pre- and post-training data collection sessions. The force gauge was attached to a lever at a fixed position tailored to each of the four positions.

<table>
<thead>
<tr>
<th>Target Muscle/Muscle Group</th>
<th>Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gluteus Maximus</td>
<td>The participant lay prone on the Motionblock™ table with knee flexed to 90° and the ankle in a neutral position. The researcher applied pressure on the participant’s lower back to prevent excessive motion. The participant was instructed to extend her thigh off the table while keeping her ASIS in contact with the table. The force gauge was positioned at the midpoint between the popliteal fossa and the gluteal fold and resisted extension.</td>
</tr>
<tr>
<td>Hip Abductors</td>
<td>The participant lay on the Motionblock™ table on the contralateral side of the gluteus medius being measured. Her hip was in a neutral position. The researcher applied pressure and visually monitored the participant's lower back to prevent excessive motion. The participant was instructed to maximally abduct the leg as the force gauge provided resistance. The force gauge was positioned 4 cm above the knee joint on the lateral aspect of the distal thigh.</td>
</tr>
<tr>
<td>Hamstrings</td>
<td>The participant lay prone on the Motionblock™ table with the knee flexed to 90°. The researcher applied pressure to the participant’s lower back to prevent hip extension and other excessive motion. The participant was instructed to maximally flex the knee as the force gauge provides resistance. The force gauge was adjusted to contact the skin at the posterior aspect of the distal shank at a knee flexion angle of 90°.</td>
</tr>
<tr>
<td>Quadriceps</td>
<td>The participant was seated at the side of the MotionBlock™ table with knees flexed at 90°. The participant was instructed to maximally extend the knee as the force gauge provided resistance. The force gauge was adjusted to contact the skin at the frontal aspect of the distal shank at a knee flexion angle of 90°.</td>
</tr>
</tbody>
</table>
Following the strength assessment, the 45 optical markers (Table 2) were placed on the participant to track their 3D movement using the Qualisys motion capture system (Gothenburg, Sweden) via eight Oqus 100 cameras. A minimum of three drop-jump landing trials were performed prior to testing. As many practice trials as necessary was allowed to ensure the participant was comfortable with the task. Once the participant was comfortable with the task, they completed 15 trials. Motion capture (240 Hz sampling rate), force platform, and accelerometer data (2000 Hz sampling rate) were collected simultaneously using the Qualisys motion analysis system.

3.4.3 Isometric Strength Training Protocol

Each participant in the Training Group (TG) performed a 6-week isometric strength training protocol, consisting of two to three supervised sessions per week and two to three unsupervised sessions per week (a total of five sessions per week), each lasting approximately 45-60 minutes. The schedule was coordinated between the experimenter and participants, therefore, the testing and protocol schedule for each participant varied. Participants were given the option to train in groups of up to a maximum of 3 people during the supervised sessions; most participants opted for the group training sessions. This helped to streamline the data collection process while maintaining an appropriate level of supervision in order to monitor proper technique for each exercise. During the unsupervised sessions, the TG group was encouraged to train in groups to maximize compliance. There were two missed
supervised sessions for four of the participants that occurred in different weeks, resulting in each of those participants having only two supervised and three unsupervised sessions for two of their training weeks.

Each exercise session consisted of five isometric exercises (Table 4), each completed as three sets of ten isometric contractions lasting ten seconds. Five to ten seconds rest was given between each contraction, and 60 seconds rest was given between each set. Each exercise was performed bilaterally, one side at a time. The exercises isolated one or more of the target muscles. Hip extension and external rotation have a relatively low range of motion, therefore isometric contractions involving these movements were performed in two angles that were specific to each participant; neutral position and full range of motion. Hip abduction was performed at two pre-determined angles (Table 4), as the range of motion is relatively large. With every exercise at fixed joint angles, resistance was applied via a rigid structure such as a wall in order to maintain the proper position for the contraction. The participant was instructed to exert a maximal effort for each contraction while maintaining the proper position and isolating the target muscle. During the contraction, if the participant felt a non-target muscle becoming active (i.e. quadriceps, low back, etc.), they were instructed to stop and rest for one or two minutes and re-attempt the exercise.
Table 4: Position, action and target muscles associated with the exercises completed during each training session. All positions were completed while lying supine, unless otherwise stated.

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Position</th>
<th>Action</th>
<th>Target Muscles</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>• Prone</td>
<td>Hip extension</td>
<td>Gluteus maximus Biceps femoris</td>
</tr>
<tr>
<td></td>
<td>• 90° knee flexion</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Ankle in neutral position</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• No lateral movement of limb</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>• Prone</td>
<td>Hip extension</td>
<td>Gluteus maximus Gluteus medius Biceps femoris</td>
</tr>
<tr>
<td></td>
<td>• Full hip external rotation</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 90° knee flexion</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 30° hip abduction</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Ankle in neutral position</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>• 0° hip abduction</td>
<td>Hip abduction</td>
<td>Gluteus maximus Gluteus medius</td>
</tr>
<tr>
<td></td>
<td>• 0° hip flexion</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 0° hip rotation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>• 30° hip abduction</td>
<td>Hip abduction and external rotation</td>
<td>Gluteus maximus Gluteus medius</td>
</tr>
<tr>
<td></td>
<td>• 0° hip flexion</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Full hip external rotation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>• 0° hip flexion</td>
<td>Knee flexion</td>
<td>Biceps femoris</td>
</tr>
<tr>
<td></td>
<td>• 90° knee flexion</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

For exercises 1 and 2, participants performed hip extensions on each side individually; one with the hip in a neutral position (no rotation), and the second with the hip in full external rotation. Lying in a prone position on the MotionBlock™ table or a foam mat, with the knee flexed to 90°, and the ankle joint in a neutral position, the participant attempted to raise the thigh off the mat while keeping both anterior superior iliac spines firmly against the mat. The trainer/researcher applied pressure to the low back as well as placed her fingers between the mat and the participants’ ASIS for additional biofeedback when necessary. For the unsupervised sessions, the participant was instructed to place their hands lightly underneath their ASIS’s to ensure they stayed in contact with the mat.
Exercises 3 and 4 involved various hip abduction and hip external rotation positions; abduction angles were at 0° and 30°, while the hip external rotation positions were neutral and full range (full range varied for each participant). The participants lay on the contralateral side to the exercising leg. Participants performed abduction where a rigid structure (usually an adjustable bar frame – MotionBlock™) was placed at the appropriate distance above the participant to ensure proper abduction angles. It is important to note that a modification of this exercise was used by some of the participants during the unsupervised sessions due to a lack of access to a bar-frame. The modification involved performing the exercise lying supine, and using the wall as the resistance. The distance of their body from the wall was determined so that the abduction angle would remain consistent. This exercise was taught during the supervised session first to ensure that the participant understood how to properly perform the exercise.

Exercise 5 isolated the hamstrings through isometric knee flexion. While lying prone on a padded surface, the participant performed knee flexion at a fixed angle of 90° against an adjustable bar (MotionBlock™) or a non-flexible band/rope that was looped around the ankle (if there was no access to a MotionBlock™ table). Lateral movement was limited by positioning the body beside the back wall of the table (standard wall for unsupervised sessions) and the participant was instructed to keep the exercising leg "lightly touching the wall”. Excessive force against the wall was strongly discouraged, as this would evoke unwanted hip internal rotation force.
3.4.4 Post-Test Data Collection

The post-training protocol was identical to the protocol used during the pre-training session.

3.5 Data Acquisition

A 64-channel analog acquisition interface was used to collect synchronized analog signals from motion capture (240 Hz), force platforms, and accelerometers (2000 Hz). Three-dimensional coordinate (motion capture) and force platform data were filtered using a dual low pass Butterworth filter with a cut-off frequency of 10 Hz (Kristianslund et al., 2012). Tri-axial accelerometer data was collected, with analysis done on the longitudinal (y-axis) values as done in previous literature as the peak tibial acceleration values in the y-axis are positively associated with peak vertical ground reaction forces, thus are linked to increased injury risk (Duquette & Andrews, 2011; Elvin et al, 2007).

All data were exported to and reduced using the Visual3D software program (C-Motion, Germantown, MD). Joint centres and joint angles were estimated using the 3-dimensional coordinates of the markers to determine joint movement in all three planes – with specific interest in valgus deviation.

3.6 Statistical Analysis

An a priori power analysis calculation showed that a participant pool of 22 was required in order to achieve a power level of 0.8. The effect size of 0.6 was
based on data and power analyses done in similar studies on lower extremity kinematic changes seen with training (Earl et al., 2011; Hewett et al., 2005; Joseph et al., 2008; Snyder et al., 2009). The sample of 14 participants is underpowered and was anticipated to not likely result in statistical significance. Therefore, the results were assessed on both a group and individual basis.

Two-way mixed Analyses of Variance (ANOVA) with between-subject factor: Group (isometric strength training (TG), control (CG)); and within-subject factor: Time (pre-, post-training) were performed to examine any mean differences in the dependent variables peak valgus angle, muscle strength (net joint moment), tibial accelerations (peak acceleration, time to peak acceleration, peak acceleration slope, and linear acceleration slope), and ground reaction force at the time of peak valgus angle during the drop-jump landing. The acceleration slope was analyzed two ways; a) the peak acceleration slope (PAS) occurring between 30% and 70%; where 0% is the base of the curve just before the slope begins to increase, and 100% is the peak amplitude, and b) the linear acceleration slope (LAS) from the 30% point to the 70% point of the curve between the base of the curve to the peak amplitude. No significant group interactions were found that required post hoc tests, and thus none were utilized.

Given the small sample size, single-participant analyses using a model statistic procedure (Bates et al., 1992) were performed. Specifically, as described by Bates et al. (2004), the basic approach was to compare differences between dependent variables in the pre- and post-testing conditions to that of a probabilistic critical difference (test statistic) on a participant-by-participant basis. If the
empirically observed mean difference ($|\bar{x}_{\text{pre}} - \bar{x}_{\text{post}}|$) was greater than the test statistic (critical value $\times [sd_{\text{pre}}^2 + sd_{\text{post}}^2 / 2]^{1/2}$, where sd = standard deviation) for a given participant, then the difference was deemed statistically significant for said participant. Critical values based on the number of trials collected and desired alpha levels (0.01, 0.05, or 0.10) were garnered from a table generated by Bates et al. (1992).

All statistical analyses were performed using SAS system software for Windows (Version 9.3.1, SAS Institute Inc., Cary, NC), with the alpha level set at 0.05.
4. RESULTS

4.1 Strength

4.1.1 Group Results

There were significant group x time interaction effects for hip extension force (Left \( P=0.0483 \), Right \( P=0.0085 \)), hip abduction force (Left \( P=0.0036 \), Right \( P=0.0255 \)), and knee flexion force (Left \( P=0.0026 \), Right \( P=0.0010 \)) from pre- to post-test (Figure 14). As shown in Figure 14, this is reflected in no significant changes in mean muscle force output (net joint moment) from pre- to post-test for the control group, while significant increases occurred across the testing positions for the training group \( (P<0.05) \).

On average (between the left and right sides), hip extension force (gluteus maximus) increased by 20.5\%, hip abduction force (gluteus medius) increased by 27.5\% and knee flexion force (hamstrings) increased by 23.5\% (Figure 15). The knee extension force (quadriceps) did not significantly change in either group from pre- to post-test \( (Left \ P=0.3018, \ Right \ P=0.6871) \).
Figure 14: Mean (SD) forces produced in the testing positions in the training (TG=solid line) versus control group (CG=dotted line) from pre- to post-test. * = A significant change (P<0.05).
Figure 15: Percent change (SD) in muscle force (net joint moment) measured against a digital force gauge for the training group and control group between the pre- and post-test. A positive value indicates an increase in force from the pre-test to the post-test. * = A significant change (P<0.05).

4.1.2 Individual Results

With significant increases in the training group for the force output (net joint moment) across the testing positions, individual statistics were not performed. The average (SD) force outputs for each individual from pre- to post-test are presented in Figures 16-19.
Figure 16: Force output (N) onto the force gauge during hip extension of the left (A) and right (B) sides from pre- to post-test for the training group (TG) and control group (CG).
Figure 17: Force output (N) onto the force gauge during hip abduction of the left (A) and right (B) sides from pre- to post-test for the training group (TG) and control group (CG).
Figure 18: Force output (N) onto the force gauge during knee flexion of the left (A) and right (B) sides from pre- to post-test for the training group (TG) and control group (CG).
Figure 19: Force output (N) onto the force gauge during knee extension of the left (A) and right (B) sides from pre- to post-test for the training group (TG) and control group (CG).
4.2 Kinematics

A total of eight kinematic variables at four events were analyzed (Table 5) to determine if there were any other observable changes in drop-jump landing kinematics following the training protocol that have been associated with ACL injury risk. The primary kinematic variable analyzed was the knee valgus (knee adduction) angle in the frontal plane. In addition to knee valgus angle, lower extremity sagittal angles were analyzed. It has been hypothesized that the mechanism of ACL injury is anterior tibial translation associated with low knee flexion angle and high vertical GRFs. Therefore, sagittal variables at the knee, as well as the hip and ankle were assessed to determine the complete lower extremity kinematic effect of the training protocol. The variables were evaluated at various events of interest based on what has been assessed in previous studies; initial contact (IC) - when the foot makes first contact with the force platform, bottom (BT) – time of the body’s lowest centre of mass, peak force (PF) – time of highest vertical ground reaction force, and peak value (PV) – the highest value obtained between IC and task completion.
Table 5: All kinematic variables analyzed at various events in the drop-jump task.

<table>
<thead>
<tr>
<th>Kinematic Variables</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knee to Toe Width Ratio</td>
<td>The ratio of the knee width to the toe width.</td>
</tr>
<tr>
<td>Sagittal Ankle Angle (deg)</td>
<td>Degree of ankle dorsi (-ve) and plantar (+ve) flexion</td>
</tr>
<tr>
<td>Sagittal Hip Angle (deg)</td>
<td>Degree of hip flexion in the sagittal plane.</td>
</tr>
<tr>
<td>Sagittal Knee Angle (deg)</td>
<td>Degree of knee flexion in the sagittal plane.</td>
</tr>
<tr>
<td>Left/Right Knee Deviation (m)</td>
<td>The distance between the knee joint centre and a body-fixed plane that passed through the hip, ankle, and toe.</td>
</tr>
<tr>
<td>Left/Right Valgus Angle (deg)</td>
<td>The angle of the tibia relative to the global vertical line (a positive value for the left shank and a negative value for the right shank indicate knee adduction/tibial abduction; medial movement of the superior end of the tibia).</td>
</tr>
</tbody>
</table>

Of the kinematic variables analyzed, significant individual changes were observed in biomechanical factors that are associated with ACL injury risk for some of the training group participants. Significant changes were seen in knee kinematics in the frontal and sagittal plane, and hip kinematics in the sagittal plane; specifically knee valgus, knee flexion, and hip flexion angles. The detailed analyses are highlighted in the sections below on both group and individual levels. Some group trends and individual changes emerged in the kinematic and kinetic factors that will also be discussed below. All detailed individual kinematic results can be found in Appendix G, in which the change from pre- to post-test of the kinematic variables are listed with the P-values and an indication of statistical significance (* = P<0.05).
4.2.1 Frontal Plane

4.2.1.1 Group Results

No significant changes in the mean peak knee valgus angle (Left P=0.1038, Right P=0.375) or knee to toe width ratio (P=0.1803) (Table 6) were seen in the training or control groups.

Table 6: Mean (SD) of the peak left and right knee valgus angle, and the peak knee to toe width ratio of the training (TG) and control (CG) groups from pre- to post-test. No significant changes.

<table>
<thead>
<tr>
<th></th>
<th>Mean (SD) Knee Valgus Angle</th>
<th></th>
<th>Mean (SD) Peak Knee to Toe Width</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Left</td>
<td>Right</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Group</td>
<td>Pre</td>
<td>Post</td>
<td>P-Value</td>
</tr>
<tr>
<td>TG</td>
<td>2.40</td>
<td>0.39</td>
<td>(5.1)</td>
<td>0.1038</td>
</tr>
<tr>
<td>CG</td>
<td>1.70</td>
<td>2.80</td>
<td>(2.6)</td>
<td>0.0923</td>
</tr>
</tbody>
</table>

4.2.1.2 Individual Results

Four TG participants significantly decreased their left peak knee valgus angle, and three TG participants significantly decreased their right knee valgus angle (two of the five TG participants with a decrease in knee valgus angle experienced a bilateral decrease) (Table 7). Participants 1 and 3 demonstrated a bilateral decrease in knee valgus angle. The left knee valgus angle decreased by 8.37° (P<0.001) and 7.17° (P<0.001), and the right knee valgus angle increased by 10.99° (P<0.001) and 6.86° (P<0.001), respectively (Figure 20).
Figure 20: Frontal view at the time of peak knee valgus angle during the initial landing for at the pre-test and post-test for Participant 1 (A and B), and Participant 3 (C and D).
Table 7: Mean (SD) peak knee valgus angles for the training (TG) and control (CG) group participants from pre- to post-test. * = A significant change (P<0.05).

<table>
<thead>
<tr>
<th>Group</th>
<th>P</th>
<th>Pre</th>
<th>Post</th>
<th>P-Value</th>
<th>Pre</th>
<th>Post</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>TG</td>
<td>1</td>
<td>4.3 (2.9)</td>
<td>-4.0 (2.3)*</td>
<td>&lt;0.001</td>
<td>-13.2 (1.9)</td>
<td>-2.2 (4.9)*</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>2.7 (1.7)</td>
<td>-4.5 (6.1)*</td>
<td>&lt;0.001</td>
<td>-3.8 (2.1)</td>
<td>3.0 (6.7)*</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>7.2 (1.7)</td>
<td>7.2 (1.4)</td>
<td>0.9893</td>
<td>-7.6 (2.0)</td>
<td>-5.7 (1.8)*</td>
<td>0.0114</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>-1.9 (2.6)</td>
<td>-4.2 (2.2)*</td>
<td>0.0125</td>
<td>-4.9 (1.6)</td>
<td>-4.3 (2.6)</td>
<td>0.4241</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>0.6 (2.1)</td>
<td>0.7 (1.6)</td>
<td>0.8902</td>
<td>-0.6 (3.3)</td>
<td>-1.4 (2.6)</td>
<td>0.5018</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>2.1 (2.1)</td>
<td>7.1 (1.7)*</td>
<td>&lt;0.001</td>
<td>0.2 (2.5)</td>
<td>-2.8 (1.9)*</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>1.8 (1.6)</td>
<td>0.5 (1.7)*</td>
<td>0.0514</td>
<td>-2.3 (1.8)</td>
<td>-3.8 (1.5)*</td>
<td>0.0173</td>
</tr>
<tr>
<td>CG</td>
<td>2</td>
<td>0.1 (1.7)</td>
<td>2.3 (2.6)*</td>
<td>0.032</td>
<td>-2.6 (2.0)</td>
<td>-3.6 (1.5)</td>
<td>0.112</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>0.4 (1.4)</td>
<td>1.7 (2.0)*</td>
<td>0.0364</td>
<td>2.2 (1.9)</td>
<td>1.6 (2.5)</td>
<td>0.4492</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>0.1 (2.0)</td>
<td>0.9 (2.3)</td>
<td>0.3407</td>
<td>-0.4 (1.1)</td>
<td>0.2 (1.3)</td>
<td>0.1562</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>2.0 (1.6)</td>
<td>4.0 (2.1)*</td>
<td>0.0061</td>
<td>-3.8 (1.1)</td>
<td>-3.6 (2.2)</td>
<td>0.8243</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>-0.4 (1.4)</td>
<td>-1.2 (1.4)</td>
<td>0.1579</td>
<td>-0.2 (1.3)</td>
<td>2.5 (1.4)*</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>5.1 (2.6)</td>
<td>6.1 (2.2)</td>
<td>0.2795</td>
<td>-2.4 (2.2)</td>
<td>-4.6 (2.3)*</td>
<td>0.0122</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>4.6 (1.7)</td>
<td>5.6 (1.2)*</td>
<td>0.0585</td>
<td>-2.4 (1.0)</td>
<td>0.1 (1.6)*</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Knee Valgus Angle = angle of the tibia relative to the global vertical line (a positive value for the left shank and a negative value for the right shank indicate knee adduction/tibial abduction; medial movement of the superior end of the tibia).

In addition, a significant increase in the knee to toe width ratio was observed at the bottom (BT) of the drop-jump landing task (0.5 to 0.78; 0.6 to 0.8, P<0.001), as well as at peak force (PF) (0.68 to 0.82; 0.63 to 0.75; P<0.001) (Table 8). Qualitatively, the participants landed with a more upright tibia and a more forward pointing foot throughout the drop-jump landing and at the highlighted points of interest (the bottom of the jump and the time of peak vertical ground reaction force).
Table 8: Mean (SD) peak knee to toe width ratio of the training (TG) and control (CG) groups from pre- to post-test. * = A significant change (P<0.05).

<table>
<thead>
<tr>
<th>Group</th>
<th>P</th>
<th>Pre</th>
<th>Post</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>TG</td>
<td>1</td>
<td>0.68 (0.05)</td>
<td>0.82 (0.04)*</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.63 (0.08)</td>
<td>0.75 (0.05)*</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0.73 (0.02)</td>
<td>0.72 (0.01)</td>
<td>0.102</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>0.87 (0.02)</td>
<td>0.87 (0.03)</td>
<td>0.729</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>0.78 (0.02)</td>
<td>0.77 (0.03)</td>
<td>0.587</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>0.80 (0.03)</td>
<td>0.77 (0.02)*</td>
<td>0.007</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>0.70 (0.01)</td>
<td>0.71 (0.02)</td>
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</tr>
<tr>
<td>CG</td>
<td>2</td>
<td>0.80 (0.04)</td>
<td>0.77 (0.04)</td>
<td>0.081</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>0.76 (0.10)</td>
<td>0.76 (0.04)</td>
<td>0.924</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>0.79 (0.06)</td>
<td>0.78 (0.03)</td>
<td>0.587</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>0.73 (0.04)</td>
<td>0.72 (0.02)</td>
<td>0.291</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>0.81 (0.02)</td>
<td>0.80 (0.02)</td>
<td>0.196</td>
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<tr>
<td></td>
<td>12</td>
<td>0.72 (0.06)</td>
<td>0.75 (0.04)</td>
<td>0.170</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>0.80 (0.03)</td>
<td>0.79 (0.02)</td>
<td>0.542</td>
</tr>
</tbody>
</table>

Mean (SD) Peak Knee to Toe Width
4.2.2 Sagittal Plane

4.2.2.1 Group Results

There were no significant group differences in sagittal trunk, hip, knee, or ankle angles at initial contact (IC), at the point of lowest centre of mass (BT), time of peak vertical GRF (PF), or maximum value obtained (PV) during the drop-jump landing task. However, there was a 10.4° decrease in the mean knee flexion at PF in the training group versus a 0.31° increase in the control group (P=0.093), with all other mean values for knee angle changes at BT, PV, and PF (control group only) being less than 1° (Table 9).
Table 9: Mean (SD) lower extremity sagittal angles of the training (TG) and control (CG) groups from pre- to post-test at the landing events assessed (IC, BT, PF, PV) and the group x time P-value.

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean (SD) Sagittal Angles</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
</tr>
<tr>
<td></td>
<td>Group</td>
<td>Mean</td>
</tr>
<tr>
<td>Ankle</td>
<td>IC</td>
<td>TG</td>
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<td></td>
<td></td>
<td>CG</td>
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<td></td>
<td>PF</td>
<td>TG</td>
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<td>CG</td>
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<td></td>
<td>PV</td>
<td>TG</td>
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<td></td>
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<td>CG</td>
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<tr>
<td>Knee</td>
<td>IC</td>
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<td></td>
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<td>CG</td>
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<td></td>
<td>BT</td>
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<tr>
<td></td>
<td>PF</td>
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<td>CG</td>
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<td></td>
<td>PV</td>
<td>TG</td>
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<td></td>
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<tr>
<td>Hip</td>
<td>IC</td>
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<td>CG</td>
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</tbody>
</table>

N = 15. All angles are in degrees. IC = initial contact. BT = at lowest centre of mass location. PF = at peak vertical ground reaction force magnitude. PV = the maximum value.
4.2.2.2 Individual Results

There were significant increases in hip flexion angle at IC for 10 participants (4 TG, 6 CG) (P<0.05), and at BT, PF, and PV for 12 participants (6 TG, 6 CG) (P<0.05), and a decrease for one TG participant (P<0.05) (see Appendix G for P-Values) (Figures 21A, 22A, 23A, 24A). There was a significant decrease in knee flexion for four participants in the training group, but only two participants in the control group at BT (4 TG vs. 2 CG), PF (5 TG vs. 2 CG), and PV (4 TG vs. 2 CG) (Figures 22B, 23B, 24B) (P<0.05). It was observed for one TG participant that the flexion angles of the hip, knee and ankle (dorsiflexion) increased significantly at BT and at PF (P<0.05). However, the remaining three participants demonstrated a significant decrease in knee flexion and an increase in hip flexion at these events (P<0.05). A summary of the kinematic variables and specific P-values for all participants can be found in Appendix G.
Figure 21: Mean (SD) flexion angles at initial contact (IC) during the initial landing at the hip (A), knee (B), and ankle (C) for each participant in the training group (TG) and control group (CG) from pre- to post-test. Negative angles for ankle flexion represent plantar flexion. * = A significant change (P<0.05).
Figure 22: Mean (SD) peak flexion angles (PV) during the initial landing at the hip (A), knee (B), and ankle (C) for each participant in the training group (TG) and control group (CG) from pre- to post-test. Positive angles for ankle flexion represent dorsiflexion. * = A significant change (P<0.05).
Figure 23: Mean (SD) flexion angles at the time of lowest body centre of mass (BT) during the initial landing at the hip (A), knee (B), and ankle (C) for each participant in the training group (TG) and control group (CG) from pre- to post-test. Positive angles for ankle flexion represent dorsiflexion. * = A significant change (P<0.05).
Figure 24: Mean (SD) flexion angles at the time of peak vertical ground reaction force (PF) during the initial landing at the hip (A), knee (B), and ankle (C) for each participant in the training group (TG) and control group (CG) from pre- to post-test. Positive angles for ankle flexion represent dorsiflexion. * = A significant change (P<0.05).
4.3 Kinetics

4.3.1 Ground Reaction Force

4.3.1.1 Group Results

There were no significant group changes in peak vertical ground reaction force magnitudes during the drop-jump landing task. The training group mean peak vertical GRF increased from 2.58 (0.25) N/kg to 2.60 (0.13) N/kg, and the control group decreased from 2.73 (0.33) N/kg to 2.69 (0.29) N/kg (P=0.5748). The magnitudes were normalized to each participant’s body mass.

4.3.1.2 Individual Results

Two TG participants (1 and 4), and two CG participants (10 and 11) demonstrated a significant change in mean PVGRF from pre- to post-test (P<0.05). Participant 1 decreased from 3.06 to 2.67 N/kg (P=0.001), participants 4, 10, and 11 increased vertical GRF from 2.45 to 2.76 N/kg (P=0.002), 2.89 to 2.69 N/kg (P=0.005), and 2.77 to 2.60 N/kg (P=0.034), respectively (Figure 25). The direction of the change was inconsistent between the training and control participants, thus no conclusions can be drawn about the association of vertical ground reaction force magnitude with isometric hip muscle force, or landing kinematics (Appendix H).
There were four participants in the training group who demonstrated a significant change in knee flexion angle at PV and BT (P<0.05). These participants also exhibited an opposite change in the peak vertical GRF (PVGRF) (i.e. decrease in knee flexion and increase in PVGRF), although this change was only significant for two participants. Participant 1 demonstrated a 15° increase in knee flexion angle at both PV (P<0.001) and BT (P<0.001), with a 0.39 N/kg decrease in PVGRF (P=0.001). Participants 3, 4, and 8 demonstrated a decrease in knee angle at PV of 6.5° (P<0.001), 6.7° (P<0.001), and 4.5° (P<0.001), a decrease at BT of 6.5° (P<0.001), 8.6° (P<0.001), and 4.6° (P=0.004), and an increase in PVGRF of 0.02 N/kg (P=0.759), 0.31N/kg (P=0.002), and 0.10 N/kg (P=0.170), respectively (Appendix H). These results suggest that the decrease in the knee flexion angle at
the time of peak vertical GRF could be associated with an increase in the vertical ground reaction force magnitude.

4.4 Tibial Acceleration

The tibial acceleration results were taken from the initial landing of the drop-jump landing task (Figure 11).

4.4.1 Group Results

There was no significant group change from pre- to post-test for peak acceleration (PA) for the left (P=0.601) or right side (P=0.387). The mean difference in PA for the training group from pre- to post-test was a 1.2 g decrease (left) and 0.3 g increase (right), however, deviations were at least four times greater (4.8 to 6.5). The control group demonstrated the same non-significant change of a 3.0 g decrease (left) and 2.0 g decrease (right), with deviations approximately double the mean differences, ranging from 5.1 to 7.8 (Figure 26A).

There was no significant group change from pre- to post-test in time to peak acceleration (TTP) during the initial landing for the right side (P=0.786). However, there was a significant group x time effect seen on the left side where the change was seen in the control group (P=0.049). The mean change for the training group from pre- to post-test was 3.2 (increase) for the left and 11.7 (decrease) for the right, but with deviations of approximately 22 ms. The control group demonstrated a mean change of 14.7 ms (decrease) for the left, and 13.2 ms (decrease) for the right, with deviations of 5-20 ms (Figure 26B).
For PAS, no significant group changes from pre-to post-test were detected on the left (P=0.819) or right sides (P=0.559). The change in the mean for the training group from pre- to post-test ranged from an increase of approximately 100 g/s to 700 g/s with deviations of at least double (~1500-2000 g/s). The control group showed slightly less variation from pre- to post-test with a decrease (left) or increase (right) of approximately 200 g/s, with deviations at least five times greater, ranging within 1000-2000 g/s (Figure 26C).

For LAS, no significant group changes from pre-to post-test were detected on the left (P=0.573) or right sides (P=0.241). The mean LAS for the training group increased (left) or decreased (right) by approximately 500 and 300 g/s, respectively, with deviations ranging from over 800 to 1300 g/s. The control group mean values from pre- to post-test showed the lowest change compared to the other acceleration variables, with a decrease (left) and increase (right) of approximately 130 and 300 g/s, respectively, and deviations that were fairly close to the means in magnitude (~450 to 1000 g/s) (Figure 26D). For a summary of the group results for all tibial acceleration variables, see Appendix I.
Figure 26: Mean (SD) acceleration results for the initial landing in the training group (TG) and control group (CG) pre- and post-test for A) peak acceleration (g), B) time to peak acceleration (sec), C) peak acceleration slope (greatest slope between 30% and 70% of the curve) (g/s), and D) linear acceleration slope (linear slope between the 30% and 70% points of the curve) (g/s). * = A significant change (P<0.05).
4.4.2 Individual Results

Several participants in both groups demonstrated significant changes in PA, TTP, PAS, and LAS (P<0.05). The direction of the change was inconsistent between the training and control participants, thus no conclusions can be drawn on the association of tibial acceleration variables with isometric hip muscle force, or landing kinematics. A summary of the tibial acceleration results and specific P-values for all participants can be found in Appendix J.

4.4.2.1 Peak Acceleration

In the training group, four participants exhibited significant change in peak acceleration for either the left and/or right side. Participant 6 and 8 showed a decrease on the left side by 8.61 g (P=0.003) and 12.0 g (P=0.001), respectively, while participants 4 and 5 showed an increase of 5.6 (P<0.001) and 10.9 g (P=0.010). On the right side, participant 3 also exhibited a decrease of 5.1 g (P=0.005), however participants 4 and 5 had an increase (opposing change of their left side) of 4.8 g (P=0.015) and 7.2 g (P=0.024). In the control group, participants 7 and 13 had a decrease in PA on the left side of 6.6 g (P<0.001) and 8.5 g (P=0.005), respectively, and participant 2 had a decrease on the right side of 8.1 g (P=0.012) (Figure 27).
Figure 27: Mean (SD) peak tibial acceleration along the y-axis of the left (A) and right (B) sides from pre- to post-test for the training (TG) and control group (CG). * = A significant change (P<0.05).
4.4.2.2 Time to Peak Acceleration

Significant changes in TTP (ms) were observed for ten participants (five TG, five CG). Significant increases were only seen in two of the TG participants, with mean (SD) pre- to post-test values of 105(11.4) ms to 123.7(5.1) ms on the left (P<0.001), and 106(8.9) ms to 21.7(8.2) ms for the right (P<0.001) for Participant 1, and 60.1(29.1) ms to 97.1(21.8) ms on the left (P<0.001) for Participant 5. Three participants in the TG exhibited a significant decrease in TTP; Participant 3 decreased on the left side from 83.7(21.6) ms to 60.0(19.1) ms (P=0.004), and on the right side from 91.4(5.5) ms to 63.2(18.6) ms (P=0.004), Participant 5 decreased on the right side from 102.5(28) ms to 81.3(30.2) ms (P<0.001), Participant 6 decrease on the left side from 98.6(7.9) ms to 89.1(13.5) ms (P=0.027), and Participant 14 decreased on the right side from 69.9(8.4) ms to 52.5(5.7) ms (P<0.001). Participants 7, 9, 10, 11, and 13 in the control group also demonstrated significant decreases in TTP from pre- to post-test (P<0.05) (Figure 28). See Appendix J for a summary of the TTP results and P-values for all individuals.
Figure 28: Mean (SD) time to peak acceleration (TTP) (sec) of the left (A) and right (B) sides from pre- to post-test for the training (TG) and control group (CG). * = A significant change (P<0.05).
4.4.2.3 Acceleration Slope

PAS results were highly variable, but showed significant changes in six out of seven TG participants. However, the direction of change (increase vs. decrease) varied between and within (left vs. right side) the TG participants (Figure 29) (Appendix J). The only TG participant to demonstrate a bilateral significant change was Participant 4, who showed a mean (SD) increase in PAS of 1434.2(356.1) g/s to 2738.1(1025) g/s (P<0.001) and 2262.2(1231.8) g/s to 3456.4(838.4) g/s (P=0.04) for the left and right sides, respectively. Four TG and four CG participants exhibited unilateral changes in either a positive or negative direction, while one CG participant (12) showed a bilateral increase in PAS of 912.1(355.2) g/s to 2121.9(807.5) g/s (P<0.001) and 962.3(763.2) g/s to 2768.2(2945.6) (P=0.029).
Figure 29: Mean (SD) peak acceleration slope [as measured between 30% and 70% of the acceleration curve between 0% (where the curve begins to slope upwards) and 100% of the peak amplitude] of the left (A) and right (B) sides from pre- to post-test for the training (TG) and control group (CG). * = A significant change (P<0.05).
LAS results were highly variable within participants, but less so than for PAS. Significant, but inconsistent changes were seen in TG participants 1, 3, 5, 8, and 14, with 1 and 2 exhibiting a bilateral change in the same direction; Participant 1 increased from 1704.3(620.7) g/s to 1911.2(1393.5) g/s \( P=0.043 \) and 601(451.1) to 2736.5(1848.4) g/s \( P<0.001 \) for the left and right sides, while participant 3 decreased from 1591.3(1098.9) g/s to 803(335.8) g/s \( P=0.013 \) and 2628.1(1949.5) g/s to 1139.2(1175.6) g/s \( P=0.017 \) for the left and right sides, respectively. Participants 5 and 14 showed a left-side increase from 1043.4(386.2) g/s to 4234.6(3331.8) \( P=0.001 \) and 427(391.4) g/s to 1108.3(295.6) g/s \( P<0.001 \), respectively. The control group (six out of seven) demonstrated significant changes \( P<0.05 \) in both increasing and decreasing directions, mostly unilateral, with one participant (12) showing a bilateral increase (Appendix J) (Figure 30). There were no clear trends that emerged, as the change in LAS appeared to be independent of group as well as other individual kinetic and/or kinematics changes.
Figure 30: Mean (SD) linear acceleration slope (LAS) (g/s) [as measured between 30% and 70% of the peak amplitude (the linear slope of the line between these two points)] of the left (A) and right (B) sides from pre- to post-test for the training (TG) and control group (CG). * = A significant change (P<0.05).
5. DISCUSSION

5.1 Overview

To date, this is the first study to quantify the kinematic changes of a drop-jump landing task following an isometric strengthening protocol of the hip musculature, targeting the hip extensors, abductors, and external rotators in female volleyball athletes. As reported in the literature (Chappell et al., 2008; Earl et al., 2011; Nadler et al., 2002), weakness in these muscle groups has been associated with an increased injury risk due to the greater knee valgus angle that can result during a drop-jump landing task. It was hypothesized that isometric strength training would a) increase the hip joint moment-generating capacity (i.e., hip muscle force produced) at the testing positions (Table 3, Section 3.4.2), which would translate into b) a decrease in the knee valgus angle (knee adduction angle) during a drop-jump landing task, c) increased tibial acceleration upon landing, and d) decreased peak vertical ground reaction force at the time of peak knee valgus angle. Other factors including sagittal lower extremity angles and peak vertical ground reaction force were also evaluated to better assess the effectiveness of the training protocol in changing lower body kinematic and kinetic factors that are associated with injury risk.

There was a significant increase in the isometric strength of all target muscles, strongly supporting the effectiveness of isometric training in improving strength. The only kinematic trend that was observed was a decrease in the knee flexion angle at the time of peak vertical GRF in four of the training group participants.
No significant group changes were observed in peak acceleration, time to peak acceleration, peak acceleration slope, or linear acceleration slope. Significant changes were seen amongst individuals, but were not limited to the training group, and the direction of change did not emerge as an associated trend with any other significant kinetic or kinematic changes that occurred on an individual basis.

5.2 Strength

Following the 6-week isometric strength training protocol, the force produced by the hip musculature in the testing positions (extension, hip abduction, and lying prone knee flexion – targeting the gluteus maximus, gluteus medius, and hamstrings, respectively) improved significantly by approximately 20.5%, 27.5%, and 23.5%. This agrees with strength increases seen in a 12-week, 4 days/week isometric knee extension protocol (20% increase) and in a 5-week, 5 days/week isometric strengthening protocol of the quadriceps (full contraction with neutral hip, full contraction with 10 cm hip flexion, and hip adduction) (34% increase) (Anwer et al., 2014). The greater strength increase seen by Anwer et al. (2014) compared to the current study may be due to the differences in focus on the number of muscles/muscle groups and frequency of training between the studies. The frequency and intensity of the training in the current study is comparable to other protocols that observed significant strength increases, with three sets of ten contractions held for ten seconds at full effort per exercise (Anwer et al., 2014; Folland et al., 2005). Anwer et al. (2014) exposed participants to exercises, which
were performed in sets of 10 repetitions. One set of the exercises was performed twice a day for the 1st week, 2 sets twice a day until the 3rd week, and then 3 sets twice a day until week five. This resulted in a total of 240 repetitions of each of the three exercises held for either five (2 of 3) or ten seconds (1 of 3). Folland et al. (2005) exposed participants to a 9-week, 3 sessions per week program, with 4 sets of 10 reps (4 exercise positions, 1 set per position) at 75% held for 2 seconds - totaling approximately 270 repetitions per exercise. In comparison, the current study is a 6-week, five days per week protocol that required 150 repetitions of each exercise, each held maximally for ten seconds.

The percent strength increases seen in this and other isometric training studies were notably higher than increases reported in longer duration dynamic strength training protocols: mean increases of 7% for 12-weeks of training (Delecluse et al., 2003) and 15.1% for 10-weeks of training (Painter et al., 2012). The results of the current study support the use of isometric training over a shorter duration as a means by which significant strength gains can be achieved at the trained angle. Holm et al., (2004) had 35 female athletes complete a neuromuscular training program, with no significant improvements in strength, whereas Fatouros et al. (2000) saw significant leg strength improvements after a plyometric (form of neuromuscular training) program. As previously discussed, there is little to no consistency in the literature with the specific protocol (specific exercises, frequency, intensity) for neuromuscular training, as the definition of the term covers a wide variety of exercise styles.
5.3 Kinematics

The training protocol in this study proved to be adequate to generate significant strength gains of the target musculature, thereby allowing for possible connections to be made between strength and changes in kinematics. However, the overall lack of significant group changes in kinematics suggests that statically stronger muscles around the hip joint may not translate into functionally significant changes in lower extremity dynamic joint kinematics of a drop-jump landing, at least for the population studied.

No significant group changes were observed in any of the kinematic variables analyzed. Significant changes were seen amongst individuals, but were not limited to the training group. This suggests that the strength increases seen in the training group did not transfer to kinematic changes during a drop-jump landing task <em>at a group-wide level</em>. There were several individual changes in kinematic measures that are discussed below.

Although the mean differences were not significant, two training group participants had significant knee kinematic changes in the frontal plane, including a knee to toe width ratio closer to 1 (indicating less medial knee deviation from the toes), and a lower knee valgus angle (knee adduction). These two factors demonstrate lower peak medial knee displacement during the drop-jump landing task, which is associated with a decrease in the strain on the ACL and a lower injury risk (Hewett et al., 2005). This suggests that isometric strengthening of the
lumbopelvic musculature to increase the joint hip extension and abduction
moments could potentially improve the frontal plane kinematics during a drop-
jump task in certain individuals. However, due to the low number of participants
and no group-wide significance found, the effectiveness of the isometric training
protocol on frontal plane kinematics is inconclusive. With only two participants
(both in the training group) demonstrating a statistically significant frontal plane
improvement (bi-lateral), it is unlikely that a larger participant pool would have
produced a significant change group-wide. It is unknown whether the magnitude of
the strength increase is related to the altering of drop-jump kinematics. The lack of
a significant group-wide change in drop-jump kinematics, or even a consistent trend
amongst all training group participants, suggests that strengthening the hip
musculature may affect each athlete differently. In addition, simply increasing the
strength of specific muscle groups (through position isolation) may not effectively
transfer to dynamic movement patterns without an attempt to perform dynamic or
neuromuscular training after an isometric strengthening program.

For the sagittal kinematics, there was a trend amongst all participants to have
a significantly higher hip flexion angle at the time of peak vertical GRF and at the
time of lowest centre of mass position of the initial landing. More notably, the
majority of the training group participants demonstrated a decrease in the knee
flexion angle at the time of peak vertical GRF (a mean decrease of 10.4°, versus less
than 1° for the control group), although this change was not statistically significant.
This trend suggests that increasing the isometric strength of the hip musculature
responsible for extension, abduction, and external rotation about the hip, may be
associated with a more rigid landing at the knee and higher resulting joint moments at the knee, thereby increasing the risk for injury as the knee may rely more heavily on the passive restraints of the frontal plane to decelerate the body (Pollard et al., 2010). With lower knee flexion, participants are potentially increasing the load on the ACL due to increased anterior tibial force through the patellar tendon from higher quadriceps activation (DeMorat et al., 2004; Withrow et al., 2006). Less knee flexion also lowers the hamstrings’ ability to produce posterior tibial shear force to alleviate stress placed on the ACL (Li et al., 1999). Lastly, there is a potential for increase joint loading due to a decreased capacity to attenuate the shock from the impact.

5.4 Kinetics

The primary kinetic variable examined in the current study was peak vertical ground reaction force. Also of interest were changes in kinematic variables at the time of peak vertical ground reaction force. Three training group participants had a statistically significant decrease in the maximum knee flexion angle at this event. In addition, although not statistically significant, a trend towards an increase in peak vertical ground reaction force was observed. The participants demonstrating this trend had increased hip flexion and decreased knee flexion. This may suggest that, after an isometric strength training protocol, risk for ACL injury may increase due to less flexion in the knees at higher peak impact forces (Boden et al., 2000; Griffin et al., 2006; Podraza et al., 2010).

Previous studies have associated hip extensor weakness in females with a compensatory strategy of overreliance on the quadriceps and passive frontal plane
tissues to absorb impact forces (Stearns et al., 2013). However, with the significant strength increases of the hip extensors seen in this study, and no significant mean change in ground reaction forces, the potential link between these two variables needs further investigation.

5.5 Tibial Acceleration

There were no significant changes seen in peak acceleration, time to peak acceleration, peak acceleration slope between 30% and 70% of peak amplitude, or linear acceleration slope measured between the 30% and 70% points of the peak amplitude in either group between the pre-and post-test. Linear acceleration slope values coincided with methodology used in previous literature (Duquette & Andrews, 2011), and demonstrated comparable values. The mean (SD) of the linear acceleration slope for the current study, averaged between the left and right side across all participants both pre- and post-test was 1533 (791) g/s, compared to a mean (SD) of 2121 (263) g/s (Duquette and Andrews, 2011). The high variability is likely due to the nature of the task, being that a drop-jump landing is more variable between trials compared to lying supine on a pendulum while being swung into a force platform (for heel impact) at a fixed distance (as done in Duquette and Andrews, 2011). The high variability seen within each group and within individuals would suggest that a much larger participant pool would be required to see significant changes in these variables at a group level. The high variability also suggests that individualized analyses should be performed for such complex movements as a drop-jump landing.
However, individuals that demonstrated significant kinematic changes in one direction had contradicting changes in acceleration factors. Training group participants that exhibited less knee flexion, decreased knee valgus angle (tibial abduction angle), a change in rate of force development, or a change in vertical ground reaction force, either had no significant change, or had a significant increase or decrease for the tibial acceleration variables for the left and/or right leg. The lack of a directional trend (despite statistical significance for individuals) in peak acceleration, time to peak acceleration, and acceleration slope (even between the left and right limb) leads to the conclusion that tibial acceleration was not influenced by the change in kinematics in the training group who experienced the isometric training program. Previous correlational studies assessed the relationship between segmental acceleration, peak vertical ground reaction force, and knee angle during a jump-landing task. It was demonstrated that tibial acceleration is positively associated with peak vertical ground reaction force (Derrick et al., 2004) - coefficient of determination of 0.81 (Elvin et al., 2007a) - and increased ground reaction force along with decreased knee flexion have been positively associated with an increased risk of ACL injury (Chappell et al., 2002; Yu et al., 2002). However, connecting tibial acceleration to knee flexion angles during landing in this study has not been successful. This could be due to the dynamic nature of a landing task in that a one-axial direction of acceleration is not enough of a predicting factor to strongly correlate to the tri-axial movement of the knee during dynamic movement. In addition, the numerous degrees of freedom throughout the body’s kinematic chain (i.e. ankle, knee, hip, and spine movements) make it possible that
multi-segment movements like drop landings can be executed in many different ways.

Studies have shown inconsistent or highly variable peak shank accelerations (vertical) for running (Derrick et al., 2004) and jumping (Elvin et al., 2007b). However, with jumping, there appears to be an increase in vertical shank acceleration with decreased landing knee flexion; the numeric results are highly variable in general (~10-40 g within one subject; correlation of 0.45 of tibial segment stiffness – as measured using axial acceleration and jump height - to knee extension angle versus 0.81 for trunk segment stiffness). In the current study, the drop-jump landing task was controlled, compared to a game-like maneuver. As such, the variability between trials was minimized through a controlled start time, rest periods, consistent verbal cues, and fixed targets for landing (force platforms). Self & Paine (2001) argue that movement artifact that occurs with skin-mounted accelerometers could compromise the accuracy of the data. However, since the accelerometers were secured tightly to the bony landmark, this movement would not likely change appreciably from trial to trial within participants, but may be different between participants. Given the variability in the tibial acceleration values reported to date, the findings of this study are therefore inconclusive.

The difference seen between the two approaches used to calculate acceleration slope (peak versus linear value between 30% and 70% of the peak amplitude) is noteworthy, as the methodology for determining acceleration slope varies in the literature (Duquette & Andrews, 2011). The large difference between PAS and LAS in the current study could be due to the misrepresentation of the
acceleration slope in the 30%-70% as a function of amplitude, as the “toe region”
(the non-linear, relatively flat section at the beginning of the acceleration curve)
may influence the slope by underestimating the most linear part of the slope. This
would explain the significantly larger values of peak acceleration slope compared to
the linear acceleration slope, as well as the results seen in previous research where
ranges larger than 35%-65% (as a function of amplitude) were reported (Duquette
& Andrews, 2011; Lafortune et al., 1996). In addition, the relatively high variability
within participants could be due to the less controlled, “sport-like” maneuver of a
drop-jump landing task, compared to the human pendulum approach used in
previous work (Duquette & Andrews, 2011; Lafortune et al., 1996), where distance,
swing speed, and impact force are relatively controlled between trials.

5.6 Limitations

One of the limitations of this study was the low number of participants (14
total), with only seven participants who completed the training program. Based on
_a priori_ statistical power calculations, it is possible that the lack of significant
findings was due to small numbers, and/or attributable to the variability with which
the participants executed the drop-jump landing task. Kinetically and kinematically,
there were some trends seen for a number of individual participants in both the
training and control groups, but no significant group effects were seen. Similar
studies assessing the kinetics and kinematics of a drop-jump task after a training
protocol had subject pools of 30 (Chappell et al., 2008), 19 (Earl et al., 2011), 50
(Cochrane et al., 2010) and 74 (Herman et al., 2007) individuals. Despite efforts to
recruit the requisite number of participants and a large interest expressed by volleyball athletes, 68 out of 109 athletes did not meet the inclusion criterion of an initial valgus angle of at least 9° during the pre-screen session. Of the 41 athletes remaining, only 7 were able to commit to the 6-week training period. Another limitation was the lack of control over the athletes’ activities outside of the isometric training protocol. Any additional training that the athletes did during the study period was controlled by asking the athletes to keep their regular level of volleyball play, and discourage excessive fitness training (more than their normal levels), or starting any new programs including resistance, plyometric, and jump training. There was a high level of adherence to these requests, established by verbal confirmation.

Methodologically, the consistency of the anatomical landmarking was controlled by having the same researcher perform the task for all pre- and post-tests. There could have been some variability in the marker placement between the pre- and post-test for the participants. However, variability in marker placement was not evaluated independently in this study. Future work should isolate the contribution that marker placement variability has on the overall repeatability of kinematic measures between multiple testing sessions.

The participants were all elite level players. Consequently, their movement patterns (drop-jump skill) may have been more engrained than a younger, less trained cohort, and could therefore be more resistant to change after a 6-week isometric strength training program.
Within each participant, they may have approached the post-test with a different mindset, compared to the pre-test, based on what they had learned about the variables being assessed. In other words, participants were more informed about the nature, and possibly the purpose of the study during the post-test session than the pre-test session, and this may have impacted their performance. At the hip joint, almost all participants increased their maximum flexion angle, angle at peak force, and angle at lowest centre of mass during the drop-jump landing task. This could have occurred if the participants deduced that lower extremity movements were being assessed, and may have altered their dynamic drop-jump landing technique due to the focus being shifted internally (to their body movement), as opposed to externally (the volleyball blocking task). The principal reason for this is based on the constrained action hypothesis, which describes how greater automaticity in movement control is fostered by an external focus (Wulf et al., 2001). It is believed that by keeping the verbal cues consistently fixed to an external focus between the pre- and post-tests, variation in the participants' mental approach to the task was minimized. Athletes commonly believe that a stiff landing will increase your risk for injury, and several of the participants were well aware of this as they had expressed their knowledge during the pre- and post-test preparations while inquiring about the details of the study. In order to deter focus from their lower extremities, responses from the primary investigator were kept to general statements about block jumping and upper body technique.
5.7 Major Contributions

This study was the first to use an isometric strengthening program targeting the extensors, abductors, and external rotators of the hip, weakness from all of which has previously been associated with poor landing kinematics, particularly knee valgus deviation. The significant gains in hip extensor, hip abductor, and knee flexor strength (with 0° hip flexion) of 20.5%, 27.5%, and 23.5%, respectively, are significantly higher than those observed in dynamic strengthening programs of comparable frequency and intensity. However, the transference of this isometric increase in strength to a dynamic activity such as a drop-jump landing is unknown. Although no statistically significant group changes in kinematics were observed, significant changes in training group individuals were seen. Two participants demonstrated a significant decrease in knee valgus angle (8.37° and 7.17°), and the training group as a whole exhibited a decrease in knee flexion angle (mean difference of 10.4° for the training group; versus <1° for the control group). This could suggest that the effects of an isometric training program may affect individuals differently, and warrants future investigation.

The MotionBlock™ training apparatus used for the majority of the training sessions could have positively influenced the effectiveness of the strength training by allowing the participants to control the exact position and direction of movement for contraction. The adjustable lever arm allowed each participant to have the ability to perform each of the exercises, and could be used in research and clinical settings to control joint position and muscle contraction.
5.8 Conclusions and Future Research

The lack of any directional trend in frontal plane kinematics between the training and control groups overall following the training program leads to the conclusion that increasing the isometric strength of the hip musculature (to the levels seen in this study) via hip extension, abduction and external rotation exercises does not consistently translate into a kinematic change in a drop-jump landing task. However, this conclusion must be qualified in that the study was underpowered and significant changes were seen in two of the training group participants. The proposed training program might be effective for certain athletes, but additional work in this area needs to be conducted in order to confirm or refute this suggestion.

An exercise program's effectiveness could vary from person to person as each individual may differ in sex, strength, muscle fibre type distribution, coordination, their specialized sport and training history, and other unique physiological and psychological factors (Cowley et al., 2006; Eynon et al., 2011; Miller et al., 1993). Increasing the strength of the hip muscles, whose weaknesses have been associated with increased valgus angle and ACL injury risk (Jacobs et al., 2007; Howard et al., 2011; Khayambashi et al., 2012; Nadler et al., 2002), could perhaps serve as a foundational program to strengthen the muscles associated with poor landing kinematics. By strengthening the individual target muscles in an isolated and controlled manner using an isometric protocol, the maximum force generating capacity of the muscle and/or activation level could increase (Del Balso et al., 2007). Isometric strengthening could be followed by an individualized
dynamic or neuromuscular training program, which might be more effective in producing significant kinematic changes. With stronger muscles, the effectiveness of dynamic or neuromuscular training could be enhanced as the muscles could activate more effectively, or produce a higher force when trained to activate in a more coordinated pattern (Tsao et al., 2008). Based on the results of the current study, increasing the force output of a muscle in a given position does not appear to alter the kinematic pattern the same way in all individuals. A recent study assessed the dynamic muscle force produced by the quadriceps at various muscle lengths after isometric strength training at a) short lengths (30˚ knee flexion), and b) long lengths (100˚ knee flexion). It was found that greater dynamic force production was generated after training the muscle at longer lengths, whereas the shorter length training was angle-specific with respect to its ability to increase force production (Noorkoiv et al., 2014). The current study implemented relatively short length exercises for the target musculature, so future studies should assess the potential dynamic effectiveness of training the hip extensors, abductors, and external rotators at longer or varied lengths to try to elicit a change in dynamic movement.

Future studies should also utilize electromyography to determine muscle activation levels during a drop-jump landing task after isometric strength training to compare the strength changes with potential changes in muscle activation. Muscle activation, as measured through electromyography, does not represent muscular strength linearly during dynamic activities, but is more a representation of neural drive to the muscle. Therefore, it might reveal changes in activation levels that could be correlated to strength and/or kinematics. In addition, the activation
timing of the muscles could be analyzed to determine any changes during a drop-jump landing task. Previous studies have linked activation timing in the landing preparatory stages as well as at the various phases of a jump to ACL injury risk (Ebben et al., 2010; Myer et al., 2005a; Palmieri-Smith et al., 2008). With the increase in strength seen with isometric training, investigation into its effect on muscle activation level and timing during a drop-jump landing task is warranted.

The effectiveness of the MotionBlock™ apparatus in training over a larger range of joint angles should also be investigated in future work. In addition, pairing isometric strengthening (using MotionBlock™ for well controlled joint angles) with follow up neuromuscular training to determine if increasing the strength of the muscle using isometrics at specific angles or a range of angles would improve the effectiveness of a dynamic or neuromuscular training program, would advance this area of inquiry. By exploring this line of research, it may be possible to develop a training program that alters poor joint kinematics that are linked to higher risk of ACL injury in landing activities. Previous studies have seen some success with neuromuscular training with the lower extremity (Chappell et al., 2008; Hewett et al., 2005), but perhaps targeting the muscles whose weakness is associated with poor kinematics through isometrics will better equip these muscles to be more effectively utilized during a neuromuscular training program.

Lastly, the large variability in and considerable difference between the peak and linear acceleration slope values calculated in this study warrants future investigation. Determining what method is most appropriate for assessing tibial
acceleration slope in a drop-jump landing task, could be important for the purpose of determining the level of correlation to joint angles, joint angle stiffness, peak ground reaction forces and, therefore, injury risk potential (Elgin et al. 2007; Holmes & Andrews, 2006).
References


Dear [Coach’s name],

My name is Kaitlin Jackson and I am a Master’s student at the University of Windsor conducting a study at the University of Toronto. The purpose of my study is to attempt to reduce the risk for ACL injuries in female volleyball athletes using isometric strengthening of the hip muscles. The protocol (including training and all pre- and post-evaluations) will last 7-8 weeks. The time commitment required for the training group will be approximately 45 minutes, 4 times per week. The scheduling of all training and testing sessions will be adjusted according to any prior team commitments your players have. I would like to arrange a meeting with you and your team to outline the purposes and procedures of the study and the benefits that the proposed training will have on strength, performance, and injury prevention.

Please contact me if you are interested in participation, I look forward to hearing from you.

Kind regards,

Kaitlin Jackson
416-333-9355
jacksong@uwindsor.ca
Appendix B: Script for Study Recruitment

My name is Kaitlin Jackson and I am completing my Masters in Biomechanics at the University of Windsor. The study I am doing has to do with lowering ACL injury risk in female athletes. The reason for this focus is because we, as female athletes, suffer ACL injuries about six times more frequently than males. Researchers are trying to find the best way to lower this injury risk by changing how your body moves, mainly through different kinds of exercise.

The purpose of this study is to see if I can use isometric exercises to change how your body handles a drop-jump landing task, like when you go up for a block jump or have to land from a jump and go right into another one. As you know, this occurs all the time in volleyball, and when you use poor movement strategies, your chance for injury goes up. I am looking to determine which of you already have high risk movement strategies and will attempt to improve these problematic strategies through exercise.

If you volunteer for this study, you will either be in an exercising group or a non-exercising group. For both groups, I will have you come into the lab at the start and end of the 7-8 week cycle for about an hour for a test session to see how you jump. We will look at the activity of several muscles crossing your hip joint, how your lower extremities move in 3D, and the forces that occur during jump landings. If you are in the exercising group, you will do basic isometric exercises for 6 weeks, 4-5 times a week in between the start and end test sessions. Isometric exercises involve you holding a position and pushing against a rigid structure with your legs. Each exercise session only takes about 35 minutes and is very mild compared to the types of exercise that you’re probably used to doing. More importantly, you could see improvements in your hip strength and landing mechanics, which could lead to higher performance and lower injury risk.

This work could benefit the volleyball community and other female athlete groups. Those who choose to participate will receive compensation that will be discussed before participation commences.

If you have any questions about the study, please contact me at your convenience.

Thank you very much for your time and for considering being a participant in this study. If you would like to participate, you may contact me or your coach to set up a time for the initial screening session.
CONSENT TO PARTICIPATE IN RESEARCH

TITLE OF THE STUDY: The Effect of an Isometric Strength Training Protocol on Valgus Angle During a Drop-Jump Landing in Elite Female Volleyball Players

You are asked to participate in a research study conducted by Kaitlin Jackson, from the Department of Kinesiology at the University of Windsor under the advisement of Dr. Dave Andrews. This research will be conducted at the University of Toronto under the supervision of Dr. Tyson Beach. The results of this study will contribute to my Master's Thesis.

If you have any questions or concerns about the research, please feel to contact Kaitlin Jackson (jacksong@uwindsor.ca; 416-333-9355), Dr. Dave Andrews (dandrews@uwindsor.ca; 519-253-3000 ext. 2433) or Dr. Tyson (Tyson.beach@utoronto.ca; 416-978-2547).

PURPOSE OF THE STUDY

To assess the effects of isometric strengthening on the biomechanics of the lower body of female athletes during a drop-jump landing task. With primary focus on valgus angle, and a secondary focus on flexion/extension angles, it is hypothesized that strengthening the hip musculature will improve the valgus angle, thereby decreasing ACL injury risk for female athletes.

PROCEDURES

You will be contacted through your coach to set up a meeting to be informed of the purposes and procedures of the study. If you volunteer to participate in this study, you will be asked to partake in the following procedures:

Pre-Screening (5 minutes):

You will be asked to jump down from a 30 cm box and immediately perform a maximal block jump in front of a volleyball net while a digital video camera records you from the front, from the waist down.

Pre-Testing (45 min - 1 hour):

You will wear a fitted tank top/T-shirt, spandex shorts, and your volleyball shoes. Your height and weight will be measured and electrodes will be placed on your skin around the hips (the skin will be shaved if necessary and cleaned with rubbing alcohol). You will perform strength tests for your hip muscles which include 24 exertions (each is a 5 second isometric contraction against resistance).
Post-Testing:
You will perform a post-testing 6 weeks after the pre-testing, which will have identical procedures to the pre-testing session.

POTENTIAL RISKS AND DISCOMFORTS
There is a risk for discomfort including delayed onset muscle soreness and/or a muscle cramp. The adhesive on the electrodes and tape may leave temporary redness on your skin. If you experience discomfort that prevents you from participation, please inform Kaitlin Jackson immediately. The closest clinic is The David L. MacIntosh Sport Medicine Clinic located in the University of Toronto Athletic Centre (same building as the lab). The closest hospital is the Toronto General Hospital at 200 Elizabeth St, Toronto (corner of University Ave. and College St.).

POTENTIAL BENEFITS TO PARTICIPANTS AND/OR TO SOCIETY
Participants will not see any benefits to participation in this study. However, they may receive information on the results of the study and may be given training details if they show a benefit.

COMPENSATION FOR PARTICIPATION
Upon completion, you will receive a Kinesiology Research T-shirt.

CONFIDENTIALITY
Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission. Your data will only be identified by a code and will be password protected and accessible only to the primary investigator (Kaitlin Jackson). Data will be retained for archival value at both the University of Windsor and the University of Toronto to answer additional research questions in the future. Data collected during the pre- and post-testing may be released to Dr. Dave Andrews and Dr. Tyson Beach for analysis. Your identity will not be disclosed to any third party.

The video collected in the study will not be used for any other purposes than those described above. You have the right to review your video recordings. Video collected during the pre-screening session will be deleted once the study is completed. Video collected during the pre- and post-testing sessions will be archived along with all other data collected for future analysis purposes. They will be secured on a password-protected computer and external hard-drive.

PARTICIPATION AND WITHDRAWAL
You have the right to withdraw from the study at any time. The investigator may withdraw you from this research if circumstances arise which warrant doing so. If you decide to withdraw after the testing sessions are complete, your data will not be withdrawn unless you specifically request it to be withdrawn.

FEEDBACK OF THE RESULTS OF THIS STUDY TO THE PARTICIPANTS

A summary of the research findings from this study will be available April 30, 2014 on the University of Windsor REB website (www.uwindsor.ca/REB).

SUBSEQUENT USE OF DATA

These data may be used in subsequent studies, in publications and in presentations.

RIGHTS OF RESEARCH PARTICIPANTS

If you have questions regarding your rights as a research participant, contact: Research Ethics Coordinator, University of Windsor, Windsor, Ontario, N9B 3P4; Telephone: 519-253-3000, ext. 3948; e-mail: ethics@uwindsor.ca

SIGNATURE OF RESEARCH PARTICIPANT/LEGAL REPRESENTATIVE

I understand the information provided for the study The Effect of an Isometric Strength Training Protocol on Valgus Angle During a Drop-Jump Landing in Elite Female Volleyball Players as described herein. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form.

________________________
Name of Participant

________________________
Signature of Participant

Date

SIGNATURE OF INVESTIGATOR

These are the terms under which I will conduct research.

________________________
Signature of Investigator

Date

Appendix D: Consent Form (Training Group)
CONSENT TO PARTICIPATE IN RESEARCH

TITLE OF THE STUDY: The Effect of an Isometric Strength Training Protocol on Valgus Angle During a Drop-Jump Landing in Elite Female Volleyball Players

You are asked to participate in a research study conducted by Kaitlin Jackson, from the Department of Kinesiology at the University of Windsor under the advisement of Dr. Dave Andrews. This research will be conducted at the University of Toronto under the supervision of Dr. Tyson Beach. The results of this study will contribute to my Master’s Thesis.

If you have any questions or concerns about the research, please feel to contact Kaitlin Jackson (jacksong@uwindsor.ca; 416-333-9355), Dr. Dave Andrews (dandrews@uwindsor.ca; 519-253-3000 ext. 2433) or Dr. Tyson (Tyson.beach@utoronto.ca; 416-978-2547).

PURPOSE OF THE STUDY

To assess the effects of isometric strengthening on the biomechanics of the lower body of female athletes during a drop-jump landing task. With primary focus on valgus angle, and a secondary focus on flexion/extension angles, it is hypothesized that strengthening the hip musculature will improve the valgus angle, thereby decreasing ACL injury risk for female athletes.

PROCEDURES

You will be contacted through your coach to set up a meeting to be informed of the purposes and procedures of the study. If you volunteer to participate in this study, you will be asked to partake in the following procedures:

Pre-Screening (5 minutes):

You will be asked to jump down from a 30 cm box and immediately perform a maximal block jump in front of a volleyball net while a digital video camera records you from the front, from the waist down.

Pre-Testing (45 min - 1 hour):

You will wear a fitted tank top/T-shirt, spandex shorts, and your volleyball shoes. Your height and weight will be measured and electrodes will be placed on your skin around the hips (the skin will be shaved if necessary and cleaned with rubbing alcohol). You will perform strength tests for your hip muscles which include 24 exertions (each is a 5 second isometric contraction against resistance).

Drop-Jumps:
The electrodes will stay on. Reflective markers will be placed on your joints to track your movement and an accelerometer will be placed on each shin bone. You will do the same jump as you performed in the pre-screening session, which comprises landing on force platforms and doing a maximal block jump immediately after. Five successful jumps will be collected with as many practice trials and rest that you need.

Training:

You will exercise 5 days per week (minimum of 3 supervised by the investigator) for 6 weeks in small groups or individually, each session lasting about 30-45 minutes. You will perform various isometric hip exercises.

Post-Testing:

After training, you will perform a post-testing, which will have identical procedures to the pre-testing session.

POTENTIAL RISKS AND DISCOMFORTS

There is a risk for discomfort including delayed onset muscle soreness and/or a muscle cramp. The adhesive on the electrodes and tape may leave temporary redness on your skin. If you experience discomfort that prevents you from participation, please inform Kaitlin Jackson immediately. The closest clinic is The David L. MacIntosh Sport Medicine Clinic located in the University of Toronto Athletic Centre (same building as the lab). The closest hospital is the Toronto General Hospital at 200 Elizabeth St, Toronto (corner of University Ave. and College St.).

POTENTIAL BENEFITS TO PARTICIPANTS AND/OR TO SOCIETY

Participants will gain knowledge about the function of the hip musculature, as well as potentially gain understanding of how these muscles control the lower body during drop jump landings. Participants will also learn if valgus angle can be improved through isometric training that they can do on their own. This might help them reduce the chance of knee injuries in the future.

COMPENSATION FOR PARTICIPATION

Upon completion, you will receive a Kinesiology Research T-shirt, and will also be entered in a draw for an iPad mini.

CONFIDENTIALITY

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission. Your data will only be identified by a code and will be password protected and accessible only to the primary investigator (Kaitlin Jackson). Data will be retained for archival value at both the University of Windsor and the University of Toronto to answer additional research questions in the future. Data collected during the pre- and post-testing may be released to Dr. Dave Andrews and Dr. Tyson Beach for analysis. Your identity will not be disclosed to any third party.

The video collected in the study will not be used for any other purposes than those described above. You have the right to review your video recordings. Video collected during the pre-screening session will be deleted once the study is completed. Video collected during the pre-
and post-testing sessions will be archived along with all other data collected for future analysis purposes. They will be secured on a password-protected computer and external hard-drive.

PARTICIPATION AND WITHDRAWAL

You have the right to withdraw from the study at any time. The investigator may withdraw you from this research if circumstances arise which warrant doing so. If you are unable to fulfill the exercise protocol requirements (i.e. cannot complete the required amount of sessions per week), you may be withdrawn from the study. If you withdraw or are removed from the study, you may not receive compensation. If you decide to withdraw after the testing sessions are complete, your data will not be withdrawn unless you specifically request it to be withdrawn.

FEEDBACK OF THE RESULTS OF THIS STUDY TO THE PARTICIPANTS

A summary of the research findings from this study will be available April 30, 2014 on the University of Windsor REB website (www.uwindsor.ca/REB).

SUBSEQUENT USE OF DATA

These data may be used in subsequent studies, in publications and in presentations.

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If you have questions regarding your rights as a research participant, contact: Research Ethics Coordinator, University of Windsor, Windsor, Ontario, N9B 3P4; Telephone: 519-253-3000, ext. 3948; e-mail: ethics@uwindsor.ca

SIGNATURE OF RESEARCH PARTICIPANT/LEGAL REPRESENTATIVE

I understand the information provided for the study The Effect of an Isometric Strength Training Protocol on Valgus Angle During a Drop-Jump Landing in Elite Female Volleyball Players as described herein. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form.

____________________________________
Name of Participant

____________________________________
Signature of Participant  _____________

_______________________________  _______________________
Signature of Investigator  Date
Appendix E: Letter of Information (Control Group)

LETTER OF INFORMATION FOR CONSENT TO PARTICIPATE IN RESEARCH

Title of Study: The Effect of an Isometric Strength Training Protocol on Valgus Angle During a Drop-Jump Landing in Elite Female Volleyball Players

You are asked to participate in a research study conducted by Kaitlin Jackson, from the Department of Kinesiology at the University of Windsor under the advisement of Dr. Dave Andrews. This research will be conducted at the University of Toronto under the supervision of Dr. Tyson Beach. The results of this study will be contributed to a Master’s Thesis. If you have any questions or concerns about the research, please feel to contact Kaitlin Jackson (jacksong@uwindsor.ca; 416-333-9355), Dr. Dave Andrews (dandrews@uwindsor.ca; 519-253-3000 ext. 2433) or Dr. Tyson (Tyson.beach@utoronto.ca; 416-978-2547).

PURPOSE OF THE STUDY

To assess the effects of isometric strengthening on the biomechanics of the lower body of female athletes during a drop-jump landing task. With primary focus on valgus angle, and a secondary focus on flexion/extension angles, it is hypothesized that strengthening the hip musculature will improve the valgus angle, thereby decreasing ACL injury risk for female athletes.

PROCEDURES

You will be contacted through your coach to set up a meeting to be informed of the purposes and procedures of the study. If you volunteer to participate in this study, you will be asked to partake in the following procedures:

Pre-Screening (5 minutes):

You will be asked to jump down from a 30 cm box and immediately perform a maximal block jump in front of a volleyball net while a digital video camera will be recording from the front to determine if you are eligible to participate. The video frame will only see you from the waist down.

Pre-Testing (45 min - 1 hour):

You will wear a fitted tank top/T-shirt, spandex shorts, and your volleyball shoes. Your height and weight will be measured and electrodes will be placed on your skin around the hips (the skin will be shaved if necessary and cleaned with rubbing alcohol). You will perform strength tests for your hip muscles which include 24 exertions (each is a 5 second isometric contraction against resistance).

Drop-Jumps:
The electrodes will stay on. Reflective markers will be placed on your joints to track your movement and an accelerometer will be placed on each shinbone. You will do the same jump as the pre-screening, landing on force platforms and doing a maximal block jump. Five successful jumps will be collected with as many practice trials and/or rest that you need.

Post-Testing:

Six weeks following the pre-testing, you will perform a post-testing, which will have identical procedures to the pre-testing session.

POTENTIAL RISKS AND DISCOMFORTS

There is a risk for discomfort including delayed onset muscle soreness and/or a muscle cramp. The adhesive on the electrodes and tape may leave temporary redness or you may have a reaction. If you experience discomfort that prevents you from participation, please inform Kaitlin Jackson immediately. The closest clinic is The David L. MacIntosh Sport Medicine Clinic located in the University of Toronto Athletic Centre (same building as the lab). The closest hospital is the Toronto General Hospital at 200 Elizabeth St, Toronto (corner of University Ave. and College St.).

POTENTIAL BENEFITS TO PARTICIPANTS AND/OR TO SOCIETY

Participants will gain knowledge about the function of the hip musculature, as well as potentially gain understanding of how these muscles control the lower body during drop jump landings. Participants will also learn if valgus angle can be improved through isometric training that they can do on their own. This might help them reduce the chances of knee injuries in the future.

COMPENSATION FOR PARTICIPATION

Upon completion, you will receive a Kinesiology Research T-shirt.

CONFIDENTIALITY

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission. A number will identify each participant’s data, which will be password protected and accessible only to the primary investigator (Kaitlin Jackson). Data will be retained for archival value at both the University of Windsor and the University of Toronto as the variables collected may be further analysed to provide answers to related hypotheses. Data collected during the pre- and post-testing may be released to Dr. Dave Andrews and Dr. Tyson Beach for analysis. Your identity will not be disclosed to any third party. The video collected in the study will not be used for any other purposes than those described above. You have the right to review your video recordings. Video collected during the pre-screening will be deleted once the study is completed. Video collected during the pre- and post-testing sessions will be archived along with all other data collected for future analysis purposes. They will be secured on a password-protected desktop and external hard-drive.

PARTICIPATION AND WITHDRAWAL
You have the right to withdraw from the study at any time. The investigator may withdraw you from this research if circumstances arise which warrant doing so. If you are unable to fulfil the exercise protocol requirements (i.e. cannot complete the required amount of sessions per week), you may be withdrawn from the study. If you withdraw or are removed from the study, you may not receive compensation. If you decide to withdraw after the testing sessions are complete, your data will not be withdrawn unless you specifically request it to be withdrawn.

FEEDBACK OF THE RESULTS OF THIS STUDY TO THE PARTICIPANTS

A summary of the research findings will be available on the University of Windsor REB website.
Web address: www.uwindsor.ca/REB
Date when results are available: April 2014

SUBSEQUENT USE OF DATA

These data may be used in subsequent studies, in publications and in presentations.

RIGHTS OF RESEARCH PARTICIPANTS

If you have questions regarding your rights as a research participant, contact: Research Ethics Coordinator, University of Windsor, Windsor, Ontario N9B 3P4; Telephone: 519-253-3000, ext. 3948; e-mail: ethics@uwindsor.ca

SIGNATURE OF INVESTIGATOR

These are the terms under which I will conduct research.

_____________________________  _________________
Signature of Investigator                  Date
LETTER OF INFORMATION FOR CONSENT TO PARTICIPATE IN RESEARCH

Title of Study: The Effect of an Isometric Strength Training Protocol on Valgus Angle During a Drop-Jump Landing in Elite Female Volleyball Players

You are asked to participate in a research study conducted by Kaitlin Jackson, from the Department of Kinesiology at the University of Windsor under the advisement of Dr. Dave Andrews. This research will be conducted at the University of Toronto under the supervision of Dr. Tyson Beach. The results of this study will be contributed to a Master’s Thesis. If you have any questions or concerns about the research, please feel to contact Kaitlin Jackson (jacksong@uwindsor.ca; 416-333-9355), Dr. Dave Andrews (dandrews@uwindsor.ca; 519-253-3000 ext. 2433) or Dr. Tyson (Tyson.beach@utoronto.ca; 416-978-2547).

PURPOSE OF THE STUDY

To assess the effects of isometric strengthening on the biomechanics of the lower body of female athletes during a drop-jump landing task. With primary focus on valgus angle, and a secondary focus on flexion/extension angles, it is hypothesized that strengthening the hip musculature will improve the valgus angle, thereby decreasing ACL injury risk for female athletes.

PROCEDURES

You will be contacted through your coach to set up a meeting to be informed of the purposes and procedures of the study. If you volunteer to participate in this study, you will be asked to partake in the following procedures:

Pre-Screening (5 minutes):

You will be asked to jump down from a 30 cm box and immediately perform a maximal block jump in front of a volleyball net while a digital video camera will be recording from the front to determine if you are eligible to participate. The video frame will only see you from the waist down.

Pre-Testing (45 min - 1 hour):

You will wear a fitted tank top/T-shirt, spandex shorts, and your volleyball shoes. Your height and weight will be measured and electrodes will be placed on your skin around the hips (the skin will be shaved if necessary and cleaned with rubbing alcohol). You will perform strength tests for your hip muscles, which include 24 exertions (each is a 5-10 second isometric contraction against resistance).
Drop-Jumps:

The electrodes will stay on. Reflective markers will be placed on your joints to track your movement and an accelerometer will be placed on each shinbone. You will do the same jump as the pre-screening, landing on force platforms and doing a maximal block jump. Five successful jumps will be collected with as many practice trials and/or rest that you need.

Training:

You will exercise 5 days per week (minimum of 3 supervised by the investigator) in small groups or individually, each session lasting about 30-45 minutes. You will perform various isometric hip exercises.

Post-Testing:

After training, you will perform a post-testing, which will have identical procedures to the pre-testing session.

POTENTIAL RISKS AND DISCOMFORTS

There is a risk for discomfort including delayed onset muscle soreness and/or a muscle cramp. The adhesive on the electrodes and tape may leave temporary redness or you may have a reaction. If you experience discomfort that prevents you from participation, please inform Kaitlin Jackson immediately. The closest clinic is The David L. MacIntosh Sport Medicine Clinic located in the University of Toronto Athletic Centre (same building as the lab). The closest hospital is the Toronto General Hospital at 200 Elizabeth St, Toronto (corner of University Ave. and College St.).

POTENTIAL BENEFITS TO PARTICIPANTS AND/OR TO SOCIETY

Participants will gain knowledge about the function of the hip musculature, as well as potentially gain understanding of how these muscles control the lower body during drop jump landings. Participants will also learn if valgus angle can be improved through isometric training that they can do on their own. This might help them reduce the chances of knee injuries in the future.

COMPENSATION FOR PARTICIPATION

Upon completion, you will receive a Kinesiology Research T-shirt, and will also be entered in a draw where you can win an iPad mini.

CONFIDENTIALITY

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission. A number will identify each participant's data, which will be password protected and accessible only to the primary investigator (Kaitlin Jackson). Data will be retained for archival value at both the University of Windsor and the University of Toronto as the variables collected may be further analysed to provide answers to related hypotheses. Data collected during the pre- and post-testing may be released to Dr. Dave Andrews and Dr. Tyson Beach for analysis. Your identity will not be disclosed to any third party.
The video collected in the study will not be used for any other purposes than those described above. You have the right to review your video recordings. Video collected during the pre-screening will be deleted once the study is completed. Video collected during the pre- and post-testing sessions will be archived along with all other data collected for future analysis purposes. They will be secured on a password-protected desktop and external hard-drive.

PARTICIPATION AND WITHDRAWAL

You have the right to withdraw from the study at any time. The investigator may withdraw you from this research if circumstances arise which warrant doing so. If you are unable to fulfil the exercise protocol requirements (i.e. cannot complete the required amount of sessions per week), you may be withdrawn from the study. If you withdraw or are removed from the study, you may not receive compensation. If you decide to withdraw after the testing sessions are complete, your data will not be withdrawn unless you specifically request it to be withdrawn.

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A summary of the research findings will be available on the University of Windsor REB website.
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SIGNATURE OF INVESTIGATOR

These are the terms under which I will conduct research.
Appendix G: Individual Kinematic Results

Mean (SD) of the left and right knee valgus angle (A), sagittal ankle (B), sagittal knee (C), and sagittal hip (D) angles, and knee to toe width (E). * = A significant change (P<0.05).

N = 15. All angles are in degrees. IC = initial contact. BT = at lowest centre of mass location. PF = at peak vertical ground reaction force magnitude. PV = the maximum value.

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Appendix H: Individual Kinetic Results

Mean (SD) of the peak vertical ground reaction force (A), jump height (B), and a comparative table of the sagittal knee angles at various landing events and peak vertical ground reaction force (C). * = A significant change (P<0.05).

N = 15. All angles are in degrees. IC = initial contact. BT = at lowest centre of mass location. PF = at peak vertical ground reaction force magnitude. PV = the maximum value.

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**Mean (SD) Knee Angles**

**Mean (SD) Peak Vertical GRF (N/kg)**
Appendix I: Group Tibial Acceleration Results

Mean (SD) of peak acceleration (PA), time to peak acceleration (TTP), peak acceleration slope between 30% and 70% of peak amplitude, and linear acceleration slope between the 30% and 70% points of peak amplitude of the left and right limb from pre- to post-test. * = A significant change (P<0.05).

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Appendix J: Individual Tibial Acceleration Results

Mean (SD) from pre- to post-test for the left and right sides of the training (TG) and control (CG) groups of peak tibial acceleration (A) (g), time to peak tibial acceleration (B), peak tibial acceleration slope that occurred between 30% and 70% peak amplitude (C), and linear tibial acceleration slope that occurred between the 30% and 70% points of peak amplitude (D). * = A significant change (P<0.05).

### Appendix J: Individual Tibial Acceleration Results

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### Appendix J: Individual Tibial Acceleration Results

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VITA AUCTORIS

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