The Effectiveness of a Neuromuscular Training Program on Hip Strength and Core Stability in Healthy Adolescent Females

By

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Abstract

Introduction: Following the onset of maturation, female athletes have a significantly higher risk for anterior cruciate ligament injury when compared with male athletes. It is therefore important to evaluate this increased risk in this population and some possible preventative measures.
Objective: To examine the effect of a neuromuscular exercise training (NME) program on hip strength and core stability in healthy adolescent females.
Study Design: Randomized Clinical Trial which employed a repeated measures design.
Participants: Healthy adolescent females aged 12-18 years old.
Intervention: A 5-week progressive perturbation NME program was administered according to previously described and validated methodologies. The supervised program was administered 2x/week for 5 weeks. The program consisted of a series of destabilizing perturbations that were applied to the unstable surfaces with the subject in a unilateral stance.
Outcome Measurements: Hip external rotation (ER) and hip abduction strength were evaluated using held-hand dynamometry. A dynamic seated stability test was used to evaluate core stability. Vertical jump test using the Vertex was used to evaluate lower extremity functional power and performance.
Results: 40 healthy adolescent females (age 13.5 ± 0.2 years, height 165.3 ± 7.5 cm, weight 70.0 ± 25.3 kg, BMI 25.2 ± 6.6 kg/m^2) were recruited. Two-way ANOVAs compared hip ER and abduction strength, core stability, and vertical jump pre- and post- NME training between the control and NME groups. Independent samples t-tests demonstrated that the percentage change in hip abduction strength and core stability was different between the control and NME group, with the NME group showing more improvement at follow-up. There was no significant relationship noted between strength scores and core stability or vertical jump performance.
Conclusions: Overall, the results suggest the possibility of some impact as a result of the NME program, but more research is still needed to clarify the results of this and other investigations which have examined the efficacy of NME training programs in specific at-risk populations such as physically active adolescent females.

Key Words:
Balance, hand held dynamometry, core stability, core strength, core, hip strength, hip, perturbation, proprioception, ACL, adolescent females, lower extremity, trunk endurance, trunk stability, lumbar spine, pelvis, hip, neuromuscular, closed chain, open chain, knee, lower limb.

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Dedications

I would like to dedicate this to my children; Teagan and Connor Heise who came into the world during this study and the creation of this document. You provided me with the drive and inspiration to complete my thesis.

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CHAPTER ONE: INTRODUCTION

1.1 Introduction

Female adolescents as a population have become increasingly involved in high impact and high-performance sports and physical activity for example an increasing number of females participating in soccer.[1] This increased involvement ranges from high level team sports, to individual sports, and involves strength training and general physical fitness.[2] As compared to their male counterparts, females are at higher risk of injury when participating in the same sport.[3] With this increased involvement in competitive sport, there has been increased incidence of lower body injuries reported within the female adolescent population specifically involving the knee.[4] These injuries result in chronic pain and ongoing dysfunction which diminishes the ability of the female patient to be active as she ages. It can lead to additional health problems, which impair the patient's overall well-being and ability to be active throughout their life.[5] As such, it is important to examine factors that may predispose adolescent females to lower body injury.

Following the onset of maturation, female athletes have a significantly higher risk for anterior cruciate ligament injury when compared with male athletes.[4] Increasing evidence in the literature indicates that core control may have a large effect on knee-joint control and injury risk. Female athletes show greater lateral trunk displacement, altered trunk and hip flexion angles, greater ranges of trunk motion, and increased hip adduction and internal rotation during sport maneuvers, compared with their male counterparts.[6] Hip strength training may decrease the risk of ACL injury by modifying high – risk positions about the knee.[6] Prevention programs targeted towards trunk and hip neuromuscular control may help decrease the risk of ACL injuries in athletes, especially female athletes.[7]

Research suggests that hip strength and core stability are factors that may influence the incidence of lower body injury.[8] However there is a lack of research describing the role that hip strength and core stability may play in preventing lower extremity injuries in adolescent females. Data

indicate that lumbo-pelvic support or core stability may have a large effect on motion of the lower extremity and risk of knee injury in an adult population.[8] Research on adolescent females shows that they demonstrate greater lateral trunk displacement and altered hip adduction and internal rotation motion during sport type movements.[8] It has been hypothesized that these types of abnormalities may occur due to weakness about the hip and a lack of core stability, contributing to an increased risk of ACL injuries.[7]

Neuromuscular exercise (NME) is a specialized form of training that is commonly used in a rehabilitation setting to develop strength and stability about the hip and core region.[9] Research involving adults indicates that it can be used to enhance trunk control, reduce valgus stress about the knee and prevent lower extremity injuries.[10] While neuromuscular exercise training (NMT) is commonly prescribed to enhance proprioception and sensory input to prevent lower extremity injuries in an adolescent population, its ability to increase gluteal strength in adolescent females is unclear.[8,11]

There is a possibility that female athletes with proprioceptive deficits possess a greater propensity for knee injury which suggests the need for pre-screening to assess injury risk before athletic participation.[12] There is strong evidence that neuromuscular control of the trunk and lower extremity can be improved with neuromuscular training.[12] Therefore, further investigation should be focused on addressing the proprioceptive deficits in female athletes by increasing neuromuscular training with the result of lowering the potential injury risk.

The main objective of this project is to investigate the effects of a neuromuscular exercise training program on hip strength and core stability in healthy adolescent females. The primary outcome measures for this investigation will be hip abduction and external rotation strength. The secondary outcome measures will be core stability and performance on vertical jump. The long-term goal of this research project is to determine whether NME can be used to enhance gluteus medius and minimus muscle strength in an adolescent female population and whether changes in strength are related to core stability and performance on vertical jump. These results could enhance the current standard of care, assist in creating preventative programing and improve long-term outcomes associated with lower body injuries in adolescent females.

1.2 **Objective**

To determine whether neuromuscular exercise (NME) has an effect on hip strength (external rotation and abduction) and core stability in healthy adolescent females.

1.3 **Central Hypothesis**

Neuromuscular exercise will increase hip strength (external rotation and abduction) and increase core stability in healthy adolescent females.

1.4 **Aims**

1. To determine whether healthy adolescent females' participation in a 5-week neuromuscular exercise program will result in an increase in hip external rotation and hip abduction strength.
2. To determine whether participation in a neuromuscular exercise program will increase core stability.
3. To determine whether there is a relationship between gluteal muscle strength and core stability
4. To determine whether there is relationship between gluteal muscle strength and vertical jump performance.

1.5 **Outcome Measures**

Primary = Hip external rotation strength with HHD

Secondary = Hip abduction strength with HHD

Third = Core stability during dynamic stability test

Fourth = Vertical jump power using the Vertec

CHAPTER TWO: LITERATURE REVIEW

2.1 **Physical Activity in Adolescent Females**

According to the Canadian Physical Activity Guidelines, adolescents aged 12-17 should participate in 60 minutes of moderate to intense physical activity daily.[13] This should include more vigorous activities three days a week and also three additional days per week of strengthening exercises.[13] Being active has many health benefits for the adolescent population including increased self-confidence, maintaining a healthy body weight, improved health and help do better in school.[13] The Physical Activity Questionnaire for older children (PAQ-C) is a physical activity questionnaire that evaluates the amount and types of activities that an older child (adolescent) may participate in during a typical week. Normative values for physically active adolescent females on the PAQ-C range between 2.3-2.6.[14] Based on the literature, only 3% of female adolescents aged 12 – 17 years old meet the physical activity requirements.[15]

2.2 **Anterior Cruciate Ligament Injuries in Adolescent Females**

Research indicates that knee injuries pose serious health burdens to athletes of all ages in many sports and represent a significant proportion of lower extremity injuries reported in high school athletics.[16] There are an estimated 150,000 -200,000 anterior cruciate ligament (ACL) tears annually in the United States.[4] The incidence of ACL injuries are higher in competition than in practice; more likely to occur in high impact sport and is more common in female athletes than their male counterparts (when participating in the same sport).[4] Knee injuries are among the most common serious injuries accounting for 60% of high school sport related surgeries.[4] This type of injury results in significant long-term rehabilitation and often requires surgical intervention. Beyond this, data suggests that females are most likely to sustain lower body injuries in basketball and soccer and at 3 to 8 times higher risk of suffering a knee ligament injury.[9] This heightened risk of injury occurs between the ages of 12 to 20 years old.[17] Prevention and preventative programming is important for this demographic because of the impact that these

lower body injuries can have on a competitive career, as well as permanent effects on physical activity.[18] Research indicates that preventative programs show great promise[19], however the availability of data regarding the efficacy of some of these intervention programs is limited for adolescent females suggesting that further research is required in this domain.

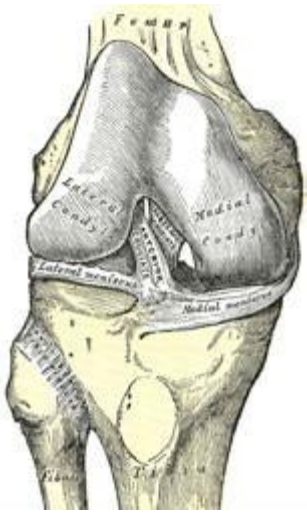
There is significant research which demonstrates the long-term effects of lower body injuries on the adolescent population.[10,16,20–22] This is often referred to "the young patient with an old knee."[21] This evidence is indicative of pain and functional impairment in the young or middle aged adult which results from the development of knee osteoarthritis (OA) due to lower body injuries sustained at a young age.[21] Research shows that injuries to the lower body significantly contribute to the risk of future OA developing in this population.[5,21] This further results in significant pain, antalgic gait patterns, reduction in range of motion, inability to participate in physical activity, changes in activities of daily living and the potential of further surgical intervention and rehabilitation.[5,21]These are serious long-term consequences that adolescent females could face due to their heightened risk of lower body injuries.[23] It is hypothesized that preventative programming such as neuromuscular training could reduce the potential for long term disability in this population as it ages.[24]

Research suggests that hip strength and core stability are factors that can influence injuries to the lower extremity.[25] However, little research has been conducted in the domain of hip strength and core stability, and its relationship to lower extremity balance in an adolescent female sporting population.

2.22 **Anatomy of the Anterior Cruciate Ligament of the Knee**

The anterior cruciate ligament (ACL) originates from the medial aspect of the lateral femoral condyle and inserts on the tibial plateau.[26] The term cruciate translates to cross which is fitting terminology due to the orientation of the ACL as it crosses the posterior cruciate ligament to form an "X".[26] The ACL originates from deep within the notch of the distal femur.[26] Its proximal fibers fan out along the medial wall of the lateral femoral condyle. There are two bundles of the ACL: the anteromedial and the posterolateral, named according to where the bundles insert into

the tibial plateau.[26] The ACL provides 85% of the restraining force to anterior tibial displacement at 30 degrees and 90 degrees of knee flexion.[26] The orientation and direction of the bands of the ACL act as a biomechanical restraint for rotation as well as limiting anterior translation of the tibia on the femur.[27]The combination of active muscle contraction with precise neuromuscular timing assists with knee stability during running, jumping, and cutting or pivoting maneuvers.[27] Any alteration in the biomechanics or muscular control of the knee increases the risk of ACL injury.[27]



https://en.wikipedia.org/wiki/Anterior_cruciate_ligament_injury

Figure 1 – Anterior Cruciate Ligament of the Knee

Due to the nature of most athletic activities involving planting the foot and rotation of the leg, the ACL is highly susceptible to injury.[18] Evidence indicates that individuals with this type of injury are still at risk for injury even after surgical intervention due to poor neuromuscular control and muscular weakness especially in the trunk/ hip region.[7] Trunk neuromuscular control has been identified as an important risk factor for initial ACL injuries.[10] Hip dysfunction may lead to altered knee loading during physical activity, leaving the knee at a higher risk of injury.[21] Lower limb rehabilitation and conditioning programs should emphasize core stabilization and hip strengthening.[28]

2.3 **Mechanisms of Injury**

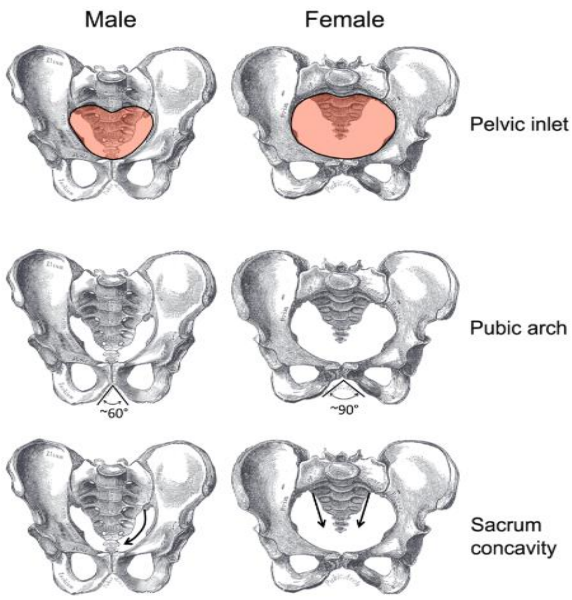
2.31 **Intrinsic & Extrinsic Risk Factors**

Risk factors for lower extremity injury within a female adolescent population can be globally classified into one of two categories: 1. intrinsic and 2. extrinsic . Examples of intrinsic risk factors are Body Mass Index (BMI), age/pubertal maturation, hormonal levels, and structural differences such as Q-angle of the hip, pelvic structure, and sacral angle.[29] Muscular strength including muscular imbalances are additional potential intrinsic factors.[30]

Extrinsic factors are external to the body itself and can include effects such as type of sport (contact vs non-contact), position in sport, level of competition, environmental factors, poor training or improper techniques, training surfaces, and equipment or footwear.[31]

2.32 **Anatomy of the Female Hip and Pelvis**

It is well documented that there are anatomical differences between the male and female pelvis and hip region (*see Figure 2)*[32] These differences have been evaluated for their potential involvement in contributing f to increased risk of ACL injury in female athletes during sport participation.[32] This exploration is additionally important for female adolescents during times of accelerated physical maturation, as it has been reported that they demonstrate increased knee valgus motion in sport movements such as landing and cutting.[24,28,32,33] This increased valgus force through the knee when loaded during push off or when landing can lead to the knee being susceptible to injury.[34] Female adolescents most commonly sustain ACL injuries from non-contact mechanisms such as this valgus force at the knee joint.[11] It has been hypothesized that an increase in hip strength and core stability could reduce knee valgus during movements and in turn, lowers the risk of injuries to the lower body in this population.[32]



https://courses.lumenlearning.com/ap1x94x1/chapter/the-pelvis/

Figure 2– Anatomy of the Female Pelvis

It has been hypothesized that static alignment of the hip of an increased Q Angle is related to an increased pelvis width.[35] Static Q angle measures do not appear to be predictive of either knee valgus or ACL injury risk during dynamic movement, thus supporting further exploration of other dynamic neuromuscular factors which may influence Q angle and their role in limb alignment during landing and cutting appear to be warranted.[36]

2.33 **Jumping Mechanics and Knee Injuries**

Landing from a jump often results in a dynamic knee valgus position with abduction about the knee.[31] Research demonstrates that females have an increased risk of these types of ACL injuries.[10] Zazulak et al. further discuss that "During landing, females demonstrate greater hip adduction and internal rotation, which create a valgus alignment and external rotation at the knee (a generalized lower extremity valgus position) and potential forefoot pronation."[10]

2.34 **Knee Proprioception in Adolescents**

As interventions aimed at injury prevention or reduction are unlikely to influence the above mentioned anatomic factors and further hormonal factors, many research and clinical efforts are focused on neuromuscular etiologies over which clinicians may have some influence.[10] Knee proprioception is often evaluated in order to determine its contribution to lower body injuries.[37] Proprioception is globally defined as sensory awareness of joint movement and position, and is also sometimes referred to as kinesthetic awareness or kinesthesia (movement sense).[20] Proprioception is typically trained through balance and perturbation training.[20] This is derived from the vestibular system of the human body and can be trained using a wide variety of interventions: bilaterally (2 legs) to single leg; eyes open to eyes closed; uniplanar to multiplanar movements; or positioning to dynamic combinations of all of the above.[38] Examples of tools to implement proprioceptive training include: Roller board, Rocker board, and Tilt-board. Proprioception provides awareness of movement and position of the body.[20] Proprioceptive sensations are usually subconscious providing information regarding joint position and the tension of the tendons and muscles. Proprioception is further described as the sense of position and movement of parts of the body relative to one another, and the sense of force and effort associated with muscle contraction.[39] Kinesthesia may also be used to describe this, however it is more strictly understood to be referring to the sense of movement.[39] Proprioception can be achieved through a summation of peripheral sensory input describing the degree of, and changes in, muscle length and tension, joint angle, and stretch of skin which may originate from a number of sources.[39] The literature demonstrates that the sense of muscle tension has been largely attributed to Golgi tendon organs, responding to force generated by the muscle.[39] This information is combined with input from vestibular apparatus of the internal ear resulting in awareness of the orientation of the body and limbs in space, independent of visual input.[38]

According to Magee, proprioceptive ability is assessed through motion related tests such as the stork standing test.[38] This is a single leg standing test which will demonstrate a loss of proprioceptive control especially once the eyes are closed. Other possible tests when assessing proprioception are the proprioceptive finger-nose test, the proprioceptive movement test, proprioceptive space test, past pointing test, and heel to knee test to name a few.[38] All the above-

mentioned tests have the patient's eyes closed and the examiner instructing the patient to move the limbs in certain motions therefore recreating the positioning without visual input resultantly testing the proprioceptive or kinesthetic awareness.[38] Programs utilizing proprioceptive training have been used in the treatment of ACL injuries in various populations,[20] however, more research is necessary to determine the effectiveness of the use of proprioceptive training as prevention for these injuries.

2.35 **Muscular Strength Imbalances**

According to a study performed by Zazulak et al., "Dynamic muscular control of knee joint alignment, specifically differences in muscle recruitment, firing patterns, and strength, may be partially responsible for the gender disparity in incidence of ACL injury."[10] It has been demonstrated in previous research, that lack of strength in knee flexion and extension may contribute to ACL injuries.[40] Furthermore, a problematic ratio between the knee extensors and knee flexors has been reported to potentially contribute to ACL injuries.[41] This lack of strength and muscular imbalances are factors in the rehabilitation of knee injures especially in a non-operative setting.[42] When patients demonstrate a positive Trendelenburg sign, this indicates a glut medius and minimus weakness.[7,38] This muscular weakness may contribute to increased knee valgus position in landing.[11,43]

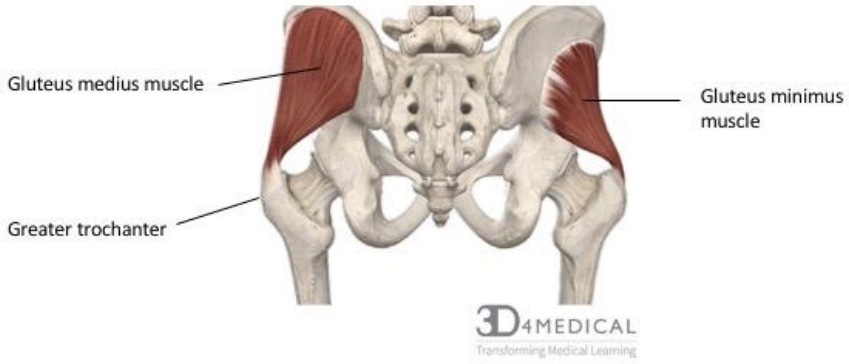
2.4 **Hip Strength**

2.41 **Anatomy of Gluteus Medius and Minimus Muscles**

The muscles of the gluteal region share a common compartment but are organized into two layers; a superficial and a deep.[26] The superficial layer consists of the three large overlapping glutei (maximus, medius and minimus) and the tensor fascia latae.[38] These muscles all have proximal attachments to the posterolateral (external) surface and margins of the ala of the ilium

and are mainly extensors, abductors, and medial rotators of the thigh.[38] The deep layer consists of smaller muscles (piriformis, obturator internus, superior and inferior gemelli, and quadratus femoris) covered by the inferior half of the gluteus maximus.[38]

As the gluteus medius and minimus muscles are the main muscles for the purpose of this study, they will be described in the most detail. These two small muscles are grouped together as they have similar action, orientation, and innervation. Their main actions are hip external rotation and hip abduction. Furthermore, these muscles act as primary hip stabilizers and prevent the pelvis from dropping during gait on the opposite side, which is known as Trendelenburg sign.[38] These muscles originate from the external surface of the ilium between anterior and posterior gluteal lines and inserts into the lateral and anterior surface of the greater trochanter of the femur.[38] Their innervation is the superior gluteal nerve, more specifically (L4, L5, and S1).[38]



https://pressbooks.bccampus.ca/advancedanatomy1sted/chapter/muscles-3/

Figure 3 – Gluteus Medius & Minimus

2.42 The Relationship of the Glutei and the Knee Joint

These glutei function as stabilizers of the trunk over the planted leg and function to power lateral leg movements. Weak hip muscles and alteration of hip/trunk position are a common finding associated with intrinsic knee injuries.[44,45] Weak hip abductors are seen in association with anterior knee pain and chondromalacia.[46] Decrease in hip muscle activity is associated with increased hip varus and hip flexion positioning as well as increased knee valgus positioning in squatting or landing.[24] The gluteus medius and minimus muscles are believed to play a central role in controlling knee valgus movements during take-off and landings.[38]

Several investigations have suggested that decreased hip muscle strength may be associated with greater knee valgus angles, knee valgus moments and loss of frontal plane postural stability.[11,45,47,48] One study performed by Khayambashi et al., indicated that a significant relationship does exist between baseline hip strength and future noncontact ACL injuries.[49] It can be hypothesized that reduced hip strength could be increased through the use of a neuromuscular training program.

2.43 **Testing Methods for Muscular Strength**

There are three primary types of strength testing that are commonly used to evaluate muscle strength in the lower extremity: isokinetic dynamometry, manual muscle testing and hand-held dynamometry.

Isokinetic dynamometry is a widely used tool for measuring muscular strength in clinical intervention programs.[50,51] An isokinetic dynamometer may be used to measure three types of muscular contractions; isometric, eccentric isokinetic, and concentric isokinetic contractions.[52] During an isometric contraction, the resistive dynamometer torque equals the muscular torque such that no joint movement occurs and the muscle length remains constant.[52] During a concentric isokinetic contraction, the knee joint moves at a constant angular velocity.[52] The Biodex is a type of isokinetic dynamometer that is commonly used in knee strength testing

procedures.[50] The Biodex is a tool utilized to assesses isokinetic strength of muscles represented in Newtons of force.[51] Isokinetic strength testing can be described as a concentric or eccentric contraction of a muscle in which the speed and tension are constant throughout the range of lengthening or shortening.[38] Isokinetic strength allows the participant to produce their maximum amount of force exerted against the machine under speed control.[40] Finally, the open kinetic chain nature of isokinetic testing deserves specific comments regarding its ability to isolate the muscle grouping of interest in comparison to closed kinetic chain type exercises such as a more functional movement of a squat.[52]

Manual muscle testing (MMT) is a procedure for the evaluation of the function and strength of individual muscles and muscle groups based on the effective performance of a movement in relation to the forces of gravity and manual resistance.[38] There are some strengths and weaknesses to performing MMT. An example of weaknesses of MMT is potential biomechanical factors from both the patient and the examiner. These biomechanical factors include joint position or angle, tester positioning and tester ability to perform consistently.[53] Benefits of MMT are that there is no special equipment required, it can be performed anywhere and has no additional costs associated with it.[53] Some additional weaknesses are that the grading scale is a subjective measure for the tester, the tester requires to be trained, and the frequency that the tester performs MMT will influence their interpretation of the results.[53]

Handheld dynamometry (HHD) is another form of strength testing that has been shown to be a valid and reliable measuring tool for strength.[54] Although the handheld dynamometer instrument has been shown to be reliable, there are some potential challenges with using such a method such as securing the participant in a stable position when performing the testing.[11] An additional weakness of using HHD is the potential of fatigue despite the use of rest intervals between repetitions.[11] One advantages to using HHD includes its portability, as it is easily transported and can be used to test at various locations.

2.44 **Absolute and Relative Strength**

Hand held dynamometry records isometric strength in Newtons of force which results in an absolute strength measure.[54] Relative strength measures take into consideration the body weight of the participant relative to their strength measure recorded by the hand held dynamometry. As strength is our dependent variable for this study, it is important for statistical analysis to evaluate both absolute and relative strength to ensure the absolute strength measured was representative in relation to their size.

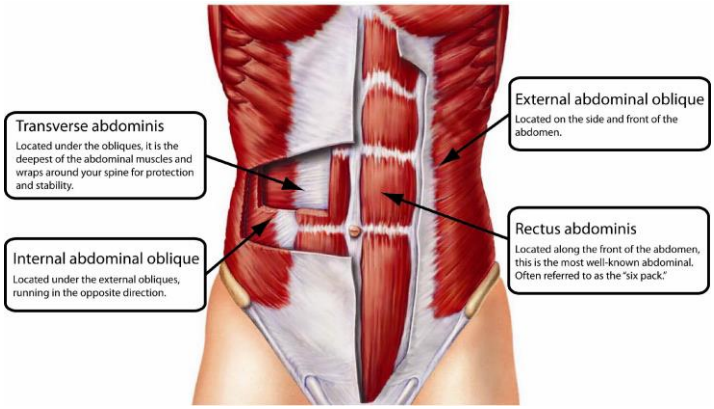
2.5 **Functional Testing**

2.51 **The Anatomy of the Core**

Core stability is a term that can be defined in multiple ways. Within the literature, terms such as core strength, hip strength, core balance, [26]trunk stability and spine stability are often used interchangeably to describe the same measure. In general terms, it refers to muscles that surround and insert into the lumbo-pelvic region which stabilize the trunk and hip and further contributes to the stability of the joints distal to the hip such as the knee joint.[8,47]

The core can further be described as the central, innermost, or most essential part of the muscular system. The muscles associated with core stability are in the trunk of the human body.[25] These muscles link the trunk-abdominal region to the shoulder girdle and pelvic region.[26] Core stability involves all the muscles that stabilize the torso, the muscles that maintain the position of the scapula as well as the lower body muscles that stabilize the pelvis.[26] The combination of all the stabilizer muscles of the body working in good order creates a strong core and a stable base. Example muscles are the abdominal obliques (internal and external), transverse abdominus and multifidus muscles.[26] Additional muscles associated with the core are ilio-psoas, the quadratus lumborum and the erector spinae.[26] Core stability can be described as trunk dynamic control that

allows the production, transfer, and control of forces and movements of the extremities during closed kinetic chain motion.[8]



https://repkefitness.com/blog/transverse-abdominis/

Figure 4 – Anatomy of the Core

2.52 **The Relationship of Core Stability and Knee Function**

The core plays an important role in stabilizing the lower extremity and knee movement during activity.[34] It is said that core activity is involved with almost all extremity activities such as running, kicking, and throwing.[34] Therefore, the position, motion and contributions of the core must be evaluated and treated as part of the evaluation and treatment of extremity injuries.[55] The core of the body includes the passive structures (such as the thoracolumbar fascia and the vertebral column) of the thoracolumbar spine and pelvis, and the active contributions of the trunk musculature.[26] The stability of the body's core is contingent on neuromuscular control of the trunk in response to internal and external forces, including forces generated from distal body parts and from expected or unexpected perturbations.[12] Deficits in core neuromuscular control may contribute to unstable behavior and injury throughout all segments of the kinetic chain.[47] Impaired core control affects control of the knee and may lead to knee injury.[34] Interventions that incorporate core training, including proprioceptive exercises, may significantly reduce knee injury risk in athletic population.[10]

Dynamic stability of an athlete's knee depends on accurate sensory input and appropriate motor responses to meet the demands of rapid changes in trunk position during cutting, stopping, and landing movements. Dynamic stability may be operationally described as the ability of the knee joint to maintain position (static stability) or intended trajectory (dynamic stability) after internal or external disturbance.[42] During these activities, the core muscles act synergistically to stabilize the trunk and hip and contribute to the stability of more distal joints including the knee joint.[12] Core stability, a critical component of the entire body kinetic chain, is especially important during unexpected dynamic situations, where insufficient control of the core may affect the control of other joints through the multi-segment system and possibly lead to injury at other joints.[34]

2.53 **Testing Methods: Core Stability**

The core can be tested by how it holds the spine in a stable position.[34] Core stability was measured by how the core musculature held the spine dynamically, or how the core maintained its position which is recorded by errors conducted.[34]

Different investigators have used different techniques to try to gauge the relative strengths of specific core muscles via electromyogram data and isometric dynamometer values.[22] Any evaluation technique needs to take into consideration that the muscles should be tested in functional positions when possible. In order to assess all of the different muscles that function together to provide core strength, evaluation of specific motion patterns and quality of movement may be done.[55] There is no consensus regarding the most reliable or reproducible evaluation system for core stability.[34]

Core stability can be measured by putting the trunk in an unstable situation where it is required to hold a set position isometrically. Examples of this type of measure are performed via the plank, V-sit or trunk stability test.[34] A review of literature indicated the use of tests such as the McGill's Core endurance test which has multiple categories such as anterior trunk flexion, lateral muscular plank test and posterior trunk extensor test.[11] A weakness noted for this test is its inability to secure the participant in these various positions.[11] It was deemed for the purpose of

the testing of the study that this multiple step core test would not be appropriate for our testing protocol as it was not our primary outcome measure. The Plank is a test of static endurance of the trunk muscles and is performed in various stages of time trials based on sport specific requirements.[56] A V-sit is a static endurance test similar to the plank test however the muscles being evaluated for endurance are the hip flexor muscles and the rectus abdominus.[11] Performing crunches is a method of testing abdominal muscle strength and may be performed in a variety of ways in order to isolate specific regions of the abdominal muscles.[57]

Typical core stability values can be ascertained from different testing methods and often are evaluated by the ability to perform the test, the number of errors committed and the symmetry of the performance.[58] Furthermore, core stability can be assessed through measures of endurance as well as evaluating isometric strength of the involved musculature.[59] Normative data indicates that a healthy adolescent female should be able to hold a standard plank for 1 minute.[59] Results of a study evaluating core stability via standard plank indicated that on average males were able to hold the plank for more time in comparison to females, that athletes were able to hold the plank for 50% longer than non-athletes and that college aged females were able to hold the plank longer than adult females or adolescent females.[59]

2.54 **Training Methods for Core Stability**

Core stability may be trained using several different exercises targeting movement or stability of the trunk such as crunches, V-sits, planks, and various forms of crunches and twisting motions.[55] Core stability is best measured by one's ability to stabilize in a position for a period of time. Research suggests that the longer you are able to hold a stable position without errors, the more stable your core.[11,47]

2.55 **Vertical Jump Measurements**

Vertical jump testing is commonly used to measure lower extremity power.[43] Furthermore, it may be used to estimate sports performance capabilities and physical fitness in children, elderly,

non-athletic and injured individuals.[60] The Vertec is a commonly used tool to assess vertical jump height as a measurement of power.[60] It is a cost effective, quick and accessible method to test vertical jump.[60] Vertical jump can be assessed without using the Vertec by measuring jump height against a measuring tape on the wall. The jump can be performed from a standstill, with a single step, with a 3-step approach or with a running approach.[60]
Vertical Jump was chosen as this study was part of a larger study involving participants with ACL injuries, it has been demonstrated that the static nature of this type of jumping test is safe for those who have sustained knee injuries (non-acute phase)[31]

2.57 **Vertec Vertical Jump Testing**

This vertical jump test assesses bilateral as well as unilateral jump height measurements. The Vertec as a tool allows for consistent measurements from one participant to another.[60] This tool is easily stored and is also transportable which was a significant benefit for participant recruitment. The Vertec is a widely used and accepted tool for measuring vertical jump height.[60]

2.6 **Neuromuscular Exercise Training**

Neuromuscular exercise can be defined as sensory awareness exercises using joint movement in which kinesthetic awareness or kinesthesia (movement sense) are challenged.[10] It is typically developed through balance and perturbation training, and involves the vestibular system of the human body.[10] Training progressions can be done bilaterally or unilaterally, be done with the eyes open or eyes closed, involve uniplanar and multiplanar movements, or positioning that involves dynamic combinations of all of the above.[20] Beyond this, neuromuscular exercise training may also involve the use of proprioceptive training devices such as a Roller board, Rocker board, or Tilt-board.[20]

Neuromuscular exercise can also be accomplished through perturbations.[22] This specialized form of neuromuscular exercise incorporates systematic translation of support surfaces with tactile and verbal cues to elicit selective lower extremity muscle contraction while balancing on a support surface that a trained professional perturbs.[22] Perturbations improve movement patterns during gait and dynamic knee stabilization.[22] Perturbations can further be described as a deviation of a system, moving object, or process from its regular or normal state or path, caused by an outside influence.[22]

Perturbation-based balance training is an intervention involving repeated postural perturbations aiming to improve control of rapid balance reactions which often incorporate balance boards.[4442] The perturbation drills utilized for the purpose of this study demonstrated the three techniques: rocker board, roller board, and roller board with stationary platform.[22]

Fitzgerald et al. (2000 a); Proposed practice guidelines for non-operative anterior cruciate ligament rehabilitation of physically active individuals were among the first researchers to develop and describe a structured neuromuscular exercise training intervention program involving perturbations, which targeted lower body muscle strength and proprioception in individuals that had suffered an anterior cruciate ligament injury.[9] The purpose of this training protocol was to establish a non-operative intervention following anterior cruciate ligament injury to restore participants to pre-injury levels of physical activity. Since then, this protocol has been widely adopted for evaluating strength and balance in physically active populations at risk of lower body injury during sport participation.[9,61,62]

There are some advantages or strengths to this protocol. It is easy to administer and it is safe for participants with ACL deficiencies.[28] Furthermore, this program is easily transportable as the necessary equipment is minimal. The sessions can take place in any location with sufficient space for balance training with perturbation and additional variables added as the program progresses. The neuromuscular exercise sessions are well suited for an adolescent female population and are safe.[22] Finally, this neuromuscular training program is a timed pre-set program which is simple to administer and train administrators which increases its reliability significantly when compared to other similar programs.[28]

Currently within the literature, neuromuscular training has been used in rehabilitation in both male and female ACL injured adults.[22] Data indicate that NME helps to enhance the probability of successful return to high-level physical activity in this adult population after sustaining an ACL injury.[21,43] NME has also been evaluated as a performance enhancement technique in the athletic population.[46] A review of literature indicates the effectiveness of NME based training protocol for ACL injured athletes, when used as fall prevention and during the rehabilitation of an elderly population recovering from hip injuries and overall has been demonstrated to be effective in enhancing performance in an athletic population.[42,62,63] To date, there is limited information available on neuromuscular exercise in an adolescent female population, and specifically whether it can be used to enhance hip external rotation strength, hip abduction strength, core stability and functional performance during vertical jump.[24]

2.61 **Perturbation Training Rational**

There are many reasons for which perturbation training was chosen for our study pertaining to lower body injuries. It is simple to implement, there is little space and equipment required to perform this neuromuscular training program and the equipment is easily acquired. It was theorized that this particular program will not only be working proprioception but also has the potential to train hip and core strength at the same time.

2.62 **Typical Neuromuscular Training Programs**

There are several established NME type training programs such as the FIFA 11+, vibration platforms and perturbation -based programs.

FIFA 11+ is an injury-prevention program which has been specifically designed to prevent soccer injuries.[63] It was developed by a panel of international experts to build on earlier injury-prevention efforts.[63] The program was established as a warm up neuromuscular training program which includes running exercises, dynamic stretching, plyometrics, agility, strengthening and

balance exercises which takes twenty minutes to complete and is designed to be performed twice a week with no specific equipment is needed.[63] This program is largely utilized for amateur soccer players, as well as college aged athletes, both male and female.[63] FIFA 11+ is described as a neuromuscular training program however it also has exercises for cardiovascular warm up, plyometric training as well as agility which can have an impact on various other health related prevention measures depending on the demographic being evaluated.[64] A review of literature demonstrates that FIFA 11+ has been widely accepted as having an impact on decreasing injury rates and results in injury prevention.

There is evidence of its success in reducing injuries more specifically a reduction in injuries injuring in soccer, and further research has shown a reduced rate of injury across other sports like elite basketball as well.[64] Additional benefits noted have been performance enhancement, improved neuromuscular control, increasing functional balance, along with improving jumping and agility results.[63]

It was concluded that this neuromuscular training protocol was not a good fit for the purpose of our project due to the fact that some of our potential participants will have suffered an injury to their lower leg, more predominantly their ACL. This training protocol is too dynamic and unsafe for those who have recently suffered from an ACL injury. Further research is required to define female adolescent groups.

Another method of performing NME is via vibration platforms. Whole-body–vibration (WBV) training is a form of neuromuscular training that has been increasingly used as a preventive and rehabilitative tool via an oscillating vibration platform which produces fast and short-term changes in the length of the muscle-tendon complex, activating the primary endings of the muscle spindles that could elicit the tonic vibration reflex.[64] A review of literature demonstrate that these physiological changes could lead to effective proprioceptive feedback, thereby improving balance ability and the active protection mechanism.[64] These improvements have been reported in those with ankle injuries as well as those with unstable ankles in college aged athletes both male and female.[64] Some downfalls to these vibration platforms are the expense of the equipment, the calibration of the machine, the lack of portability of the equipment as well as a general lack of training to properly use the equipment.[64]

Perturbation based programs have been used as NME programs as it is easily administered, is progressive in nature, engages dynamic stabilization involving both coper and non-coper mechanisms of neuromuscular control.[44] Research has shown that perturbation-based programs have demonstrated to be effective in increasing proprioception as well as increasing strength in the surrounding musculature in the involved joint being evaluated.[44] Perturbation based programming is transportable, easily demonstrated for those to create the disturbances and is safe for those recovering from injuries.[22] For these reasons, perturbation based programming has been used during treatment and prevention of injuries for a variety of ages, a variety of sport participation as well as level of performance in both males and females.[44]

CHAPTER THREE: METHODOLOGY

3.1 **Hypotheses**

Null Hypothesis = Participation in an NME training program will result in no increase in hip strength and core stability within an adolescent female population compared to a control group.

Hypothesis = Participation in an NME training program will result in an increase in hip strength and core stability within an adolescent female population compared to a control group.

3.2 **Aims**

Primary= To determine whether an NME training program will have an effect on hip strength (hip external rotation & hip abduction)

Secondary = To determine whether an NME training program will have an effect core stability

Tertiary = To determine whether there is a relationship between hip strength and scoring on vertical jump or core stability testing.

3.3 **Outcome Measures**

Primary = Hip external rotation strength

Secondary = Hip abduction strength

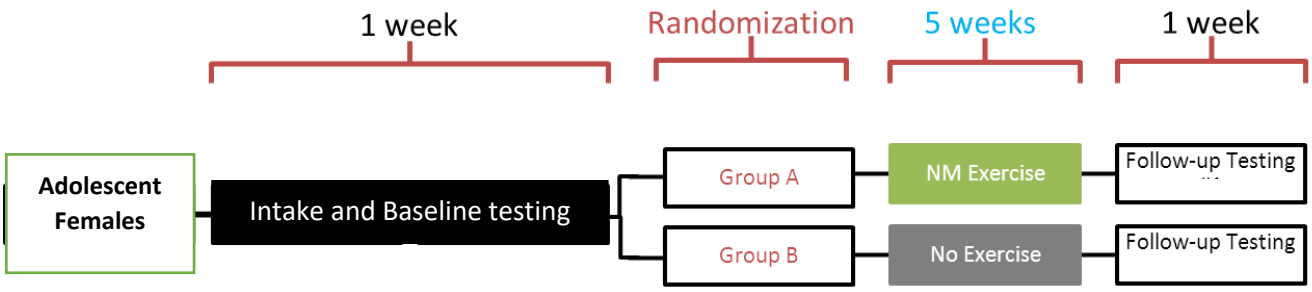
Third = Core stability

Fourth = Vertical jump power

3.4 **Study Purpose**

The purpose of this study was to examine the effect of a perturbation-based NME program on hip strength and core stability in healthy adolescent females. Specifically, the study had the following objectives: 1. Determine whether completion of a 5 week NME training program would affect hip strength as measured using hand-held dynamometry; 2. Determine whether completion of a 5 week NME training program would affect core stability; 3. Determine whether changes in strength following completion of a 5 week NME would correlate with changes in core stability; 4. Determine whether changes in strength following completion of 5 weeks of NME would correlate with changes in vertical jump results.

3.5 **Study Design**



The study was a 7-week Randomized Clinical Trial which employed a repeated measures design. Following initial intake and baseline testing, participants were randomized into 2 equal groups: Group A completed a 5-week NME training intervention; Group B served as the control group.

This study was a portion of a larger study being conducted on adolescent females with ACL deficiencies. The purpose of the larger study was to examine the effect of an established NMT program on knee joint function in skeletally immature healthy and ACL-deficient individuals.

3.51 **Sample Size**

A sample size calculation was performed based on normative data for the primary outcome measure of hip external rotation strength. A standard deviation of 8 was observed from normative data on hip strength testing with handheld dynamometry. Using an alpha = 0.05 and a beta = 0.20, as well as a sample size increase of 20% to account for withdrawal from the study, an estimated sample size per group is: n=2{(1.96+0.84) 0.33/0.22} x 1.20 = 42.336.[65] participants.

Therefore 42 healthy and physically active adolescent female participants were recruited for this study (21 neuromuscular exercise, 21 non exercise group).

3.52 **Randomization**

Randomization was performed for all 42 participants to place them into one of the two groups – Group A = NME training group: Group B = control group. The randomization took place at the end of the baseline testing to determine if the participant would continue to perform the NME training program or return after a 5-week waiting period to perform follow-up testing.

The randomization technique used was the block randomization method. Participants were randomized into groups of control and intervention that each result in equal sample sizes.[65]

3.53 **Ethics Approval**

The study was approved by the University of Manitoba Health Research Ethics Board ***HS20283 (B2016:110).***

3.54 **Participant Recruitment**

A total of forty-two healthy adolescent female participants were recruited from the general patient population of the Children's Minor Injury Clinic at Pan Am clinic, local orthopedic surgeons, physicians, community sports clubs, and local schools. Advertisements were placed around the facilities, and presentations and circulation of project information were done through physicians, surgeons, and therapists as a referral process.

3.6 **Inclusion Criteria**

1. Healthy female adolescents ages 12 to 18.
2. Pass the PAR-Q.

3.61 **Exclusion Criteria**

1. Recent history (within the last 6 months) of a traumatic head (concussion), hip, knee, or ankle injury.

3.7 **Testing Protocols**

See appendix for copy of forms described below

Baseline and follow-up testing were conducted at the Pan Am Research facility by the primary and/or secondary research investigator and included the following forms and procedures for both the control and NME training groups. These testing sessions included completing Consent and Assent forms, the PAR-Q, PAQ-C, and the PMOS, followed up by testing procedures which will be discussed in greater detail below. These two testing sessions lasted approximately one hour

each in duration with some parents waiting and some of the older consenting participants coming on their own. The participants were screened by the primary research investigator once referral had occurred and then booked for baseline testing which usually would occur within a week of the referral and screening process. At both baseline and follow-up testing, the participants would enter the testing session and begin by completing the consent forms and filling out all questionnaires. They would then change into exercise clothing and begin with a 5-minute warm up on a stationary bike. Both the baseline and follow-up testing occurred in the same order and the same researcher assessed the same participant at baseline and follow-up. Upon completion of the warm-up, the participants would proceed to the demographic data collection, which was then followed by anthropometric measurements. They then would perform the HHD strength testing, followed by the core stability testing and finish with the vertical jump test.

3.71 **Questionnaires**

Physical Activity Questionnaire for older children (PAQ-C):

The PAC-Q is a self-administered, 7-day recall questionnaire that measures general physical activity levels in children ages 8-14 years.[66] Validity and reliability of this assessment tool has been established.[13,14,66] In order to evaluate physical activity readiness of the participants recruited, the physical activity questionnaire for children (PAQ-C) was administered.[14] Normative values for healthy physically active adolescent females on the PAQ-C ranges between 2.3-2.6.[14]

Pubertal Maturation Observational Scale (PMOS):

The PMOS is a self-administered, self-observational scale rating state of pubertal development.[67] The PMOS categorization is based on 8 secondary sex characteristics such as muscle development, increased perspiration with physical activity, acne, facial or body hair, deepening of the voice, menarche and breast development, in addition to parent report of less obvious characteristics such as growth spurt.[67] Based on the number of items identified on the PMOS questionnaire, participants were classified as follows: 1 or less: pre-pubertal; 2-5 with growth

spurt: pubertal; 6 or greater with growth spurt completed: post-pubertal.[67] A growth spurt was defined as an increase in height of 3 to 4 inches in the past year.[3,68–70]

3.72 **Anthropometric measurements**

Anthropometric measurements included height (centimeters) and weight (kilogram) which were used to calculate BMI [height(cm)/ weight(kg)²] Leg length measurements were measured from the ASIS to the medial malleolus on the same leg and was recorded on bilaterally. Leg girth measurements were measured at the knee joint line circumference, 6 inches above the knee joint line and 6 inches below the knee joint line also performed bilaterally and recorded. Active knee range of motion was recorded bilaterally using the goniometer with the goniometer axis as joint line, the stationary arm aligned with femur and the moveable arm aligned with the fibular head. Knee flexion and extension were measured three times and an average was calculated of the three trials. All anthropometric measures were recorded at baseline and at follow-up.

3.73 **Strength Testing**

Hand-Held Dynamometry

Hand-held dynamometry (HHD) is a valid and reliable measure of isometric muscle strength in adolescents.[71] The "make-test" method, in which the examiner holds the dynamometer stationary while the subject gradually builds resistance for a 5 second push against the dynamometry, is preferred for use with adolescents as it is more reliable and comfortable.[71] Standardized positions to assess the hip external rotators, hip abductors (gluteus medius and minimus), knee flexors (hamstrings), knee extensors (quadriceps) and ankle plantar flexors (gastrocnemius-soleus complex) were utilized.[72] In order to test hip external rotation strength, the participant was positioned the following way. Using the Biodex machine for stabilization the participant was positioned in a seated position strapped into Biodex with knees bent at 90 degrees with the HHD placed on the medial aspect of the lower leg. When testing hip abduction strength, the participant was positioned in a side lying with the HHD positioned on leg slightly above the knee on the

lateral aspect of the femur. Testing of knee flexion and extension had the same participant set up with the placement of the HHD either being placed on the front of the ankle joint or posteriorly on the Achilles tendon region: using the Biodex machine for stabilization, sitting strapped into Biodex with knees bent at 90 degrees. Finally, the ankle plantar flexion strength was measured the following way: participant seated on the treatment table in an upright position, legs straight with knees in extension, the HHD was placed on the ball of the foot with the participant pushing down simulating a gas pedal movement. Three attempts of HHD measurements were conducted for each muscle group. Strength was measured in Newton-Meters, and the average results for each muscle group were used for analysis. [10,10,12,71,72]

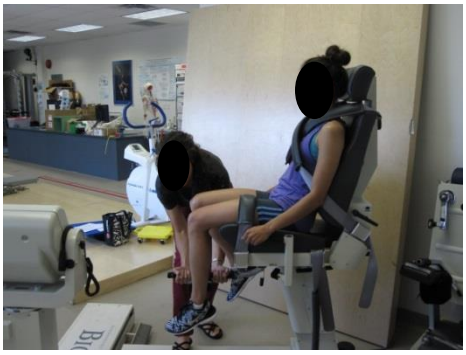


Figure 5. HHD Hip External Rotation Strength Testing



Figure 6. HHD Hip Abduction Strength Testing

3.74 **Core Stability**

Core Stability Test

The core stability test is a valid and reliable test for determining core stability.[7] This test is an unstable trunk sitting test performed on an exercise ball beginning with both feet planted on the ground, the hips and knees at 90 degrees flexion. During testing, the participant's arms were folded across the chest and the individual was sitting up straight. Their eyes were kept open for the practice trial; then the test was performed bilaterally with eyes open and then repeated bilaterally with eyes closed each trial counted for 30 seconds per leg. This core stability test records the number of errors which occur while the individual attempts to maintain this position for the 30 seconds of the test. Examples of possible errors are the foot touching the floor, the arms coming uncrossed, the individual opening their eyes or the individual reaching for the wall/chair located beside them. The individual was instructed to try to maintain this position and to return to this position as quickly as possible once an error had occurred as the 30 seconds continued despite an error occurring. The individual has the choice of which leg to begin the test and then alternates legs in between trials. The total numbers of errors per leg were recorded for each participant; a maximum of 20 errors resulted in a complete failure on the test.[7]



Figure 7. Core Stability Test

Equipment required: stability ball, client in athletic clothing and runners
Description: 65 cm exercise ball (knees and hips at a 90/90 position), place a chair/wall on either side to assist with stability, sit on exercise ball with ankles in a neutral position with feet on the ground, hip and knees flexed at 90 degrees, cross arms across chest, lift one foot slightly up and forward (client to choose which one to begin with) recording number of errors, alternating legs in between each trial
Errors = counted by any breaking from this position, 1 point per error
6 possible deviations/errors
1. Lifted foot touches the ground
2. Arms reach for something for stability
3. Their planted foot begins to shift
4. Arms come uncrossed (but do not touch anything)
5. Rest the lifted knee against planted leg
6. Open their eyes
* additional errors if unable to return to test position within 1 second[54]

3.75 **Functional Performance**

Functional performance was tested by evaluating vertical jump scoring from "Vertec" testing.[73] Investigations of double-leg and single-leg vertical jump height using "The Vertec" which is a widely used commercial device to measure the vertical jump height, are routinely used to calculate the difference between standing reach-height and the maximal vertical jump reach-height.[73,74] After measuring standing reach-height, participants performed three maximal effort jumps: a double-leg take-off, and a single-leg stance take-off for each limb. The order of the testing was standardized for all participants as follows; double-leg take off trials were first followed by single-leg stance take-off starting with the participant's dominant limb which was determined during initial evaluation by self-report. The average of 3 test trials for each of the methods was used for analysis.
Vertical jump performance was assessed bilaterally with a stationary double leg jump and unilaterally with a single foot static jump which is repeated on both limbs.[43]

Functional performance of the lower body is furthermore often assessed with the broad jump technique as well as the single leg hop test.[43,75] These functional tests involve dynamic movements whereas the vertical jump test is a static jump test assessing power and therefore is most often used when discussing lower body injuries for safety reasons.[43]

3.8 **NME Training Program**

Neuromuscular Exercise Training Sessions

The Neuromuscular Exercise Training protocol used during this investigation was a supervised, progressive program in which the participants maintained balance on three different support surfaces while a clinician administered purposeful manipulations of the support system.[9] The patient maintained a single-leg stance on the roller board and tilt board surfaces, and a two-leg stance with one foot on a roller board while the other was on a platform. Participants randomized to Group A completed two training sessions per week for five weeks for a total of 10 training sessions. During each session, both legs received training for 2-3 sets of 1-minute duration on each of the support surfaces. Participants completed all training sessions under the supervision of a Certified Athletic Therapist or Physiotherapist at the Pan Am clinic. Over the 5-week training period, the NME program used the following progression:

Technique	*Sets/Duration*	*Direction of Board Movement*	*Application*
Rocker board 	2-3 sets 1 min each	Anterior/Posterior, Medial/Lateral	Begin in bilateral stance for 1st session; perform single-leg stance for remaining sessions
Roller board/platform 	2-3 sets 1 min each	Initial: Anterior/Posterior, Medial/Lateral Progression: Diagonal, Rotation	Subject force is counter-resistance opposite of roller board, matching intensity, and speed of application so roller board movement is minimal; leg muscles should not be contracted in anticipation of perturbation, nor should response be rigid co-contraction
Roller board 	2-3 sets 1 min each	Initial: Anterior/Posterior, Medial/Lateral Progression: Diagonal, Rotation	Begin in bilateral stance for 1st session; perform single-leg stance for remaining sessions. Perturbation distances are: 2.54-5.08 cm (1-2in)

Early phase (Sessions 1-4)

Treatment Goals:

- Expose subject to perturbations in all directions
- Elicit an appropriate muscular response to applied perturbations (no rigid co-contraction)
- Minimize verbal cues

Middle phase (Sessions 5-7)

Treatment Goals:

- Add light sport specific activity during perturbation techniques
- Improve subject accuracy in matching muscle responses to perturbation intensity, direction, and speed

Late phase (Sessions 8-10)

Treatment Goals:

- Increase difficulty of perturbations by using sport-specific stances
- Obtain accurate, selective muscular responses to perturbation in any direction and any intensity, magnitude, or speed

3.9 **Methods of Statistical Analysis**

3.91 **Block Randomization**

Block randomization (also known as randomized block design) is a method in research design used to select and divide participants into different groups or conditions in order to avoid selection bias.[65] It ensures that participants are assigned to conditions or groups with equal probability.[65] For this study, randomization was performed at the end of the baseline testing session. A block of numbers that would then be associated with a participant would randomly be assigned. Once the participant completed the baseline testing and consented to participate in the study, they were assigned a number which had already been randomized into the groups of either control or NME. The participant was handed a small envelope with their randomly assigned number which contained the assignment of either control or NME. This allowed the randomization to be completely blinded as per the outlined research design.[65]

3.92 **Goodness of Fit Testing**

The goodness of fit testing is observed in order to determine if your data corresponds with the values expected by the established hypothesis.[65] It is a statistical model that describes how well it fits a set of observations.[65] Measures of goodness of fit typically summarize the discrepancy between observed values and the values expected under the model in the hypothesis.[76]

3.93 **Normality Distributions**

When performing statistical analysis, an important step is to determine if your data is normally distributed. Data that is normally distributed will appear symmetrically distributed about the mean with 95% of all results appearing within 2 standard deviations of the mean value.[76] Overall, a normally distributed data set provides confidence that outlying data (i.e. the data that is more than two standard deviations away from the mean) are in fact significantly different from a majority of the observed values in the data set.[65] When your data is normally distributed to the

mean, this will increase the strength of your study and your potential results during your data analysis.[76] If continuous data follows normal distribution, then the mean value is presented which can then be utilized to compare groups and calculate significance.[76] The normal distribution further is where most of the scores fall in the middle of the scale and progressively fewer fall at the extremes.[65,76]

3.94 **Shapes of Distributions**

When analyzing normality, the results of the analysis representing the distribution among the mean will be demonstrated with a bell-shaped curve. Different arcs may occur based on the skewedness of your data. When data is normally distributed, a typical bell shape curve will be demonstrating the distribution of the data set about the mean.[76] If the data is represented in a bell-shape that is also symmetric about the mean it is assumed that the data is normally distributed.[76] Other representations graphically demonstrate departure from normality. When the data is positively skewed (skewed to the right) most of the scores cluster at the low end and only a few scores at the high end have caused the tail of the curve to point toward the right.[76]When the tail or the skewedness is distributed negatively to the left.[65,76]

Normal distribution may further allow the assessor to evaluate the possibility of Type 1 or Type 2 errors. Type 1 error is the rejection of a true null hypothesis (false positive) whereas the Type 2 error is the non-rejection of a false null hypothesis (false negative).[65] When the data is normally distributed, there is less than 5% probability of committing the above-mentioned errors.[65]

The highest point of the curve is representative of the mean, mode or median. When the curve is more traditionally bell shaped, as mentioned previously, this is representing that the data is normally distributed among the mean, mode or median. When your arc is flatter or less bell shaped, this is an indication that your data is more spread out and not close to the mean, mode or median. The flatter the curve, the larger the distribution i.e., further away from the mean which indicates that the data is less distributed around the mean. This would result in your data not being normally distributed and being further away from the mean. When the data is normally

distributed the mean, mode and median will be equal, however once the data is further distributed away from the mean, the mode and median will no longer be even.[65]

3.95 **T-Tests**

T-test are used during analysis as the test of the null hypothesis which indicates that the two groups being compared are equal.[65] Data analysis using paired t-test is utilized when evaluating measurements in the same individuals whereas independent sample t-tests evaluate a comparison of two different groups which is what was utilized for analysis.[65] When discussing analysis using paired and unpaired t-tests, we must discuss the possibility of type 1 or type 2 errors. A type 1 error is the rejection of a true null hypothesis and can be known as a "false positive", while a type 2 error is the non-rejection of a false null hypothesis and can also be known as a "false negative".[65] Some methods of minimizing the possibility of such errors are selecting a low threshold (cut-off) value and modifying the alpha (p) level, which can increase the quality of the hypothesis testing.[65]

3.96 **Correlations**

Correlation testing is used in order to evaluate whether there is a relationship between two measures. In the current study, we evaluated the relationship between our primary outcome measure of hip strength and core stability, and hip strength and vertical jump. Pearson's Correlations are utilized for numerical data.[65] Results from data analysis can range from 1 to -1, 0 indicating no relationship and a result of 1 would indicate a strong relationship.[65]
Data analysis was performed using Pearson's correlation testing to determine the R values which are presented with the associated symbol to the group it is representing. Correlation coefficients above 0.80 were believed to be representation of a strong relationship between variables.[65] A P value of equal to or less than 0.05 was representative of statistical significance.[67]

3.97 **Two-way ANOVA**

First it is important to differentiate between parametric and non-parametric tests. Parametric tests require that the assumptions of normality and homogeneity of variance be met to a reasonable degree for validity of analysis. Nonparametric tests for group comparisons without normality or variance assumptions are also known as distribution-free tests.[65]

Two-way ANOVA analysis is a mixed design method. With a two-factor analysis, there is a combination of between-participants or independent factors and within participants or repeated factors analysis. Two-way ANOVA is a statistical technique wherein the interaction between factors can be determined.[65]

CHAPTER FOUR: RESULTS

4.1 **Demographic data**

Table 1. Demographic Data at Baseline

Demographic	Control	NME Training	Total
Number of Participants	N= 20	N = 20	N = 40
Age (years)	14.8±1.6 (12.0- 17.0)	14.2±1.6 (11.0-17.5)	14.5±1.7 (11.0 -17.5)
PMOS (0-8 scale)	6.2±1.8 (2.0-8.0)	6.1±1.8 (2.0-8.0)	6.1±1.8 (2.0 -8.0)
PAQ-C (0-7 active days)	2.4±0.9 (1.0-4.3)	2.6±0.7 (1.2-3.9)	2.5±0.8 (1.0-4.3)

Mean ± SD: range in brackets
PMOS = pubertal maturation observational scale (pre (0.0-3.0) – mid (4.0-5.0) – post pubertal (6.0-8.0))
PAQ-C = physical activity questionnaire for older children (mean of all answers = level of physical activity)

Demographic data for all study participants are presented in Table 1. Two participants were lost from the study due to injury and lack of ability to attend sessions after baseline testing resulting in a total of 40 athletes. Independent samples t-tests indicated that there were no significant differences between the control and NME training groups at baseline ($p>0.05$). Additionally, no significant differences were observed when comparing each group's baseline and follow-up data for the pubertal maturation scale (PMOS) as well as the Physical activity questionnaire (PAQ-C).

4.2 **Anthropometric Data**

Table 2. Anthropometric Data at Baseline

Anthropometric parameter	Control	NME Training	Total
Number of Participants	**N= 20**	**N = 20**	**N = 40**
Height (cm)	163.6 ± 6.3 (153.0-177.0)	163.9 ± 5.6 (150.0-176.0)	163.8 ± 6.0 (150.0-177.0)
Weight (kg)	59.2 ± 10.8 (43.5-77.5)	61.3 ± 15.6 (37.0-106.0)	60.3 ± 13.5 (37.0-106.0)
BMI (weight(kg)/height(cm)^2)	22.0 ± 3.4 (17.5-27.9)	22.7 ±4.9 (16.4-34.2)	22.4 ± 4.2 (16.4-34.2)
Knee circumference (cm)	34.3±2.1 (31.0-39.0)	35.6±3.1 (30.0-43.0)	34.9±2.7 (30.0-43.0)
6 inches above knee leg circumference (cm)	46.0±5.1 (39.0-55.0)	46.5±6.7 (37.0-60.0)	46.2±6.0 (37.0-60.0)
6 inches below knee leg circumference (cm)	34.0±3.6 (30.0-45.0)	33.8±3.5 (27.0-41.0)	33.9±3.6 (27.0-45.0)
Leg length – right (cm)	87.1±4.6 (77.0-99.0)	87.1±3.6 (80.0-95.0)	87.1±4.1 (77.0-99.0)

Mean ± SD: Range in brackets

Anthropometric data for all study participants are presented in Table 2. T-tests were used to compare each participant's right to left leg at baseline and at follow-up. No significant differences were observed ($p>0.05$). Therefore, only right leg data is presented. All measures are from baseline testing for the right leg. T-tests was performed to compare baseline data between the two groups. No significant differences were observed ($p>0.05$). Additionally, T-tests also

indicated that there were no significant differences when comparing each group's baseline and follow-up data.

4.3 **Strength**

Initially, relative strength measures were calculated for each participant to eliminate body weight as a confounding variable when comparing strength scores across participants with different body anthropometry. An analysis using t-tests revealed no significant differences in any relative strength measures between groups at baseline. Absolute strength measures are therefore being presented as they were the original measures hypothesized for the purpose of this study.

Absolute strength (measured in NM) data for the right leg of each participant is provided in Table 3. While both left and right legs were tested, right leg data was chosen to be presented because no significant differences between legs were noted for either the control or NME training group.

All variables were tested for normality. Despite some variables not passing the normality test, we used two-way ANOVAs because it is a robust test even if all assumptions are not met.[65] When comparing percentage change between the groups, if variables did not pass the normality test, we used the Mann-Whitney Rank Sum Test.

4.4 **Overall Study Results**

Table 3. Strength, Core Stability and Vertical Jump Results

			p-values	p-values	p-values
	Control Group	**NME Group**	**Time**	**Treatment**	**Time x Treatment**
Hip External Rotation Strength (NM)	Baseline 189.2 ± 109.6 Follow-up 199.9 ±102.6	Baseline 166.9 ±85.5 Follow-up 184.6±106.9	0.45	0.59	0.76
Hip Abduction Strength (NM)	Baseline 111.2±21.3 Follow-up 104.6± 16.2	Baseline 106.4±18.6 Follow-up 115.3±50.1	0.48	0.36	0.09
Knee Extension Strength (NM)	Baseline 221.9 ± 85.3 Follow-up 236.0±92.8	Baseline 236.8± 90.7 Follow-up 236.7 ±111.2	0.46	0.59	0.94
Knee Flexion Strength (NM)	Baseline 211.7± 31.6 Follow-up 207.0±30.8	Baseline 193.9± 42.5 Follow-up 186.1±55.4	0.87	0.09	0.69
Core Stability eyes closed (# of errors)	Baseline 7.8 ± 6.0 Follow-up 6.6 ± 5.4	Baseline 6.4 ± 4.6 Follow-up 2.6 ± 2.2	*0.04	*0.02	0.31
Vertical Jump Single Leg Right (cm)	Baseline 89.5±3.8 Follow-up 89.6±3.9	Baseline 90.2±1.6 Follow-up 85.9±2.0	0.86	0.30	0.97

NME = neuromuscular exercise; NM= Newton-Meters; * significant p> 0.05

There was no change in hip external rotation, hip abduction, knee extension, or knee flexion strength, or vertical jump over time or between the groups. The NME group had better core stability than the control group at both baseline and follow-up. To control for baseline scores, we then compared percentage change between groups which is described below. (Table 4)

Table 4. Comparison of Percentage Change Between Groups

	Control Group	NME Group	P VALUE
Hip External Rotation Strength	Median = 0.5 Range = -28.9 to 3.7	Median = -8.1 Range = -64.5 to 41.5	p =0.39
Hip Abduction Strength	Median = 4.1 Range = -2.5 to 15.6	Median = - 8.3 Range = -24.8 to 0.7	*p=0.01
Knee Extension Strength	Median = -1.5 Range = -12.7 – 4.6	Median = - 6.5 Range = -14.4 to 0.6	p=0.50
Knee Flexion Strength	Median = 2.0 Range = - 2.3 to 9.7	Median = -2.2 Range = -17.0 to 11.5	p=0.24
Core Stability eyes closed	Median = 11.1 Range = -18.8 to 48.2	Median = 66.7 Range = 40.0 to 84.6	*p=0.01
Vertical Jump Single Leg Right	Mean = -0.1 SD = 3.3	Mean = 0.5 SD = 3.6	p=0.58

NME = neuromuscular exercise; * significant p≤ 0.05

When comparing percentage change between the control and training group, there was no difference found for hip external rotation strength, knee extension strength, knee flexion strength, or vertical jump.

However, hip abduction strength demonstrated a significant difference between groups with the training program demonstrating more improvement than the control group (negative number means an improvement between baseline and follow-up). Core stability when performed with eyes closed with the right leg planted also demonstrated a significant difference between groups with the training group demonstrating more improvement than the control group.

4.5 **Correlations**

4.51 **Strength vs Core**

Figure 8. The Relationship Between Hip External Rotation Strength and Core Stability

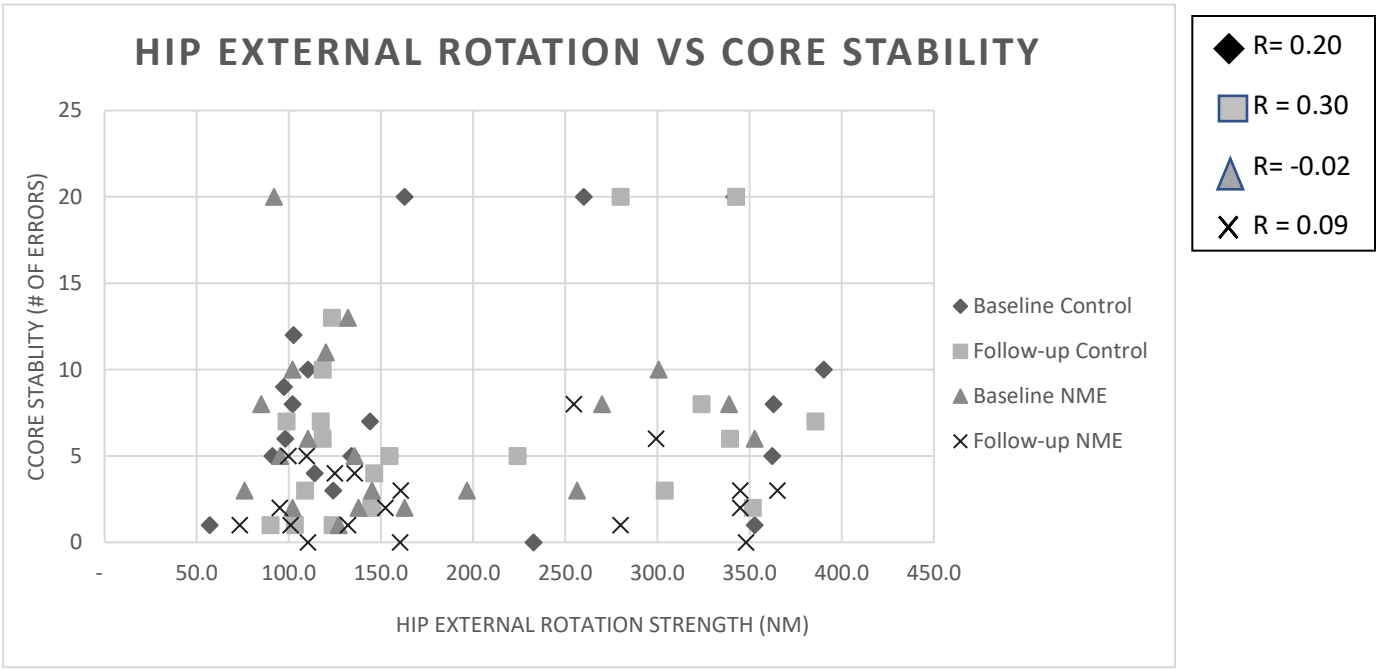


Figure 8 presents the relationship between hip external rotation strength and the number of errors committed on the core stability test. Hip external rotation and core stability were measured at baseline and at follow-up for both the control and the NME training groups. There was no relationship between the two measures.

Figure 9. The Relationship Between Hip Abduction Strength and Core Stability

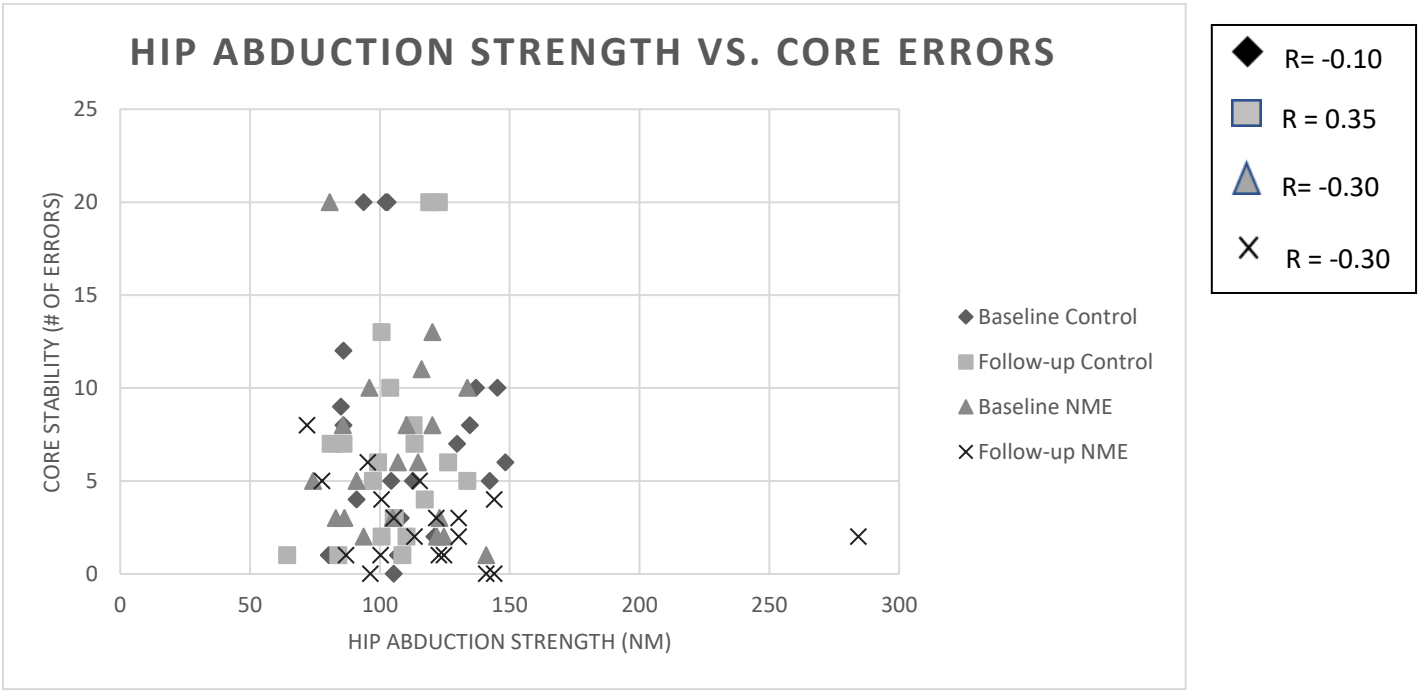


Figure 9 presents the relationship between hip abduction strength and the number of errors committed on the core stability test. Hip abduction and core stability were measured at baseline and at follow-up in the control group and the training group. There was no relationship between the two measures.

4.52 **Strength vs Vertical Jump**

Figure 10. The Relationship Between Hip External Rotation Strength and Vertical Jump performance

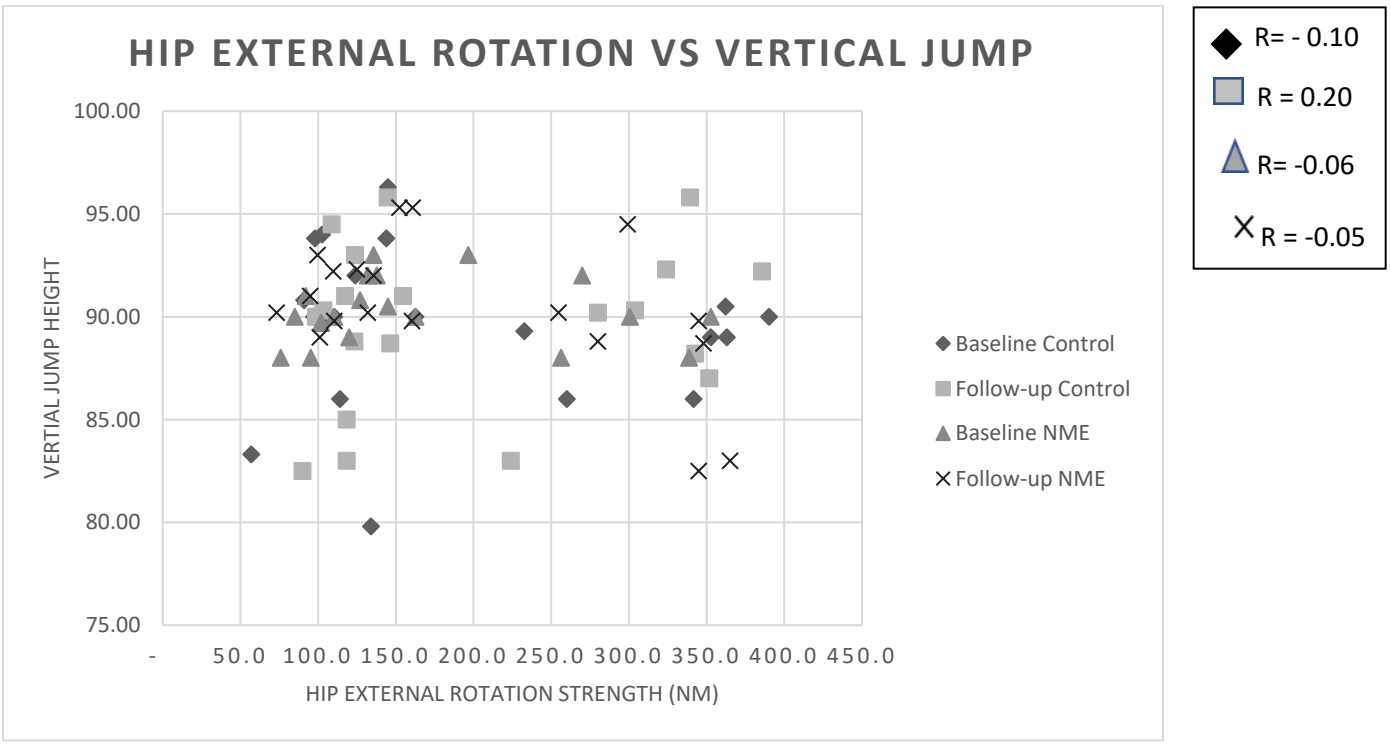


Figure 10 presents the relationship between hip external rotation strength and vertical jump height for a single leg jump on the right leg. Hip external rotation and vertical jump were measured at baseline and at follow-up in the control group and the training group. No relationship was noted between the two measures.

Figure 11. The Relationship Between Hip Abduction Strength and Vertical Jump

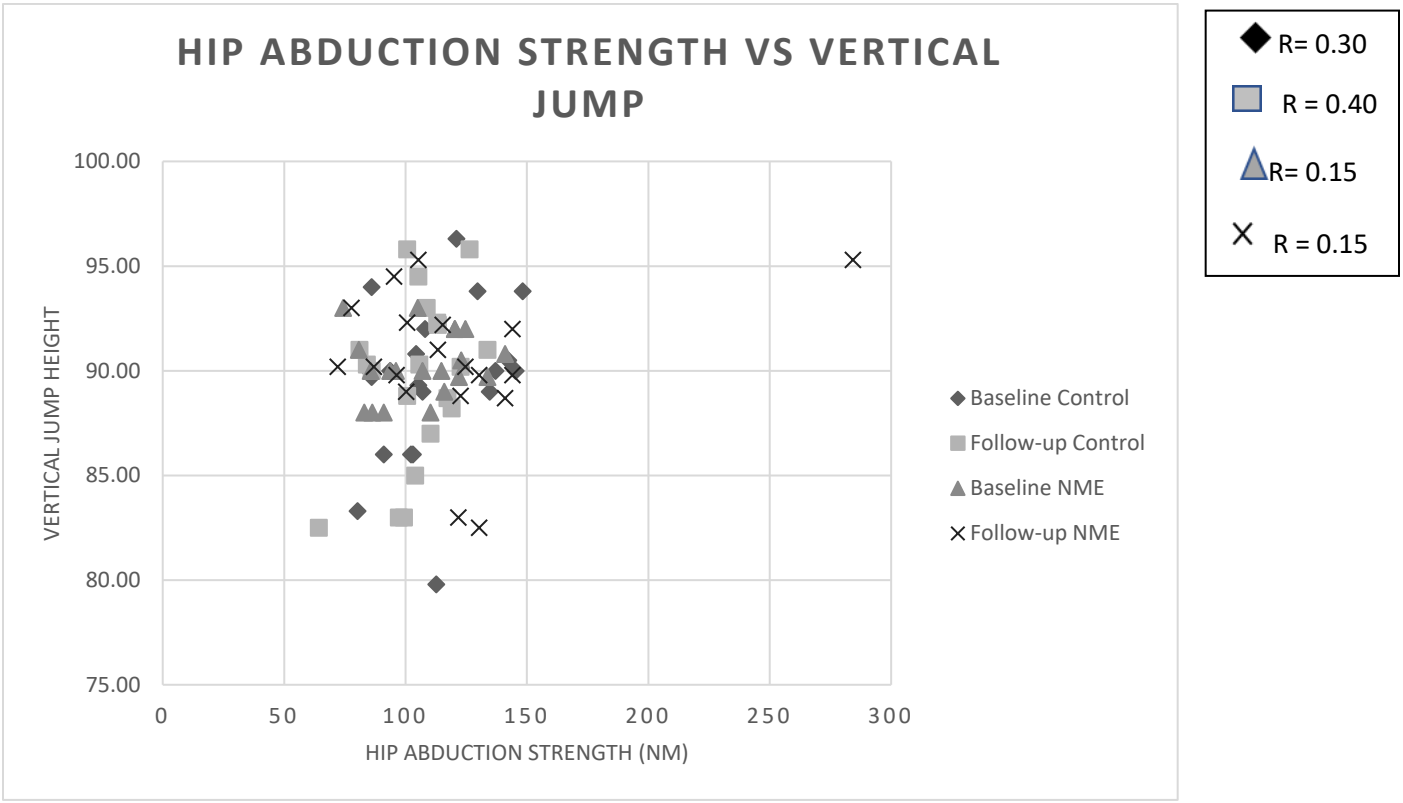


Figure 11 presents the relationship between hip abduction strength and vertical jump height for a single leg jump on the right leg. Hip abduction and vertical jump were measured at baseline and at follow-up in the control group and the training group. There was no relationship between the two measures.

CHAPTER FIVE: DISCUSSION

5.0 **Discussion**

The objective of this research project was to determine whether a perturbation-based neuromuscular exercise (NME) training program would have an effect on hip strength (hip external rotation and hip abduction) and core stability in healthy adolescent females. It was hypothesized that the NME program would increase hip strength (hip external rotation and hip abduction) and increase core stability in healthy adolescent females.

Results for the demographic data and anthropometric data determined that the control group and training group were equal at baseline. There were no significant differences in hip external rotation strength between the control and training groups at baseline and following administration of the 5-week NME program. The NME group showed an improvement in hip abduction strength when compared to the control group. The NME group showed an improvement in percent increase in core stability when compared to the control group. There was no difference in vertical jump scores between the groups or between baseline and follow-up. There were no significant relationships between hip strength and core stability, or hip strength and vertical jump. Based on the results of data analysis, the central hypothesis was partially supported.

5.1 **Demographic Data**

Data collected suggest that all participants were meeting the activity standards for the healthy adolescent female population by regularly participating in sporting activities such as ringette, dance, baton, volleyball, and soccer. A review of literature revealed that normative values for physically active adolescent females on the PAQ-C ranges between 2.3 to 2.6; [11] our participants had an average score of 2.5.

Participants enrolled in the study scored an average of 6.1 on the PMOS which correlates to a mid-pubertal status. The control group had an average of 6.1 and the training group had an average of 6.2. A review of literature was conducted and revealed that the maximum score on the PMOS is 8, therefore our participants were on average at mid pubertal status.[85]

5.2 **Anthropometric Data**

Anthropometric data was collected for all study participants at baseline and at follow-up. Average height of our sample was 163.8 $\pm$ 6.0, average weight 60.3 $\pm$ 13.5kgs equating to an average BMI of 22.4 $\pm$ 4.2. The average height for this population is 159.7cm, the average weight is 52.1kg which would equate to an average BMI of 20 which is indicative of a healthy body mass index.[13]

Results indicated that there were no differences between the right and left leg anthropometric data at baseline as well as at follow up. Therefore, only the data of the right leg was presented in the results section. Anthropometric data was further compared at baseline and at follow-up. With no differences observed, it was determined that our anthropometric data did not change during each individual participant's 5-week intervention period, nor did it change for the control group during their waiting period. This allows us to rule out that our anthropometric data would have had an impact on the study results. These anthropometric results are important because it enhances the generalizability of our results to the population of healthy adolescent females. Furthermore, these results allow us to have confidence that our participants were evenly distributed/randomized to both our control and intervention groups.

5.3 **Strength Data**

When comparing percentage change between the control and training group, there was no difference found for hip external rotation strength, knee flexion strength, or knee extension strength. However, hip abduction strength demonstrated a significant difference between groups with the training program demonstrating more improvement than the control group.

Perhaps the amount of intervention did not provide sufficient stimulus to create more change. According to the ACSM, neuromuscular training should be performed 2-3 days a week for 20-30 minutes.[77] While the training sessions were about 30 minutes in duration, it was a 5 week protocol of 10 sessions resulting in the sessions being 2 days per week which was on the low end of what the FITT principle presented. Furthermore, the guideline reveals that the volume, intensity, progressions and patterns are not known at this time.[77] These guidelines further discuss the FITT principle for resistance evidence based recommendations, which allow us to highlight that the training program utilized was a neuromuscular training program and not a strength program. It was hypothesized that performing NME training could have an effect on strength, however in order for additional effects in all the strength measures, incorporation of an actual resistance component following such guidelines could have been beneficial. Finally, it is important to note that during perturbation and balance training exercises, the participant may lose balance which the number of times one lost balance varied from one participant to the next. In 30-minute, training session, there would have been variety on how long each participant was truly being active based on the number of falls or as the distractions increased or how many times the participant had to go retrieve the distraction and cease performing the exercise.

Although there was an increase in hip abduction strength there was no change in hip external rotation strength. It has already been discussed that perhaps the amount of stimulus from the NME program was not sufficient to create more change. The NME program could further be reviewed for the types or directions of stimulus and the potential effect on the results found. The majority of the perturbations were in the frontal plane of movement, whereas fewer were in the transfers plane where we would potentially see more of an effect on hip external rotation strength.

The participants' body types may have impacted the results of the study as their structure could influence the amount of musculature which could have an impact on their strength output. Those with more muscle mass have demonstrated a greater ability to produce force during strength testing.[78]

Increased hip abduction strength is important in this population because of their increased incidence in knee injuries that could potentially be occurring due to weak hip abductor muscles.[4,10] It is hypothesized that increasing hip abduction strength in a preventative setting may contribute to lowering the incidences of knee injuries.[10] ACL injuries frequently occur when the knee falls into the risky position of knee valgus which is prevented largely by hip abduction strength.[10]

5.4 **Core Stability Data**

Core stability when performed with eyes closed with the right leg planted demonstrated a significant difference between groups with the training group demonstrating fewer errors than the control group at follow-up testing. In similar findings in previous studies performed on female college aged athletes, there were no significant differences between the right and the left leg planted during the core stability test.[7] The average number of errors for our subjects in the NME program were 6.4 $\pm$ 4.6 at baseline and 2.6 $\pm$ 2.2 at follow-up. Similarly, the study participants of adult females were 5.8±5.1 at baseline and 1.3±1.1 at follow-up.[7]
Increased core stability was also found in previous studies of adolescent female athletes undergoing core conditioning and trunk strengthening interventions.[79] Increased core stability is important in this population as there has been discussion in the literature surrounding a link between core stability and lower limb dynamic control.[47] Better lower limb dynamic control is associated with decreased injury risk[80] and may be linked to better athletic performance[81] Increasing core stability could function as potential preventative programing in preventing knee injuries in this population.[7]

Overall, our study found an increase in hip abduction strength as well as an increase in core stability which justifies the use of perturbation training on unstable surfaces in preventative programing in the prevention of knee injuries.

5.5 **Vertical Jump Data**

There was no difference in vertical jump results between the groups or between baseline and follow-up. The average value measured for our study participants was 13 inches for a double leg jump, which is similar to normative values for adolescent girls.[82] Vertical jump was assessed as a measure of functionality, and vertical jump is a measure of power. Perhaps there was not sufficient stimulus or the correct type of muscle contraction in the intervention protocol to create changes in the power output measured by vertical jump. Typically, maximal force production types of exercises/activities are required to improve power[77], whereas as fast endurance types of exercises/activities are required to improve strength.[77] Therefore, it makes sense that vertical jump height as a measure of power was not correlated to hip strength in our study.

There could have been impact on the results due to the order of testing. Vertical jump was the last test to be completed during baseline and follow-up testing for all participants. As a measure of power, perhaps by the time that the participants completed all the range of motion, flexibility, proprioceptive and strength measures, they were not able to generate enough power for a notable effect. . It was also observed that not many of our participants had conducted vertical jump testing previously which could have impacted their results as they were unfamiliar with the study and were not practiced in this skill.

5.6 **Correlations**

The possibility of a relationship between strength measures and the number of errors committed during the core stability test was evaluated during this study. There were no significant relationships between hip strength and core stability. Not similarly to our study, significant positive correlations between hip abduction strength and a test of dynamic postural control has been demonstrated on an adult population.[83] Perhaps the study protocol did not provide sufficient stimulus to create change for this demographic and perhaps the length of the protocol was not long enough to have an effect which would create a relationship between these measures.[77] FITT principles demonstrate that the evidence based recommendations for a neuromuscular exercise program should be 2-3 days per week as well as for a minimum of 20-30 minutes per session.[77] There is still more information required on the amount of intensity, type, volume and pattern of neuromuscular training therefore it is a possibility that the amount and type of perturbations did not create sufficient stimulus, especially in a healthy adolescent population to result in more of an effect.

The measures being evaluated were strength measured in absolute strength in Newton-Meters of force and the core stability test was measured as numbers of errors committed. These errors should decrease as improvement or a positive effect is being demonstrated. Perhaps the lack of relationship is as a result of the lack of ability to truly compare these two outcome measures as having a relationship. Furthermore, the core stability test was a dynamic sitting test; the gluteus medius and minimus muscles that perform hip abduction and external rotation are not that active in such a seated position.[48] Strength and stability are fundamentally different outcome measures which require different stimulus to produce improvement. Stabilization requires constant adjustments whereas strength is the peak amount of force a muscle can produce.

There are several potential reasons as to why there was a lack of relationship between all strength measures and vertical jump. Vertical jump was measured as a test of functional power. Strength was measured as an isolated isometric measure. Similarly, to the core stability test, vertical jump and HHD strength were not similar enough to be able to evaluate them in respect to having a relationship. When performing a vertical jump, the main muscles utilized are the quadriceps and the gluteus maximus. When performing hip external rotation and hip abduction strength testing,

the muscles being tested are the gluteus medius and minimus. Not only were the muscle groups being tested in different measures with vertical jump assessing power and HHD assessing strength, but they were also assessing different muscles which would result in the inability to produce a relationship between the two. A similar study assessing strength and vertical jump found no correlation between single leg vertical jump height and hip external rotation strength or hip abduction strength in young adults.[84]

5.7 **Study Limitations**

5.71 **Sample Limitations**

The purpose of this study was to evaluate healthy female adolescents in regard to a specific NME training program. One limitation of the study is that the results are only applicable to this demographic and would be challenging to apply to other populations.

Adolescent females should be participating in 60 minutes per day of physical activity with a minimum of 3 days of strengthening and 3 days of aerobic training.[13] Although our healthy adolescent population was consistent with the amount of physical activity on the PAQ-C, there was variability in the amount and frequency observed. The amount and type of physical activity varied significantly in our sample. This variability in physical activity could have impacted the results of our study.

Another possible limitation with the sample studied was the large age range of 12-18 years. Subcategories could have been created for analysis. The results of the PMOS determined that the majority of our participants were in the mid-pubertal category, but we did not control for PMOS score in our analysis. We could have broken the participants into subcategories matching the 3 levels of pubertal maturation; pre-pubertal, mid, and post pubertal. This however would have resulted in having to significantly increase our sample size, needing to recruit over 120 participants which would not have been feasible for the nature of this master's thesis.

It is possible that the NME program was not long enough to create more of training effect for hip external rotation strength, knee extension and knee flexion strength for this healthy adolescent female population. the intervention program was selected as it demonstrated that it was a valid and reliable program to use.[7] However, this earlier research was based on college aged female participants. Perhaps the protocol demonstrated a training effect on that particular demographic, but the same protocol was not transferable to our healthy adolescent female population.

5.72 **Protocol Limitations**

Although the protocol used was safe and effective, as well as valid and reliable[28], perhaps it was not sufficient in length and difficulty in order to demonstrate strength changes in this healthy population. The duration of the study made it easy for recruiting however this may have impacted the potential results. Perhaps they would have benefited more from increased perturbations as well as increased length of the overall intervention program.

Although participants did not have familiarization sessions, they were allowed practice repetitions. A familiarization session could increase the consistency in results and increase the repeatability of the study.

Some variables did not follow a normal distribution which was due to the sample size limitation of the study, and the nature of the outcome measures.

5.73 **Confounding Variables**

For the control group, we did not monitor or restrict what they did during the 5-week period in between baseline and follow-up testing other than stating that they were not to participate in another preventative rehabilitation program. There was the potential that the results may have been influenced by a seasonal effect, as this was not controlled throughout the almost 2 years of data collection. Some participants began the study at the end of their athletic season, while some began the study at the beginning of their athletic season. There is the possibility that the timing

of the testing / intervention (i.e., seasonal effect) may have had an impact on study results and served as a limiting factor which complicated interpretation of the data. Another example of timing was that there were some completing the program at the end of their competitive season where their strength would have been limited as a result of fatigue and playoff involvement. Some participants completed the program during their off season which could have also affected their performance. Other similar studies controlled for this seasonal effect in their protocol.[22,32] This could be addressed moving forward by scheduling the NME program to take place at a similar time for all participants; for example the inclusion criteria could be expanded to include participants only in the middle or end of their sport season. They would be excluded from the study if they were at the beginning of their sport season.

5.74 **Limitations of the Core Stability Test**

During testing, there appeared to be a significant learning curve observed during the core stability test which could have had an impact on the results. This adolescent population is going through so much growth and neurological maturation that their improvements on the core stability tests could have occurred as a result of this learned effect. Although pilot testing was conducted and the core stability test was selected based on the parameters of the study and its suitability to the outcome measures and the population being assessed, it may not be the most valid and reliable test to use with this population. Recording the number of errors also had several shortcomings. It was not well laid out what was considered an error. Once 20 errors were recorded then the participant would be at their maximum. If the participant fell off the ball, they were instructed to get back on and continue for the remainder of the 30 seconds timed trial. However, if one person fell off 2 times and another fell off 5 times, they both maxed out at 20 errors. The number of errors tended to cluster together, which makes it challenging for data analysis especially when performing correlations. Recording the errors is also a subjective decision by the tester, and inter-tester reliability may have been lower then expected and thus influenced the scoring on this test.

5.75 **Limitations with Strength Measures using HHD**

Although the HHD is a valid and reliable method of testing isometric strength[54], there were several shortcomings identified during its use in this study. One is variability between evaluators who must meet the resistance of the participant in order to measure strength with the handheld device. The strength of this healthy adolescent population could overpower the tester. The tester may not have been as reliable on their third participant of the day as their first. Participants may not have put forth the same amount of effort on all trials and from baseline to follow-up. The time of day for testing could have had an effect on the results depending on the participant's level of fatigue. This was not something that was controlled for during the testing procedures and could have impacted the results. Many of the participants tested directly after school, some came later in the evening after their activities and then the remaining were tested on weekends at varying times of the day. However, we chose hand-held dynamometry because the ease of use and transportability greatly assisted with participant recruitment and ease of data collection.

5.8 **Future Directions**

After discussion and evaluation of the results, there are a number of questions which arise that may warrant future investigation. A future direction would be to repeat the study on healthy adolescent males. This would assist with the evaluation of the repeatability of this study protocol and testing procedures. Furthermore, this same protocol could be repeated on a similar group of adolescent females that are less active and control for the activities participants are doing outside of the study. Finally, the same study could be repeated with a larger sample of healthy female adolescents randomized into 3 groups based on their pubertal maturation status.

If this same study were conducted again on a healthy adolescent population, the protocol could incorporate more challenging perturbations and a lengthier intervention program. The current protocol calls for 10 sessions over a 5-week period. Increasing the protocol to 20 sessions over a 5-week period could have more significant effect on hip strength and core stability in this healthy population. In addition to increasing the amount and the length of the stimulus within this NME

protocol, it would be beneficial to add a strength component to the protocol in order to have more of an impact on the outcome measures.

A future recommendation would also be to not use the same core stability test. It would be beneficial to attempt a static hold core test as well as a dynamic core test and perform an analysis of correlations.

Further evaluation of the vertical jump results such as video analysis of the knee valgus position when landing could be performed as part of future testing. It would be beneficial to further study another functional power measure such as a squat or lunge as a correlational measure to isometric strength.

5.9 **Conclusion**

The purpose of this project was to evaluate the effectiveness of a perturbation-based neuromuscular exercise training program on hip strength and core stability in healthy adolescent females between the ages of 12-18 years old. The main outcome measures were hip strength (hip external rotation and abduction), core stability, and vertical jump. A repeated measures study design was used to evaluate hip and knee strength with the hand-held dynamometry, dynamic core stability and vertical jump before and after the implementation of a 5-week neuromuscular training program. Percentage of change data indicated that hip abduction strength demonstrated a significant difference between groups with the training program demonstrating more improvement than the control group. Core stability when performed with eyes closed with the right leg planted also demonstrated a significant difference between groups with the training group demonstrating fewer errors than the control group. There was no significant relationship noted between strength scores and core stability or vertical jump performance. Overall, the results suggest the possibility of some impact as a result of the NME program, but more research is still needed to clarify the results of this and other investigations which have examined the efficacy of NME training programs in specific at-risk populations such as physically active adolescent females.

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GLOSSARY OF TERMS

ACL – anterior cruciate ligament

ASIS – anterior superior iliac spine

BKLT- bent knee lowering test

BMI – body mass index

ER – external rotation

HHD – hand held dynamometry

JPS – joint position sense

MVIC – maximal voluntary isometric contraction

NM – newton meter

NME – neuromuscular exercise

NMT – neuromuscular exercise training

OA – osteoarthritis

PAR-Q – physical activity readiness questionnaire

PAQ-C – physical activity questionnaire for older children

PMOS – pubertal maturation observational scale

RA – response angle

ROM – range of motion

SEBT – star excursion balance test

TA – transversus abdominus

TA – test angle

WB – weight bearing

APPENDIX

Appendix A: Consent Forms

Appendix B: Data collection forms

Appendix C: Advertisements

Appendix A: Consent forms

RESEARCH PARTICIPANT INFORMATION AND CONSENT FORM
(ASSENT FORM FOR CHILDREN UNDER 17 YEARS OF AGE)

Title of Study:
The Effects of Neuromuscular Training on Hip Strength and Core Stability in Healthy Adolescent Females.

Principal Investigator:
Dr. Jason Peeler, University of Manitoba.

Why you are here?
The researchers want to tell you about a study about exercises to help adolescents prevent knee injuries. They want to see if you would like to be in this study. This form tells you about the study. If there is anything you do not understand, please ask your parents/guardian or the study staff.

Why are they doing this study?
The researchers want to see if the exercises can help improve how the knee works & strength in adolescents with healthy knees.

What will happen to you?
If you want to be in the study these things will happen:

1. The study will last 6 weeks, but you do not have to come in every day. You will be asked to come to the Pan Am Clinic for 2 visits to perform activities to test your knee, and potentially for 10 visits to perform exercises for your knee.
2. At the initial test session, you will be randomized into one of two groups, an exercise group, and a non- exercise group. The exercise group will require the attendance of the 10 sessions whereas the non-exercise group will not. The non-exercise group will be required only to come to initial and follow up testing sessions.
3. The 2 test visits for your knee will be once at the beginning and once at the end of the study. Each test visit will last around 1 hour. The researchers will ask you to perform some simple activities to test your lower leg, for example activities to see how strong it is.
4. The 10 exercise visits will be 2 visits per week for 5 weeks. Each exercise visit will last about 1 hour. A therapist will work with you to perform exercises for your knee, like balancing on a surface that moves.

Will the study hurt?
The movements that you will be asked to do are ones that you do every day when walking or playing and should not hurt at all. If for some reason the movements hurt, you can stop right away.

Will you get better if you are in the study?
The purpose of the study is to measure core stability and hip strength, therefore an increase in strength may occur with participation in the study.

What if you have any questions?
You (or your mom or dad) can ask questions any time, now or later. You should feel free to talk to the researchers, your family or someone else about this study at any time.

Who will know what I did in the study?
Any information you give to the study staff will be kept private (*or secret*). Your name will not be on any study paper and only the study staff and the researcher will know that it was you who was in the study.

Do you have to be in the study?
You do not have to be in the study. No one will be mad at you if you do not want to do this. Participating in the study is on a volunteer basis.

If you do not want to be in this study, just say so. We will also ask your parents if they would like you to be in the study. Even if your parents want you to be in the study you can still say no.

Even if you say yes now you can change your mind later. It is up to you.

Do you have any questions?

Assent

I want to take part in this study. I know I can change my mind at any time.

Child's printed name: _____ Verbal assent given Yes □

Child's signature: _____ Age: _____

Date: _____
(day/month/year)

I confirm that I have explained the study to the participant to the extent compatible with the participants understanding, and that the participant has agreed to be in the study.

Printed name of person obtaining assent: _____

Signature of person obtaining assent: _____

Date: _____
(day/month/year)

CONSENT TO PARTICIPATE IN RESEARCH STUDY

Title of Study: The Effectiveness of Neuromuscular Training on Core Stability and Hip Strength in Healthy Adolescent Females.

Principal Investigator:

Dr. Jason Peeler PhD., CAT(C)
Faculty of Medicine, Department of Human Anatomy & Cell Science,
University of Manitoba, (204) 272-3146

Date: JAN 24TH, 2019

Your adolescent is being asked to participate in a clinical research study. Please take your time to review this consent form and discuss any questions you may have with the study staff. You and your adolescent may take your time to make your decision about participating in this study and you may discuss it with your friends, family or (if applicable) your doctor before you make your decision. This consent form may contain words that you and your adolescent do not understand. Please ask the study staff to explain any words or information that you and your adolescent do not clearly understand.

1. Purpose of the Study

This clinical trial is being conducted to determine the effect of an established neuromuscular training (NMT) program on the lower leg function in healthy female adolescents. Neuromuscular is a term used to describe the muscles and the nerves working together. For this study, neuromuscular it is best described as training your nerves to make your muscles contract and hold your body in a stable position. This investigation should provide researchers and clinicians with valuable information regarding the effectiveness of NMT in the adolescent female population in regard to its effects on core stability and hip strength.

2. Time Commitment

The total time commitment for your participation in the study will be a maximum of 12 hours. Each session will be approximately 1 hour in duration. Over 6 weeks, participants will participate in 2 test sessions and the potential of 10 neuromuscular training sessions (2 times per week for 5 week of the study). After the initial intake testing session, individuals will be randomized into an exercise and a non-exercise group. The exercise group will be participating in the 10 neuromuscular training sessions and the non-exercise group will only be required to come for follow up testing after 5 weeks.

3. Study Procedures

Initial Intake Session

For the investigation, approximately 40 healthy participants will be recruited. During the initial intake session, all participants will complete a standardized screening protocol to ensure they are physically fit for participation in the testing and neuromuscular exercise training program. Baseline data will be collected during a pre-exercise test session; participants will then be randomly assigned to into one of two groups.

Training Session

The NMT protocol requires that the participant attends 2 supervised training sessions per week, over the 5-week period (for a total of 10 sessions). During each training session the patient maintains balance on three different support surfaces, while a clinician administers purposeful manipulations. Over the course of the program the manipulations will progress from one-direction movements that are verbalized prior to application to multi-directional, random manipulations. Each leg will receive training for 2-3 sets of 1-minute duration on each of the support surfaces.

All testing will be administered by a Research Assistant under the supervision of the Study Coordinator. Training sessions will be with a Certified Athletic Therapist.

Participants will be asked to complete the following forms or procedures as part of the data collection for the assessment of lower leg function:

- Anthropometric form
- Standardized Screening protocol
- Pubertal Maturation Observational Scale (PMOS)
- Physical Activity Questionnaire for older children (PAQ-C)
- Biodex Isokinetic Dynamometer testing
- Dynamic Core Stability test

4. Discomfort and Risk

Your adolescent may feel slight discomfort while performing the assessment of knee function and NMT, but this should be no more painful than what they experience during everyday activities such as playing.

5. Benefits

By participating in this study, your adolescent will be providing information to the study researchers, clinicians and doctors that will allow them to better manage lower body injuries in the adolescent female population.

You and your child are not waiving any of your legal rights by signing this consent form nor releasing the investigator(s) or the sponsor(s) from their legal and professional responsibilities.

6. Compensation

You are participating in this study on a volunteer basis, and all clinic and professional fees, diagnostic and laboratory tests that will be performed as part of this study are provided at no cost to you. There will be no cost for the study assessment that you will receive.

7. Confidentiality

Information gathered in this research study may be published or presented in public forums; however, your name and other identifying information will not be used or revealed. Medical records that contain your identity will be treated as confidential in accordance with the Personal Health Information Act of Manitoba. Despite efforts to keep your personal information confidential, absolute confidentiality cannot be guaranteed. Your personal information may be disclosed if required by law. All study documents related to you will bear only your assigned patient number (or code) and /or initials.

*The University of Manitoba **Health** Research Ethics Board may review research-related records for quality assurance purposes.*

All records will be kept in a locked secure area and only those persons identified will have access to these records. If any of your medical/research records need to be copied for any of the above, your name and all identifying information will be removed. No information revealing any personal information such as your name, address or telephone number will leave the Pan Am Clinic.

8. Voluntary Participation/Withdrawal from the Study

Your adolescent's decision to take part in this study is voluntary. Your adolescent may refuse to participate or withdraw from the study at any time. However, we would like to encourage you and/or your adolescent to talk to the study supervisor and/or staff, prior to making such a decision. Your decision not to participate or to withdraw from the study will not affect your care at this centre.

If the study staff feels that it is in your child's best interest to withdraw you from the study, they will remove you without your consent.

We will tell you about any new information that may affect your health, welfare, or willingness to stay in this study.

9. Medical Care for Injury Related to the Study

In the case of injury or illness resulting from this study, necessary medical treatment will be available at no additional cost to you. If you should become physically injured as a result of any research activity, the study doctor will provide any necessary treatment, at no charge, to help you promptly recover from the injury.

You and your adolescent are not waiving any of your legal rights by signing this consent form nor releasing the investigator(s) their legal and professional responsibilities.

10. Questions

You and your adolescent are free to ask any questions that you may have about your treatment and your rights as a research participant. If any questions come up during or after the study or if you have a research-related injury, contact the Principal Investigator: Dr. Jason Peeler at xxx-xxx-xxxx and/or the Study Coordinator: Christine Johnston Heise at xxx-xxx-xxx. For questions about your rights as a research participant, you may contact The University of Manitoba, Bannatyne Campus Research Ethics Board Office at xxx-xxx-xxxx.

Do not sign this consent form unless you have had a chance to ask questions and have received satisfactory answers to all your questions.

11. Results of the Study

All individuals who participate in this study are eligible to receive information on the outcomes of the study, via a 1-page synopsis of the key findings of the research. The current study is registered on a publicly available registry databank. ClinicalTrials.gov is a website that provides information about federally and privately supported clinical trials. A description of this trial will be available on http://ClinicalTrials.gov. This website will not include information that can identify you. At most, the website will include a summary of the results. You can search this website at any time If you would like to receive information on the results of this study, please state your mailing address below:

Address: _____

City: _____

Postal code: _____

Email: _____

Statement of Consent:

I have read this consent form. I have had the opportunity to discuss this research study with Dr. Jason Peeler or his study staff. I have had my questions answered by them in language I understand. The risks and benefits have been explained to me. I believe that I have not been unduly influenced by any study team member to participate in the research study by any statements or implied statements. Any relationship (such as employer, supervisor, or family member) I may have with the study team has not affected my decision to participate. I understand that I will be given a copy of this consent form after signing it. I understand that my adolescent's participation in this study is voluntary and that I may choose to withdraw them at any time. I freely agree to allow my adolescent to participate in this research study.

I understand that information regarding my adolescent's personal identity will be kept confidential, but that confidentiality is not guaranteed.

By signing this consent form, I have not waived any of the legal rights that I (or my adolescent) have as a participant in a research study.

I give permission to be contacted for future research in relation to this study.
☐Yes ☐ No

Parent/Legal Guardian's printed name: _____

Parent/Legal Guardian's signature: _____

Child's printed name: _____

Child's signature: _____

Date: _____
(day/month/year)

I, the undersigned, have fully explained the relevant details of this research study to the participant named above and believe that the participant has understood and has knowingly given their consent

Printed Name: _____ Date _____
(day/month/year)

Signature: _____

Role in the study: _____

Relationship to study team members: _____

Appendix B: Data Collection Forms

Participant Information Form

Study Identification #:

Participant Name: _____

Parent/Guardian Name(s): _____

Mailing Address: _____

City: _____ Postal Code: _____

Home Phone #: _____ Cell Phone #: _____

Participant email: _____

Parent email: _____

Participant Information Form

Study Identification #:

Study Title:	*The Effectiveness of Neuromuscular Training on Hip Strength and Core Stability on Healthy Adolescent Females*
Study Location:	Pan Am Clinic Foundation (3rd floor, 75 Poseidon Bay)
Study Coordinator:	Christine Johnston Heise xxx-xxx-xxxx
Principal Investigator:	Dr. Jason Peeler xxx-xxx-xxxx

Future Testing dates:

Pre-Exercise Testing:	
Follow-up #1:	
Follow –up #2:	
Test-Retest	

Exercise Training dates:

Week	Session 1	Session 2
#1		
#2		
#3		
#4		
#5		

Knee Demographic Form

Study Identification #: Date:

Sport/Activity Information:

1. What is your main sport/activity?
2. Main sport/activity level?

Fun	Recreational		Competitive
1-2	3-4	5-6	7 or more

3. How often do you participate each week?
4. List any additional sport/activities that you regularly participate in.
5. Have you ever been treated for a lower body injury before?
6. Are you currently experiencing any knee pain?

Anthropometric Data Collection Form

1. Complete Questionnaires

☐ PMOS ☐ PAQ – C

2. Anthropometric Information

Height (m)

Weight (kg)

BMI (kg/m^2)

Leg Length	Right	Left
ASIS – malleolus		

Leg Circumference	Right	Left
6” above		
@ joint line		
6” below		

Observation:

Knee alignment	Right	Left
Valgus		
Varus		
Neutral		

3. Proprioception

- 2 practices; report mean score of 3 tests as difference from set degree

WB Joint Position Sense	Right				Left			
	T1	T2	T3	AVG	T1	T2	T3	AVG

Degree		

4. Flexibility

- 3 practices; report the mean score of 3 tests

Ankle – WB lunge	Right				Left			
	T1	T2	T3	AVG	T1	T2	T3	AVG
Distance (cm)								

Knee – Active ROM	Right				Left			
	T1	T2	T3	AVG	T1	T2	T3	AVG
Flexion								
Extension								

Hip – Standing toe touch	Right				Left			
	T1	T2	T3	AVG	T1	T2	T3	AVG
Distance (cm)								

5. Strength – Hand-Held Dynamometry

- 2 submaximal practices, report maximum score of 3 test trials

Hip	Right				Left			
	T1	T2	T3	AVG	T1	T2	T3	AVG
Abduction								
Ext. rotation								

Knee	Right				Left			
	T1	T2	T3	AVG	T1	T2	T3	AVG
Flexion								
Extension								

Ankle	Right				Left			
	T1	T2	T3	AVG	T1	T2	T3	AVG
Flexion								
Extension								

6. Performance

	Vertical Jump Test		
	T1	T2	AVG
2-legs			
Right			
Left			

7. Core Test

Trunk Stability Test	Right		Left	
	Eyes Open	Eyes Closed	Eyes Open	Eyes Closed
Number of Errors				

Appendix C: Advertisements

pan am CLINIC FOUNDATION INC.

Balance & Strength Training to Prevent knee Injuries in Female Adolescents

UNIVERSITY OF MANITOBA

Are you between the ages of 12-18??
Are you concerned about injuring your knee??
Are you interested in a specialized knee injury prevention program??

The University of Manitoba, in conjunction with Pan Am Clinic, is recruiting participants for a study examining the effects of a supervised exercise training program in healthy female adolescents.



Participants must be:
- Female Adolescents between the ages of 12 – 18.
- Able to pass standardized screening tests
-6 week study requires potential participation in 2 test & 10 exercise sess
(each approx. 1 hour)

If interested in participating, please contact either:

Study Coordinator: Christine Johnston Heise CSCS, CAT(C)

Principal Investigator: Dr. Jason Peeler

The Effectiveness of Neuromuscular Training on Core Stability and Hip Strength in Healthy Adolescent Females.
J. Peeler, J. Leiter, J. Parsons
October 2018