The Acute Effects of Proprioceptive Neuromuscular Facilitation (PNF) Stretching on Selected Performance Parameters

Julie Gage

A thesis submitted to the faculty of the University of North Carolina at Chapel Hill in partial fulfillment of the requirements for the degree of in the Department of Exercise and Sport Science (Athletic Training).

Chapel Hill

Advisor: Dr. William Prentice

Reader: Dr. Darin Padua

Reader: Ms. Cathy Brown

Reader: Ms. Michelle Boling

ABSTRACT

JULIE GAGE: The Effect of Proprioceptive Neuromuscular Facilitation (PNF) Stretching on Selected Performance Parameters
(Under the direction of William Prentice)

Acute static stretching has been shown to decrease strength, power, and endurance. The effects of acute PNF stretching have not been investigated. Additionally, a population with tight musculature may respond differently to stretching than those who have a normal muscle length. This study investigated how PNF stretching affected anterior pelvic tilt, hip extension range of motion (ROM), hip extensor strength, agility, and vertical jump height in those with and without tight hip flexors. Tight subjects had reduced ROM when compared to not tight subjects. There was a significant increase in ROM after stretching in both tight and not tight subjects. Following stretching, both tight and not tight subjects experienced a significant reduction in anterior pelvic tilt. There were no significant differences between groups or tests in vertical jump height or strength variables. PNF stretching increases stretch tolerance, but does not appear to influence antagonist muscle strength.

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

Abbreviation	Definition
1. GTO	Golgi tendon organ
2. EMG	Electromyographical
3. MVC	Maximal voluntary contraction
4. NTS	Not tight stretch group
5. PNF	Proprioceptive neuromuscular facillitation
6. ROM:	Range of motion
7. SEMO	Southeastern Missouri Agility Drill
8. TC	.Tight control group
9. TS	Tight stretch group
10. TTPT	Time to peak torque
11. VJ	Vertical jump

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE-INTRODUCTION

Hip flexor tightness is commonly noticed in athletes. This may be due to the amount of time athletes focus on stretching their hamstrings and because some athletes spend a lot of time with their hips flexed, such as those who participate in tennis and rowing. Muscular tightness may cause alterations in performance due to altered movement patterns. Studies have shown that individuals with tight hip flexors exhibit a shorter stride length than those with unrestricted hip flexors, presumably because the hip flexors limit hip extension [1]. Hip flexor tightness has also been correlated to adolescents with low back pain [2]. Because hip extension is a result of anterior pelvic tilt and limb extension [3], if hip flexor tightness limits hip extension, then compensatory increases in anterior pelvic tilt must occur to allow for normal hip extension. Anterior pelvic tilt may already be exaggerated in individuals with hip flexor tightness due to the attachment of this muscle group on the pelvis. Hip extension may be altered in this population due to the smaller amount of anterior pelvic tilt available for hip extension motion.

If muscles are shortened or lengthened beyond their optimal length, the amount of tension the muscle can produce decreases [5]. This phenomenon is known as reciprocal inhibition [5]. The gluteus maximus is the strongest hip extensor muscle, but if this muscle is elongated, the gluteus maximus may become weakened [5].   If the gluteus maximus muscle is not functioning normally because of an altered length, abnormal movement patterns may result. Because hip extensor strength is vital to jumping and sprinting, a decrease in hip extensor strength could cause a decrease in agility speed, and vertical jump height [6, 7].

If tight hip flexors inhibit the performance of the hip extensors, then elongation of the hip flexor muscles may correct an imbalance in the length tension relationship between the hip flexors and hip extensors. This may decrease anterior pelvic tilt, increase hip extension range of motion (ROM), increase hip extensor strength, and improve vertical jump height, and agility speed. Additionally, if the hip flexors are not restricted, then the elongation of these muscles will also alter the length-tension relationship between the hip flexors and hip extensors, but cause different outcomes. If unrestricted hip flexors are lengthened, it may cause the pelvis to rotate posteriorly, shortening the hip extensors. Because this would also alter the length of the hip extensors, a decrease in hip extensor strength could cause decreases in vertical jump height and agility performance.

Athletic trainers commonly use static, active, and proprioceptive neuromuscular facilitation (PNF) stretching techniques to increase ROM and lengthen tight muscles. PNF stretching is thought to increase ROM more than static or active stretching. Traditionally this has been attributed to neural mechanisms [8-11]. Besides increasing flexibility, stretching has also been thought to reduce risk of injury, enhance athletic performance and decrease pain [12]. Recent studies investigating acute stretching have shown decreases in force, strength, and power output [1, 9, 10, 13-16] following stretching. This has led some clinicians to advise athletes against acute stretching before athletic activity. However, many of these studies have utilized stretching protocols that are difficult for athletic trainers to incorporate due to time and space constraints in the typical athletic training room [12, 14, 17, 18]. More importantly, since these studies have not reported ROM statistics for their subjects [1, 14, 17, 18], it is unclear if they tested those with tight musculature. Because athletic trainers stretch many athletes with tight musculature, research is needed to determine the acute effects of stretching on this population, since individuals with tight musculature may respond differently than those with normal muscle lengths. Short and effective stretching protocols need to be developed and evaluated to assist the clinician in deciding which athletes to stretch, and which stretching techniques to utilize.

Purpose

The purpose of this research was to determine how individuals with and without hip flexor tightness score on measures of anterior pelvic tilt, hip extension ROM, hip extensor strength, agility speed, and vertical jump height. If those without tight muscles perform better on the strength tests than those with tight muscles, then these results would provide a foundation for the concept of reciprocal inhibition and a rationale for lengthening tight hip flexor muscles in athletes. Additionally, this project will examine how an acute bout of PNF stretching affects individuals with and without hip flexor tightness on the previous measures. The results from this part of the study will help the clinician decide who to stretch utilizing a PNF technique. Furthermore, this study will investigate the relationship between hip flexor tightness and anterior pelvic tilt, hip extension ROM, and hip extensor strength.

Research Questions

1. Is there a difference between individuals with and without hip flexor tightness on the following measures:

    a. Anterior pelvic tilt

    b. Hip extension range of motion

    c. Hip extension strength

    d. Speed in an agility drill

    e. Vertical Jump height

2. Does acute PNF stretching in those with tight hip flexors change the following variables:

    a. Anterior pelvic tilt

b. Hip extension range of motion

c. Hip extension strength

d. Speed in an agility drill

e. Vertical Jump height

3. Does PNF stretching of the hip flexor musculature in individuals without hip flexor tightness affect the following variables pre and post stretching:

a. Anterior pelvic tilt

b. Hip extension range of motion

c. Hip extension strength

d. Speed in an agility drill

e. Vertical Jump height

4. Is there a correlation between hip flexor tightness and anterior pelvic tilt, hip extension ROM and hip extensor strength?

Hypotheses

1. Individuals with hip flexor muscle tightness will demonstrate the following in comparison to individuals without hip flexor muscle tightness:

a. Increased anterior pelvic tilt
b. Decreased hip extension range of motion
c. Decreased gluteus maximus strength
d. Decreased vertical jump height
e. Decreased running speed in an agility drill

2. Individuals with hip flexor tightness will benefit from acute PNF stretching which will cause

a. Decreased anterior pelvic tilt

b. Increased hip extension range of motion
c. Increased gluteus maximus strength
d. Increased vertical jump height
e. Increased running speed in an agility drill

3. Individuals who do not exhibit hip flexor tightness will respond to PNF hip flexor stretching by

a. Decreased anterior pelvic tilt
b. Increased hip extension range of motion
c. Decreased gluteus maximus strength
d. Decreased vertical jump
e. Decreased running speed in an agility drill

4. There will be a correlation between hip flexor tightness and anterior pelvic tilt, hip extension ROM and hip extensor strength.

a. There will be a positive relationship between hip flexor tightness and anterior pelvic tilt

b. There will be a negative relationship between hip flexor tightness and hip extension ROM

c. There will be a negative relationship between hip flexor tightness and hip extensor strength

Null Hypotheses

1. Individuals with hip flexor muscle tightness will differ from those without hip flexor tightness with:
    a. Decreased or no difference in hip extension range of motion
    b. Increased or no difference in anterior pelvic tilt

c. Decreased or no difference in gluteus maximus strength

d. Decreased or no difference in vertical jump height

e. Decreased or no difference in and running speed in an agility drill

2. Individuals with tight hip flexor muscles will exhibit

a. Decreased or no change in hip extensor ROM

b. Increased or no change in anterior pelvic tilt

c. Decreased or no change in hip extensor strength

d. Decreased or no change in vertical jump height

e. Decreased or no change in running speed in an agility drill

after an acute bout of PNF stretching.

3. Individuals without tight hip flexor musculature will exhibit

a. Decreased or no change in hip extensor ROM

b. Decreased or no change in anterior pelvic tilt

c. Increased or no change in hip extensor strength

d. Increased or no change in vertical jump height

e. Increased or no change in running speed in an agility drill

after an acute bout of PNF stretching.

4. There will be no correlation between hip flexor tightness and anterior pelvic tilt, hip extension ROM, and hip extensor strength

a. A negative or no relationship between hip flexor tightness and anterior pelvic tilt

b. A positive or no relationship between hip flexor tightness and hip extension ROM

c. A positive or no relationship between hip flexor tightness and hip extensor strength

Variables

The independent variables in this study were group (tight control (TC), tight stretch (TS) and not-tight stretch (NTS) groups) and test (pre-test and post-test). There were ten dependent variables. Active hip extension ROM was measured by a digital inclinometer in degrees. Anterior pelvic tilt in standing was measured in degrees using calipers and a digital inclinometer. Isokinetic concentric peak torque, concentric angle of peak torque, concentric time to peak torque (TTPT) and eccentric peak torque, eccentric angle peak torque, and eccentric TTPT were measured on the Biodex at 60º/sec and normalized to the subject's body weight. Vertical jump height was measured using the Ver-tec and was measured in centimeters. Running speed in an agility drill was measured with a hand held stop watch and recorded in ms for the Southeastern Missouri (SEMO) drill.

Operational Definitions

1. Anterior pelvic tilt: Angle between the anterior superior iliac spine and posterior superior iliac

spine relative to the horizontal.

2. Hip extension ROM: Degrees that the hip can be actively extended past 180 degrees measured

with a digital inclinometer in a prone position with the knee bent to 30 degrees.

3. Recreational athlete: A subject who participates in at least 3 hours of activity per week.

4. Tight hip flexors: Lacking at least 10 degrees of motion from zero during a modified Thomas

Test

Assumptions

1. Subjects accurately reported activity levels and any relevant previous medical history.

2. Subjects maximally performed on hip extension strength, vertical jump and sprint tests.

3. The measurements taken by the inclinometer and Biodex were reliable and valid.

4. Intratester reliability was similar to reported intratester reliabilities reported for similar protocols.

5. Static measurements of anterior pelvic tilt and hip extension were relevant to dynamic movements.

Limitations

Recreational athletes had different training and injury histories.

Instruments used may have had errors.

Static postural measurement may not have been applicable to dynamic movements.

Standard deviations on measures were so large, that the power of study to find a statistical or clinical significant finding was low.

Stretching one leg may not cause a large enough effect in double-legged tasks to show a significant finding.

Delimitations

Subjects were excluded if they have experienced any lower extremity musculoskeletal problems

within the last 3 months.

Subjects were excluded if they have a history of a leg length discrepancy or a measured leg length discrepancy of greater than 0.5 cm.

An equal number of males and females were placed in each group.

Each of the three groups was equal in number.

A modified Thomas test measured in the sagittal plane determined if the subject had tight hip flexors.

Significance of the Study

The acute effects of static stretching have been investigated. Although these studies have found decreases in force, they had significant weaknesses because the ROM statistics were often not reported. It is unclear if the subjects exhibited muscular tightness or if there were any lengthening effects following the stretching treatment which caused the deficits in force production [1, 17, 19]. Additionally, the stretching protocols were often not clinically applicable due to time constraints of the athletic trainer [1, 17]. Even if significant force decreases are seen after stretching, this may not affect athletic performance. One study utilizing a static stretching protocol found that even with significant decreases in force, vertical jump heights did not change following stretching [17].

There is limited research exploring the effects of acute PNF stretching on postural and performance parameters. Because this method of stretching is clinically utilized, research needs to explore the acute effects of PNF stretching. If PNF stretching does not produce decrements in performance parameters, then PNF stretching should be chosen over static stretching before athletic activity.

While some speculate that tight musculature will elongate the muscle's antagonist and cause decreases in its force production [5], this has not been demonstrated in the literature. This study will evaluate if those with tight hip flexors do exhibit decreased force production in their hip extensors when compared to those without tight hip flexors. Furthermore, this study will investigate if stretching elongates the hip flexors and increases the force production of the hip extensors.

This study will test for differences in anterior pelvic tilt, hip extension ROM, hip extensor strength, vertical jump height, and sprint speed between those with normal hip flexor length as measured by the Thomas test and those without tight hip flexors. If subjects with tight hip flexors demonstrate improvements on the selected variables, the addition of PNF stretching to their training regimen could have positive effects on their performance and minimize risk of injury. Conversely, if subjects without restricted hip flexors show a decrease in performance after PNF stretching, then the athletic trainer should not utilize PNF stretching on individuals who have do not have tight hip flexors.

Summary

Because static stretching has been shown to cause acute deficits in strength, power, and balance, some clinicians do not recommend stretching prior to participation in athletic activity. PNF stretching may produce different results than static stretching, but the acute effects of PNF stretching have not been thoroughly investigated. Additionally, stretching is commonly utilized by athletic trainers to lengthen tight muscles. There has been little research done on the acute effects of stretching on those with tight musculature. Those with tight musculature may respond differently to stretching than those with normal muscle lengths.

CHAPTER TWO-A REVIEW OF THE LITERATURE

Introduction

Hip flexor tightness and anterior pelvic tilt is noted in athletes, especially in lower-extremity intensive sports. Tight hip flexor muscles will anteriorly rotate the pelvis and can cause excessive lumbar lordosis because of the hip flexors' attachments on the spine and pelvis [19]. Muscle tightness of the hip flexors may alter normal movement at the hip and down the kinetic chain. Optimal movement requires proper musculoskeletal movement and force to occur in symphony at the lumbo-pelvic-hip complex. Anything to alter normal lumbo-pelvic-hip function may decrease performance [5]. This could lead to increased risk of injury, decreased athletic performance, and hip pain. If the pelvis is excessively chronically anteriorly rotated, the hamstrings and gluteus maximus will be held on stretch [5]. Because muscle length will affect the ability of the muscle to produce force [4], the hip extensors may not function properly. The altered length-tension relationship between the hip flexors and hip extensors may result in abnormal movement patterns.

It is important for the athletic trainer to identify s tight hips flexors and anterior pelvic tilt o the athlete can correct muscular imbalances which may lead to injury if left untreated. Additionally, recreational and competitive athletes want to maximize performance, so abnormal length-tension relationships should be corrected to help them attain their goals.

The Thomas test is often used to test for mono-articular and bi-articular hip flexor tightness as well as identifying tightness of the hip abductors [19]. This test assesses the degrees of hip extension range of motion (ROM) with contralateral leg pulled toward the chest and the pelvis posteriorly rotated. A modified Thomas test is often done by keeping the hip in a neutral position relative to abduction and adduction. This allows for the assessment for tightness in only the hip flexor muscles.

When the athletic trainer finds an athlete with a positive Thomas test, stretching is often recommended to correct the problem. Three main techniques of stretching include static, dynamic and proprioceptive neuromuscular facilitation (PNF). Static stretching involves taking an agonist to maximal length and holding it in that position [20]. Dynamic stretching involves actively moving a muscle through a range of motion to increase flexibility. PNF stretching combines a contraction of the agonist to allow for greater ROM gains than with static stretching. There are several methods for utilizing PNF stretching including hold-relax, contract-relax, and slow-reversal-hold [11].

Most studies have demonstrated that PNF stretching produced the greater increases in ROM when compared to static stretching protocols [21-23].

While there is a great body of research on the chronic and acute effects of static stretching on performance, more research needs to be done on how PNF stretching affects performance variables. PNF stretching could increase athletic performance, especially in those with tight hip flexors and excessive anterior pelvic tilt by restoring optimal muscle length of the hip flexors and hip extensors allowing for an increased the strength of the hip extensors. In those without hip flexor tightness, stretching the hip flexor musculature could decrease performance by the same mechanisms.

Anatomy

The hip joint is a ball and socket joint, where the head of the femur sits in the acetabulum of the pelvis, providing a great amount of stability. The surrounding ligamentous tissue is strong and there is extensive musculature about the joint.

On the pelvis, the anterior superior iliac spine is a boney landmark on the anterior iliac crest serving as an attachment site for the sartorius and tensor fascia latea. The posterior superior iliac spine is a boney landmark on the posterior pelvis just lateral to the sacro-iliac joint.

The largest muscle groups about the hip are the hip extensors and the hip flexors. The hip extensors are the gluteus maximus, the gluteus minimus and hamstring muscles. Because the hamstrings primarily to flex the knee, the gluteus maximus is the prime hip extensor muscle. There are seven hip extensor muscles that are either mono-articular or bi-articular. The mono-articular muscles are the psoas major, psoas minor, iliacus, and pectineus. The bi-articular muscles are the sartorius, rectus femoris, and tensor fascia latea. These muscles also contribute to movement at the knee.

Hip Flexor Tightness

Anecdotally, clinicians notice hip flexor tightness in athletes participating in sports involving running such as track, soccer, and other lower extremity intensive sports. This may occur because athletes concentrate on stretching their hamstrings without stretching their hip flexors. The hip muscles were one of the least stretched muscles in a survey of 238 athletes across 10 different sports [24]. However, this study did not specify which muscles were considered hip muscles in their survey. Additionally, in some sports, athletes spend great amounts of time with their hips flexed, such as in tennis and rowing.

Kendall has described hip flexor tightness as an inability to achieve full hip extension when in the modified Thomas test position [19]. The Thomas test is perhaps the most common method of assessing tight hip flexor musculature. This test involves having the patient sit at the edge of the table and bring the ipsilateral knee towards his or her chest. Then the patient is instructed to lie back on the table. While keeping the sacrum flat on the table, the examiner measures the angle between the hip and the table to assess the flexibility of the mono-articular hip flexors. The angle at the knee assesses the flexibility of the biarticular hip flexors. This test can also assess iliotibial band tightness by measuring the angle of abduction at the hip joint. When assessing flexibility in subjects who are hypermobile, the examiner needs to ensure the pelvis is not posteriorly rotated, as this could have a false positive result [19]. Many clinicians modify the Thomas test to solely assess hip flexor musculature. By ensuring the leg does not rotate, the modified Thomas test will strictly assess hip musculature tightness in the saggital plane.

Harvey reported normative data for 117 elite athletes for the modified Thomas test and found an average of 11.91±5.57 degrees of hip extension [25]. However, the ability of the Thomas test to determine functional hip extension in activities such as running and kicking may be limited. A significant but weak correlation (r=.41, P < .05)was found between the degree of hip extension in the modified Thomas test and the degree of hip extension utilized when walking at a comfortable speed in those with hip flexor contractures [26]. There was almost no correlation between the amount of hip extension during the Thomas test and the degree of hip extension during running[27]. In kicking, there was a significant correlation between hip extension in a Thomas test and maximal hip extension (r=.65, P < .01) and with hip angle at maximal knee flexion (r=.70, P <.01) [28]

Another study recently introduced the iliacus test to assess to hip extension allowed by the structures that cross solely the hip joint. In this test, subject and tester positioning is similar to the Thomas test, though the tester will apply posterior pressure to the anterior superior iliac spine to counteract the force of the leg being extended. Because of the significant decrease in motion in this test compared to the Thomas test, the authors concluded that the iliacus complex may be more limiting of hip extension that the other hip flexors [29].

There is limited information in the literature regarding the association between tight hip flexor musculature and injury to the lumbo-pelvic-hip complex. However, Clark has suggested that any tightness will alter biomechanics throughout then kinetic chain [5]. One study demonstrated that hip flexor tightness will decrease contralateral step length as well as gait economy [26]. Though this study employed subjects with cerebral palsy and other disorders which commonly present with tight hip flexors, this still may be applicable for the athletic population. Hip flexor stretching has been shown to increase static and dynamic hip extension as well as peak plantarflexion torque [30, 31]. An increase in ROM could, in theory, decrease the risk of injury. Additionally, if an athlete has tight hip flexors, the athlete will most likely have some pain in the anterior hip. If this pain is moderate to severe, this could hinder athletic performance by altering the motion of the pelvis.

Anterior Pelvic Tilt

Control of the pelvis is critical for core stability. The muscles about the pelvis may not be able to maintain the proper position because of tightness or weakness. Pelvic tilt in the saggital plane is a common dysfunction and excessive or diminished movement at the pelvis will result in abnormal movement patterns. To perform motions efficiently, the pelvis must move to meet the demands of the activity.

When the hip flexor muscles are tight, they may cause excessive anterior pelvic tilt because of the iliopsoas' attachment on the pelvis. Anterior pelvic tilt is defined as the rotation of the pelvis perpendicular to the vertical axis [26]. Kendall [19] stated that normal anterior pelvic tilt should be zero degrees so that the anterior superior iliac spine (ASIS) should be in vertical alignment with the pubic symphysis. Additionally, the posterior superior iliac spine (PSIS) and the ASIS would be in the same horizontal plane. However, studies have reported anterior pelvic tilt values between 1.68 and 11 degrees in standing[32, 33]. Most studies measure pelvic tilt as the angle between the ASIS and PSIS because it is more cost efficient than determining the angle between the pubic symphysis and the ASIS. This could cause anterior pelvic tilt values to be skewed because it is common for the female pelvis to exhibit a lower ASIS. This could be misinterpreted as an increase in anterior pelvic tilt [34]. Unwanted tilting of the pelvis can be caused by poor neuromuscular control of the lumbo-pelvic-hip musculature and/or tight hip flexors [34].

Excessive anterior pelvic tilt may predispose athletes to lumbo-pelvic-hip injury and decreased athletic performance. Lumbo-pelvic-hip complex injuries account for 14% of injuries [32]**.** While this is not a large percentage of injuries, many of these injuries are musculoskeletal in nature and take longer to heal than injuries to other areas of the body [32]. Additionally, an increase in anterior pelvic tilt has been associated with an increased risk for an anterior cruciate ligament (ACL) injury according to two retrospective studies [33, 35]. While females had significantly higher anterior pelvic tilt than males, in both sexes there was a strong correlation between ACL injury and degree of anterior pelvic tilt [33]. Because there may be a relationship between tight hip flexors and anterior pelvic tilt, then hip flexor tightness may be indirectly related to an increased rate of ACL injury.

While anterior pelvic tilt ranges from 1.68 and 11 degrees in standing, this will change during movement [27, 32, 36]. Pelvic tilt increased from 11 degrees to peaks of 15-20 degrees during running, increasing as running speed increases. During running, the pelvis will be most posteriorly rotated during the stance phase and become most anteriorly rotated during toe off. The pelvis will exhibit another cycle of tilting during the swing phase; at the beginning of swing, the pelvis will be slightly posterioly rotated and will move in anterior rotation during the late swing phase [32]. If the pelvis is not allowed this motion during activity, compensatory motion must come from other structures and may cause injury.

Hip Extension

Hip extension involves osteokinematic motion at the hip joint as well as anterior pelvic tilting to have normal motion. According to the American Academy of Orthopedic Surgeons and the American Medical Association normal hip extension ROM is 30 degrees, although only ten degrees of hip extension are necessary for normal walking [37]. Hip extension can be measured with a digital inclinometer or a standard universal goniometer. One study assessed the reliability and validity of the electric inclinometer compared with the two universal and found that the inclinometer consistently measured a greater ROM for active hip internal and external rotation and for passive hip extension, internal and external rotation [38]. However, the inclinometer did have high intratester reliability for measuring all hip motions. Intertester reliability was also higher than the goniometer for assessing internal and external hip rotation. This study did not compare measurements active hip extension [38].

Proper measurement of hip extension ROM is important because the hip extensors play a vital role in activity. Hip extension could be limited because of tight hip flexors. Additionally, restricted hip flexors could hold the hip extensors on stretch. This chronic lengthening could reduce the strength of the hip flexors.

Reduced strength of the hip extensors will decrease performance. During normal gait, the gluteus maximus is activated during late swing phase as it begins to eccentrically decelerate the thigh. Additionally, it assists in pelvic stabilization during the beginning of the swing phase. The hip extensors accelerate the body's center of gravity and 88% of running speed can be explained by the averaged horizontal forces during the push-off phase of running [6]. Electromyographical (EMG) data of the gluteus maximus demonstrated while the amplitude of muscle activity increased with increased running speed, its duration of activity remained constant even though ground contact time decreased as running speed increased [6].

Increased EMG amplitude of the hip extensors was reported after restricted hip flexors had myofascial release [39]. Hip extensor strength has been shown to have a strong correlation with sprint speed in Division 1 athletes[40], since the hip extensors are the prime movers for accelerating the body [41]. In this study, the protocol for measuring isokinetic strength was done in a functional upright position as opposed to other protocols which did not find significant correlations between hip strength and speed.

Force-length Relationship

The ability of a muscle to produce enough force at the right time is critical for athletic performance. A muscle can only develop maximum force when myofilaments overlap optimally; therefore a muscle will generate maximal force at a certain length.

Myofibril cross-bridging will decrease in shortened or elongated muscle fibers, decreasing the amount of force the muscle is able to generate [42, 43]. The length of a muscle will be influenced by connective tissue about the muscle, sarcolemma, muscle fibers, tendons, and friction within the hip joint [44]. Reciprocal inhibition can also affect the length of muscles. When tension develops in one muscle, its antagonist muscle must reflexively relax to allow the agonist muscle to move through a ROM. If a muscle is tight, tension develops within the sarcomeres. This could, in theory, cause reciprocal inhibition of the antagonist muscle.

Because there is only one length where a muscle can produce maximal force, all muscles regularly produce force at a length that is less than optimum [45]. Lengthening the muscle-tendon unit of the soleus one centimeter decreased the peak torque by 30% [43]. Progressive shortening of the muscle will correspond to decreasing voluntary and involuntary torque. One of the reasons for this could be that as a muscle shortens the insertion angle of the muscle fibers change. One study reported that when the gastrocnemius had shortened 24mm, the angle of the muscle fibers increased by 22 degrees [46]. To compensate for the decrease in torque production, the central nervous system (CNS) may increase the number and rate of motorneuron firing. Once these already shortened muscle fibers reach maximal contraction, their contribution to force production will be limited. Additionally, a decrease in motor neuron activation of shortened fibers has been demonstrated. The decrease in strength in lengthened muscles may be a result of onset activation time and/or muscle fiber type. In addition to a decrease in strength, shortened muscle fibers had a delayed onset of activation. This could be do to higher brain centers reducing the number of motorneuron pools stimulated or, more likely, reducing activity of peripheral afferent receptors such as muscle spindles. Research has not demonstrated whether or not the decrease in excitability occurs in the entire motor unit or just the fibers which are shortened [45]. One study measuring nerve conduction velocity in muscles in stretched and shortened positioned found that conduction velocity slowed 22% when the muscle was lengthened and increased 33% when the muscle was shortened [4]. Slow twitch muscle fibers are generally recruited before fast twitch fibers. However, if their length is decreased, slow twitch fibers will be inhibited and fast twitch fibers will be recruited first [45]. If this phenomenon occurs in the hip extensors which produce the force for increased running speed, optimal athletic performance will be hindered.

If an athlete presents without tight hip flexors, lengthening their hip flexor musculature could be deleterious to their athletic performance and risk of injury because this alters the force-couples and length-tension relationships about the hip. However, if an athlete presents with tight hip flexors, lengthening them may lead to increased performance, decreased risk of injury, and decrease in anterior hip pain due to restored force-couples and length-tension relationships about the hip. One of the most common and efficient ways to accomplish this is through stretching.

Stretching

Rationale for Stretching

Stretching is often used to decrease injury and improve performance. One of the most common reasons stated for employing a stretching program is injury prevention, which is certainly a worthy goal. However, the literature is divided on whether or not stretching will in fact reduce the risk of injury [12]. A sampling of a stretching protocols among intercollegiate athletics found that the hamstrings were the most commonly stretched muscle, but also that injury to the hamstrings were one of the most common reported muscular injuries [12]. Even so, stretching is often utilized as a prophylactic measure in individuals with no known pathology [42], though recent studies do not support the assumption that stretching will reduce risk in musculoskeletally asymptomatic individuals [42]. Stretching may reduce injury by causing structural changes within the muscle that will increase resistance to eccentric forces. Because eccentric overload is a common mechanism of muscular injury, the increase in muscle length could decrease the incidence of overstretch.

Several studies have demonstrated that chronic stretching will lead to an improvement in performance. Improvements in sprint speed, eccentric and concentric strength have been found after several weeks of stretching intervention. Chronic static stretching has been shown to increase sport specific performance [47] and been shown to improve running economy[48]. One study found that a rebound bench press was improved after stretching, probably due improved ability to store and release elastic energy [17].

In recent years, many studies have been published concerning the negative acute effects of stretching [1, 9, 10, 14, 17, 18, 42, 49-51] Most have reported decreases in strength, peak torque, reflex activity, power, and balance immediately following static stretching. The length of time that these deficits exist varies between studies, most likely due to stretching protocol. These studies suggest that acute stretching will decrease athletic performance.

Types of stretching

Static, dynamic and proprioceptive neuromuscular facilitation (PNF) stretching are employed by athletic trainers to elicit increases in ROM, lengthen chronically tight tissues, facilitate faster movements [50], decrease injury and increase athletic performance [12, 51-53]. Several authors report that static stretching is the most common method of stretching employed for muscle lengthening[12, 54].

Static stretching involves passively stretching an antagonist muscle by placing it in a maximal stretch and holding it there [20]. The increases in ROM when using static stretching were thought to be due to the tensile stress applied to the muscle. However, one study concluded that the majority of the ROM increases from static stretching comes from the tensile stresses applied to the muscle [42].

Dynamic stretching involves actively moving muscles through a given range in a series of patterns. Dynamic stretching is thought to improve flexibility in the sport-specific motion through which it is performed.

PNF stretching involves a combination of muscle contractions and stretches to maximize neurogenic mechanisms for increases in ROM. PNF stretching was first defined by Knott and Voss as a method of "…promoting or hastening the neuromuscular mechanism through stimulation of the proprioceptors". Some studies have shown that gains in ROM from PNF are comparable with gains seen from static stretching. One study found no significant differences between static and PNF stretching done with and without 60 minutes of exercise [23], but still recommended PNF stretching following exercises because of the extra gains observed.

Three methods for performing PNF stretching are contract-relax, hold-relax and slow-reversal-hold. Contract-relax involves a stretch of the antagonist muscle followed by a contraction of the antagonist muscle through a range of motion and a further stretching of the antagonist muscle after it relaxes. Hold-relax involves a stretch of the antagonist followed by an isometric contraction of the antagonist and further stretching of the antagonist after relaxation of the agonist. The pre-stretch contraction in theory allows for autogenic inhibition mediated by the golgi tendon organs (GTO's). Slow-reversal-hold involves active contraction of the agonist muscle, stretch of the antagonist muscle, an isometric contraction of the antagonist followed by further stretching of the antagonist muscle. The activation of the agonist muscle in theory allows for further ROM gains through reciprocal inhibition.

Several theories exist for why PNF stretching will increase ROM. One is that the contraction of the muscle will decrease muscular stiffness. Several studies suggests that increases in ROM result due to a reduced sensitivity to stretch [55-57].

PNF stretching will increase muscle temperature because of the use of muscular contractions. This will increase nerve conduction velocities which have been linked to more forceful contractions. Additionally, the increase in metabolic rate and decrease in muscle viscosity will allow for smoother muscular contraction and therefore improved muscular function [12]. Active stretching has been shown to improve antagonist function, though research has not shown that this method is significantly better than static stretching for tight agonist lengthening [42]. Strengthening of the antagonist muscle may allow for greater dynamic ROM in activity. Since slow-reversal-hold PNF stretching utilizes an active antagonist contraction, it may allow these benefits of active stretching.

The amount of time that increases in ROM last varied depending on stretching protocol. One study employed a modified hold relax stretch with the hamstring muscles and found that significant increases in ROM only lasted six minutes. In this study, the subjects lay still after being stretched [8]. Perhaps engaging in physical activity would increase the length of time the ROM increases would last.

Many studies employing static stretching techniques found decreases in performance parameters such as strength, power, and reaction times. These reductions could be due to reductions in neural excitability [11]. It appears that a muscle contraction will increase neural excitability. Young and Behm (2003) found that a warm-up protocol of stretching and running produced the lowest values on a jumping activity. The same warm-up with added jumps produced the largest values. This could be due to the increase in muscle activation often seen after contractions. Increased Hoffman (H) reflex activity present ten minutes following contractions suggested that muscle contraction can influence motor neuron excitation. This suggests that active muscular activities will increase the muscles' ability to perform in strength and power activities. If PNF stretching is used, perhaps the neural excitement occurring during the contractions will help offset some of these decreases.

Chronic PNF stretching will result in increases in muscular strength. Handel et al (1997) found increases in torque angular velocities of eccentric, isometric, and concentric contraction [50]. It has been suggested that the contractions utilized during PNF stretching could have similar effects as isometric strength training. In an isometric training protocol where total contraction time was 1200 seconds, an increase of isometric strength of twenty percent was seen. If PNF contractions were performed consistently over time, increases in strength could be expected. Chronic stretching could also alter the inert structures around the joint such as ligaments and joint capsules that could result in altered mechanics during movement.

There is limited research on the ability of PNF stretching to cause the same decreases in force, reflexes, endurance and reaction time as static stretching. One study stretched found that using PNF stretching of the hip extensors decreased peak torque, muscle activation, and increased ROM [58]. Another study found decreases in the stretch reflex in some of the hamstrings, but not the others after an acute bout of PNF stretching. It suggested that these results were due to muscle spindle desensitization and muscle size [59].

Effects of Stretching on Short Muscles

Limited research has been done on the effects of stretching on tight or short musculature. When assessing the effects of passive straight leg raise stretching on subjects with tight hamstrings, Halbertsama (1999) found no difference between pre and post stretch for ROM, stretch tolerance, onset of EMG, pelvic tilt, or onset of pain. Because other studies have shown increases of stretch tolerance and onset to pain (Magnusson, 1995 #130;Kubo, 2002 #129), this study may suggest that people with tight musculature will respond differently than those with normal muscle length and compliance [44].

In one study on the effects of a single bout of stretching short hamstrings, five successive stretches were performed until the first sensation of pain. After the fourth stretch, a submaximal contraction was performed. The musculotendinous stiffness on the fifth stretch was not different from that of the fourth, suggesting that either multiple submaximal contractions or a longer stretch period will be needed to change mechanical properties of the muscle. In this study, the leg was lowered immediately after the first sensation of pain was felt. Additionally, EMG data collected in the study suggests that the first sensation of pain represents the muscle's stretch tolerance since the first sensation of pain was when the muscle activity began to increase [44]. With this information it would appear that when applying a passive stretch to those with tight muscles, the stretch should be increased until the first sensation of pain is felt. However, in another study, EMG data collected during a PNF stretching in gymnasts was not correlated with reaching maximal stretch [60]. The varying onset of EMG activity may be a result of the rate of stretch, which if increased, would cause EMG activity before maximal stretch was achieved. Additionally, the gymnasts may or may not have had tight muscles before the stretch was applied. These two studies suggest increases in ROM that do not correspond with EMG activity, muscle stiffness or tension.

Affects of Acute Stretching

Most studies dealing with the effects of acute stretching on performance parameters employ static stretching. Acute static stretching has been shown to decrease muscular endurance[16], as well as maximal strength [15]. Reductions in strength followed acute stretching and ranged from 5-30% [1, 14, 16, 17]. While these differences may not seem large, in elite athletes, small decreases in force could change competition results. Additionally, acute static stretching of the hamstrings increased perceived exertion ratings during sub-maximal hamstring curls, although this did not change the number of repetitions performed [61].

As the stretching protocols utilized in many research studies are not used clinically, the results must be carefully interpreted and applied. Avela et al (1999) found a significant 23% decrease in MVC of the triceps surae muscles, but the stretching protocol allowed one hour of continuous stretching [62]. While one study found no decrease in force after a clinically relevant 135 second intermittent stretching protocol [1], most studies report significant force decrements after static stretching. Kokkonen et al (1996) reported 7% and 8% decreases in maximal knee flexion and extension after an acute bout of 180 second intermittent static stretching [15].

One study found that the plantarflexors had decreased strength 60 minutes following 30 minutes of passive stretching [14], but another study showed strength returning to pre-test measures after 15 minutes. Some studies looking at different isokinetic testing speeds found significant decreases in strength in lower speeds, but not others [10]. Slower speeds, 60, and 90 deg/sec (1.57 rad/sec), produced significant force decreases while faster speeds, 120, 180, and 200 deg/sec (2.62, 3.67, and 4.71 rad/sec), did not produce significant decreases. When comparing isokinetic torque at different speeds after stretching, authors concluded that knee extensor sarcomere length caused decreases in isometric torque at 162 degrees flexion of but not at other angles. The decreases in torque associated with stretching appeared to be velocity dependent [10]. However, a more recent study found decreases as slow and fast speeds, suggesting that force decreases are not velocity dependant [58]. One of the shortcomings of measuring isokinetic strength is that speed is controlled. Functional activities often reach maximum velocities that are too great to measure on an isokinetic machine as well as employ changing speeds at different segments that accelerate and decelerate at different rates.

Several studies have investigated the length of time that deficits after acute stretching last. Fowles et al (2000) found significant decreases in MVC of the plantarflexors 60 minutes after 30 minutes of passive stretching. This decrease in force was associated with decreased muscle activation and was present 45 minutes after full activation of the plantarflexors was restored [14]. Sixty percent of the force lost immediately following stretch was considered to be mediated by neural mechanisms and the remaining 40% was muscularly mediated. This was calculated using Duchateau's formula, which divides force into motor unit activation and muscle force parts. At 30 minutes post stretch, the muscular changes accounted for only 10% of the force loss [14]. Power et al (2004) investigated the results of a less continuous stretching protocol. However, even after a bout in 270 seconds of intermittent stretching, significant reductions in force lasted up to 120 minutes post-stretch. Additionally, a significant reduction in quadriceps activation was measured in the stretching group [17]. Interestingly, the other muscle groups in the study did not exhibit significant force reductions. Although there were slight decreases in EMG activity, peak twitch forces and jump heights but these differences were statistically non significant. This may indicate that a less continuous stretching protocol will still induce significant decreases in force and inhibition, but this may not cross over into performance variables, such as jumping [17]. The concurrent inactivation of the quadriceps and decrease in maximal voluntary contraction (MVC) suggested that a neurologic mechanism is the cause of the decrease.

In an attempt to explain the force loss for such an extended period of time, Fowles discounted golgi tendon organ (GTO) feedback because the stretch in his protocol was not intense enough to illicit a strong GTO response and because GTO's are not active throughout a continuous stretch. Additionally, the force decrements are probably not due to the H-reflex because the inhibitory effect of this is only present during a stretch stimulus [14], though other studies have shown decreases in H-reflex activity several minutes after stretching ceased [62]. Another study discounted the role of the H-reflex causing decreases in strength because inconsistent deficits in isokinetic tests at different speeds [10]. If the central nervous system was responsible for force loss, it would seem that force decreases would be seen at all speeds of isokinetic testing. However, in other studies, prolonged stretching causes reductions in reflexes, which are directed by the central nervous system [62, 63]. Mechanoreceptors and nociceptors could have caused the post stretch muscle inactivation. Increases in intra-articular pressure can result in muscle inactivation as well. Performing stretching with the joint in a close-packed position may illicit such a response [17]. In one study, four thirty second stretches static stretches increased ROM for only three minutes [64], suggesting that the force decreases may not be associated solely with muscle length.

In addition to strength losses, an acute bout of stretching has been shown to decrease balance, reflexes, speed, joint position sense and reaction times [1, 60] and the angle at which peak torque is developed [9]. Behm (2004) found no significant difference between stretch and non stretch groups when comparing ability to judge 30% and 50% of maximal voluntary contraction (MVC). However, there were significant changes in both balance and reaction time when comparing pre-stretch and post-stretch test differences [1]. To balance on an unstable surface where anticipatory adjustments are necessary, the musculature of the lower extremity responds before the central nervous system. Neural or mechanical changes to the muscles that stabilize the body could alter ability to balance [1]. Avela et al (1999) found significant reduction on reflex activity after one hour of continuous passive stretching of the triceps surae muscles [62, 65] and another study found significant decreases in sprinting speed in young gymnasts after an intermittent stretching protocol lasting only two minutes [60]. One study looked at deficits in vertical jump and found that the knee joint angle where peak force was produced was not different between stretch and non stretch conditions [10], although Nelson et al (2001) concluded that the strength deficits following stretching were specific to joint angle [9]

Extensibility of the muscle is limited by both static and dynamic tissue. The static tissues, collagenous tissue surrounding the muscle fibers and the tendons, are most effectively lengthened through low-load long duration stretching, though this method is not as effective at increasing motion in contractile tissue, or muscle fibers. Two mechanisms that limit the flexibility in contractile tissue are neurogenic and myogenic components. Neurogenic components are autogenic and reciprocal inhibition. These have not been directly measured in current research, but rather suggested by the diminished H reflex during PNF stretching. The H-reflex measures the excitability of the motorneuron and the ability of the Ia afferents to transmit signals to the motorneuron [18]. Myogenic components are the myofibrils resistance to stretch. Another factor affecting the extensibility of the muscles could be the muscle fiber type, as slow twitch fibers appear to be more pliable than fast twitch fibers [17]. Muscles that produce a lot of power which are dense with fast-twitch fibers may respond differently to stretching protocols than muscles composed primarily of slow twitch fibers. Changes in muscle and tendon mechanical properties and changes in neuromuscular components of the musculoteninous unit have been hypothesized to be responsible for changes in muscle performance due to stretching.

Stretching is hypothesized to change the mechanical properties within the muscle, namely an increase in length. An increase in muscle length could decrease stiffness within the muscle. Stiffness is defined as the ratio of a change in force divided by the change in length of the muscle while stretching [66]. After an extended stretching routine, Fowles et al (2000) found an increase in fascicle length of 8mm, causing a decrease in stiffness. A decrease in stiffness could slow the rate of force transmission, the rate at which muscle length and tension are detected, as well as the transmission of forces within the musculotendinous unit. Additionally, reduced stiffness may decreases muscle activation and could result in decreases in reaction time and the amount of time it takes to perform a task [14]. The increase in length of the muscle could also decrease the amount of cross-bridging within the muscle. One study investigating the relationship between static stretching and maximal voluntary contractions on the Achilles tendon concluded that static stretching decreased stiffness and internal resistance to stretch, while muscular contractions only decreased stiffness [67]. While passive musculotendinous stiffness has been reduced after static stretching, active stiffness, the ability to store elastic energy within the series elastic component, was not altered after passive stretching of the triceps surae group [68]. This suggests that passive stretching will not affect the ability of the muscle to store elastic energy, and consequently, not affect power activities such as vertical jumping.

In addition to mechanical changes, stretching could also affect neural mechanisms. Stretching has been shown to be detrimental to the CNS due to decrease in reflex sensitivity after prolonged static stretching. Even though neural propagation was not altered after 1 hour of stretching, the excitation of the afferent H reflex was significantly reduced. Additionally, one study found that stretching one leg led to significant decreases in contralateral leg force production [13]. This research supports the theory that the CNS will alter neural mechanisms after acute stretching. Rosenbaum (1995) concluded that increases in tendon length due to stretching caused decreases in peak force, rate of force development, and EMG amplitudes of Achilles tendon reflexes. After a warm up, these decreases were non significant, though it was not determined if this was due to time from the stretching stimuli or the excitatory effect of muscular activity [69].

Athletic Testing

Many athletic teams use testing to assess different aspects of fitness for their team members. Common tests include mile runs, vertical jumps, agility runs, strength tests, and timed sprints. Coaches use the information from these tests to identify weakness of their teams. Vertical jumps and agility tests are common in athletics because leg power and ability to quickly change directions are crucial components of many athletic events.

Vertical Jump

Vertical jump(VJ) testing can be performed a variety of ways including single leg, double leg, with or without arm swing, and with or without takeoff steps. The VJ is a complex movement that can be affected by multiple factors. Trunk strength contributed about 10% of total vertical jump height in one study that evaluated segmental contribution to VJ height [70]. Arm swing has been shown to contribute around 10% to VJ height [7], though one study found it supplied 21% [71]. Amplitude and speed of countermovement, amount of time between eccentric and concentric contraction, as well as timing of segmental movements all have been shown to affect VJ height [70].

Vertical jump heights has been correlated with leg strength and power, particularly of the leg extensor muscles [7]. Young (2001) questioned the validity of using the vertical jump to assess leg extensor function as shoulder and hip flexor training increased jump height in the absence of leg extensor changes. However, only two of the five jump types were greater than the control group. These two jumping techniques involved free arm swing or single leg jumps. In the single leg jumps, the free leg and was not controlled, potentially changing the results instead of the training protocol [7]. Bobbert and Van Soest (1994) analyzed the effect of leg extensor training in a simulation on vertical jumps and found decrease jump height despite strength changes when timing of each body segment was controlled. However, when no limits were set for movement timing, significant increases were measured [72]. Young and Wilson (2001) found good test – retest reliability when zeroing the lowest point of the yardstick device to the highest reach of the subjects' reach when standing flat-footed. The subject would then stand on both feet and move as many arms of the yardstick device as possible. The moved arms from previous jumps were not returned to the starting position for motivation purposes [7].

Two studies utilized a vertical jump to assess decreases in power after static stretching [73, 74]. PNF stretching of the hamstrings and quadriceps reduced vertical jump heights when compared static stretching and no stretch condition [73]. Groups that performed a warm-up with static stretching and those just completing a warm-up did not differ in maximum vertical jump height [73]. However, another study found no decreases in VJ height, despite significant strength decreases in quadriceps muscle strength [17].

Agility Test

Agility tests examine the ability to change directions while maintaining speed. The Southeastern Missouri (SEMO) agility test involves side-shuffling, forward sprinting, and backward pedaling. The SEMO agility test has an inter rater reliability of .97 as well as a .63 correlation with the American Alliance for Health, Physical Education and Recreation (AAHPER) shuttle run test [75].

Summary

Muscular tightness is common in athletics and can cause alter movement patterns which can decrease performances or predispose someone to injury. Because athletes want to perform optimally, maintaining muscular balances is important. Stretching is commonly utilized by the clinician and athlete to lengthen tight muscles. Stretching is thought to enhance performance and decrease risk of injury.

Static stretching is the most common method of stretching and the literature has generally shown that chronic static stretching will improve performance [48], though many studies have demonstrated deficits in strength, speed, power and balance after acute static stretching. However, several of the stretching protocols are not typically performed in the athletic world. One study demonstrated no strength deficits after a shorter bout of acute stretching [1].

PNF stretching is commonly used in the clinical setting. However, there is little information regarding the effects of PNF stretching. While static stretching causes deficits in strength, the effects of acute PNF stretching have not been thoroughly investigated.

Additionally, even if there are decreases in force, these decreases may not be of a magnitude that will significantly affect functional performance.

The relationship between tight musculature, stretching, and performance needs to be understood better. With this knowledge, the clinician can make decisions about acute stretching in those with and without tight musculature.

CHAPTER THREE-METHODS

All testing was performed done in the Sports Medicine Research Laboratory in Fetzer Gymnasium at the University of North Carolina Chapel Hill. Each subject reported to the research laboratory for one testing session. Upon arrival, subjects read and signed an informed consent form as approved by the Biomedical School IRB. Then, subjects completed a short questionnaire about activity type, previous medical history, and their height and weight were recorded

Each subject warmed-up on the bike for five minutes before testing procedures. The distance from the anterior superior iliac spine to the base of the medial mallelous was measured to determine leg length. Hip extension range of motion (ROM), anterior pelvic tilt, leg extensor strength, vertical jump height and agility were measured. The testing order for these measures was counter-balanced. The dominant leg, determined by which leg the subject would use to kick a soccer ball, was tested for all procedures. The principle investigator was blinded to subject group.

Subjects

Forty-five recreationally active (18-25 years) students from the University of North Carolina Chapel Hill were recruited for the study. Subjects were placed into one of three groups. Thirty subjects with hip flexor tightness were randomly assigned without replacement to a tight stretch (TS) and a tight control (TC) group. Fifteen subjects without tight hip flexors were assigned to the not tight stretch (NTS) treatment group. Subjects regularly participated in physical activity at least three hours per week. No testing procedures were done if the subject had participated in strenuous activity within the past four hours. Subjects were excluded if they have had a lower extremity injury within the past three months which restricted activity for more than one day, lower extremity surgery within the last six months, current participation in a formal rehabilitation program for a lower extremity condition, or previous diagnosis of a leg length discrepancy. Additionally, subjects were excluded if the cause of the tightness in their hip flexors was due to iliopsoas trigger points. Subjects were excluded for active trigger points if they had to modify their activity for one day or more because of hip pain in the past three months since tightness caused by trigger points is often treated with myofascial release instead of stretching. All subjects were instructed to wear athletic shorts and athletic shoes during the testing procedure.

Modified Thomas Test:

The Thomas test was performed and recorded by a research assistant to determine which group the subject was placed in. The primary researcher was blinded to the results of the Thomas test until after the data for that subject had been collected. The subjects sat on the edge of the treatment table and held their non-dominant leg to their chest and then lay on their back with their pelvis flat on the table (see Figure 1). The examiner ensured the pelvis is on the table by palpating the posterior superior iliac spine and ensuring contact with the table. The examiner aligned a universal goniometer with the axis at the greater trochanter and the arms aligned with the lateral femoral condyle and midline of the rib cage. If the leg angle was10 degrees or more from horizontal plane of the table, then the subject was placed in the tight hip flexor group. If the subjects' leg was flat on the table, the subject was placed in the normal hip flexor group.

Testing Procedures

Figure 1

Modified Thomas Test

Hip Extension ROM

The subject lay prone on the examiners table and flexed their dominant knee thirty degrees [37]. This was measured by the researcher using a digital inclinometer and the subject was instructed to maintain the joint position for the test. The inclinometer was placed on the mid-posterior thigh. The subject then actively extended his/her hip as far as they could without lifting their pelvis off the table (see Figure 2). The examiner ensured that the subjects' anterior superior iliac spine (ASIS) remained in contact with the table. Subjects performed this action two more times and the average of the three measurements was used to calculate hip extension ROM. The ICC (2,1) for the three ROM measurement was 0.99 with an SEM of .64 degrees. The ICC (2,k) for the TC group pretest and posttest was 0.99 with an SEM of 0.57 degrees.

Figure 2

Hip Extension ROM

Anterior Pelvic Tilt

Anterior pelvic tilt measurements were taken with the subject standing in a neutral position. To ensure that posture was neutral, each subject was instructed to reach their hands to their knees, flexing at the trunk and to return to a comfortable upright position five consecutive times. A digital inclinometer was used to measure anterior pelvic tilt. Calipers were placed on the PSIS and the ASIS and the angle between the two was measured (see Figure 3) using an inclinometer. A bubble level was placed on the calipers to ensure the calipers remained level in the frontal plane so that the measurement of anterior pelvic tilt was recorded in the saggital plane. This measurement was taken three times and the average of the three measures was used to calculate anterior pelvic tilt. The ICC (2,1) for the three anterior pelvic tilt measurements was 0.99 with an SEM of 0.258 degrees. The ICC (2,k) for the TC group pre and post test was 0.99 with an SEM of 0.62 degrees.

Figure 3

Anterior Pelvic Tilt

Agility

Agility was measured using the Southeastern Missouri (SEMO) test. The SEMO agility test measured the ability of maneuvering the body forwards, backwards and sideways. It is a test designed to measure general agility of a subject [75]. The SEMO test was tested on a tile floor (see Figure 4). Subjects performed two warm-up trials, once to familiarize themselves with the course and once at full speed. The subject ran the test two times with one minute rest in between tests. The average of the two trials was recorded. The test was timed using a handheld Accusplit Eagle Memory 100 stopwatch. If the subject ran the wrong way during the test, the trial was not counted. If the subject moved a cone, the trial counted as long as they completed the drill correctly. Only three of the 45 subjects needed to repeat the SEMO drill because they did not follow the pattern. These subjects were given a one minute rest period before repeating the test.

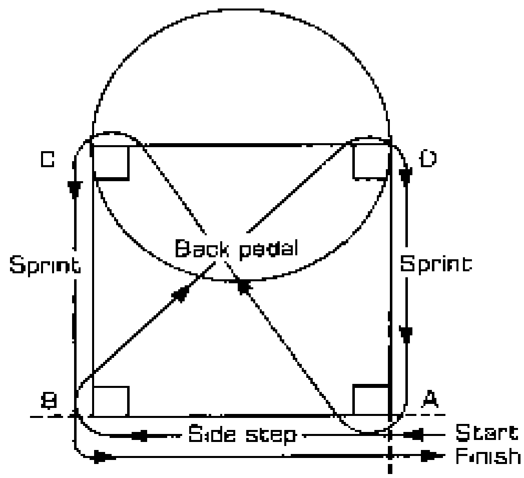


Figure 4

SEMO Drill

Vertical Jump

Vertical jump was measured with the Ver-Tec (Sports Imports, Hilliard, OH) normalized to subject reach height. The vertical jump is a common test utilized to measure power in the lower extremities [7, 76, 77]. A countermovement jump is a modified vertical jump where the subject is allowed to lower him/herself and jump vertically. Countermovement jumps have been significantly correlated to sprint speed and leg press strength [78]. Each subject performed two warm-up counter-movement jumps. The subjects stood with their feet shoulder width apart with their arms at their sides. No steps were allowed. They moved at a self-chosen speed as they bent their knees then and maximally jumped up and tapped as many markers as possible with their hand. Arm movement was self-chosen. The markers were not replaced after each attempt. After three repetitions, the highest jump was recorded. In between each jump, the subject rested thirty seconds.

Hip Extensor Isokinetic Strength

All hip extensor strength testing was done using the Biodex isokinetic dynamometer (Biodex, Shirley, NY). Each subject was tested on eccentric and concentric hip extensor strength through forty degrees of hip extension range of motion (see figure 5). The starting position was ninety degrees of hip flexion. The Biodex logged eccentric and concentric contractions.

Testing was done with the subject facing the chair of the Biodex which was level with the subject's anterior superior iliac spines. The subject's trunk was flexed to ninety degrees and the subject's held the support grips of the chair of the Biodex for stabilization. The non-dominant leg supported the body and was bent at the knee to 30 degrees. Each subject was allowed to practice the motion five times with resistance after set up. Although the manufacturer does not use this testing position, this method has been shown to be reliable and valid [35], and identical testing procedures were followed. This method was utilized because it may be more related to functional tasks, such as sprinting [40].

Peak torque, angle of peak torque and time to peak torque of eccentric and concentric contractions were tested at 60 degrees/second for each repetition. Concentric was measured first, then eccentric contractions. The subject performed five repetitions of each contraction. The middle three contraction values were recorded. The concentric and eccentric torques were divided by the subject's body weight to determine relative isokinetic strength.

Figure 5

Biodex Testing

Stretching Intervention

After all of the above testing was completed, subjects in a stretching group were stretched by the researcher. Stretching was done with the subject side-lying on their non-dominant leg. The subject's knee was bent to 90 degrees and the examiner stabilized the subject's pelvis on his/her posterior ilium. The examiner's other hand was placed on the subject's anterior thigh (see Figure 6). The examiner pulled posteriorly against the subject's thigh while stabilizing the subject's pelvis for 10 seconds [79]. The subject exerted an isometric force they estimated to be 50% of their MVC for 10 seconds [21, 79]. This was repeated five times. Those not stretched rested for 1 minute and 50 seconds, which was the stretch duration of the stretch group. After stretching or resting, the subjects completed the testing in the same order as the pre-test condition.

Figure 6

Stretching Intervention

Statistical Analysis

For all statistical analysis, SPSS 13.0 (SPSS Inc, Chicago, Illinois) was used. A 3x2 group by test repeated measures ANOVA was run for each of the ten dependent variables. A

Tukey post hoc analysis was run to determine if there is a significant difference in any of the ten omnibus ANOVAs. A priori α level was set to 0.05.

A correlation analysis was performed to determine if relationships existed among anterior pelvic tilt, hip extension ROM, and hip extensor strength. Correlations were determined between degrees of hip flexor tightness and degrees of hip extension ROM and hip extension peak torque.

Table 1
Summary of Research Questions

Research Question	IV's, DV's	Statistical Analysis
Is there a difference in those with and without hip flexor tightness in anterior pelvic tilt, hip extension ROM, hip extensor strength, speed and VJ height?	IV – Group (tight or not) DV's - anterior pelvic tilt, hip extension ROM, hip extensor strength, speed and VJ height	10 3x2 ANOVAs
Does PNF stretching affect those with tight hip flexors in anterior pelvic tilt, hip extension ROM, hip extensor strength, speed and VJ height?	IV – Group (stretch or control) DV's - anterior pelvic tilt, hip extension ROM, hip extensor strength, speed and VJ height	10 3x2 ANOVAs
Does PNF stretching affect those without hip flexor tightness in anterior pelvic tilt, hip extension ROM, hip extensor strength, speed and VJ height?	IV – Group (pre-stretch or post-stretch) DV's - anterior pelvic tilt, hip extension ROM, hip extensor strength, speed and VJ height	10 3x2 ANOVAs
Is there a relationship between hip flexor tightness and anterior pelvic tilt, hip extension ROM and hip extensor strength?	IV – hip flexor tightness DV's – anterior pelvic tilt, hip extension ROM, hip extension strength	Correlation analysis

CHAPTER FOUR-RESULTS

Forty-five subjects were tested. Average height was 174.78 ± 11.08 centimeters and average weight was 80.98 ±15.55 kilograms. There were 8 females and 7 males in both the tight control (TC) and not tight stretch (NTS) groups. The tight stretch (TS) group had 7 females and 8 males. The means and standard deviations for all variables are reported in Table 2. Graphs of results and interactions can be found in Appendix B.

Research question one examined how those with and without tight hip flexors differed on anterior pelvic tilt, hip extension range of motion (ROM), eccentric and concentric strength, time on the Southeastern Missouri (SEMO) agility drill and vertical jump (VJ) height. The TC group had significantly more anterior pelvic tilt than both the TS and NTS groups ($F_{2,42}$=10.28, p≤0.001). There was a significant group by test interaction for hip extension ROM ($F_{2,1}$=,17.14 p≤0.001). Tukey post hoc analysis (MSD = 2.53 º) revealed that the TS and TC exhibited significantly less ROM than the NTS stretch group in pre-test (3.80º and 3.15º respectively, suggesting that those with hip flexor tightness have less hip extension ROM than those who are not tight. There were no significant differences between those with and without tight hip flexors in SEMO agility time, VJ height, concentric peak torque, concentric angle of peak torque, concentric time to peak torque (TTPT), eccentric peak torque, eccentric angle of peak torque, and eccentric TTPT (p>0.05) at pre-test and the observed power for all these tests was less than 0.12.

Research questions two and three investigated how stretching affected the NTS group and the TS group. For anterior pelvic tilt, there was a significant decrease after stretching

($F_{1,42}$=74.01, $p \leq .001$). The observed power for both the TS and the NTS was greater than 0.99. There was a significant group-by-test interaction for anterior pelvic tilt ($F_{2,1}$=18.77, $p \leq 0.001$). Tukey post hoc analysis (MSD = 1.67º) revealed that following stretching both the NTS (3.09º decrease from pre-test to post-test) and TS (3.98º decrease from pre-test to post-test) groups demonstrated significant decreases in anterior pelvic tilt and there was no change in anterior pelvic tilt for the TC group (0.19º change from pre-test to post-test). For hip extension ROM, there was an increase in ROM after stretching ($F_{1,42}$=75.40, $p \leq 0.001$). The observed power for the NTS was greater than 0.94 and was greater than 0.84 for the TS group. There were significant decreases in anterior pelvic tilt after stretching in both the TS group and the NTS ($p \leq 0.001$, $p \leq 0.001$, respectively). There was a main effect for the SEMO agility speed for test, ($F_{1,42}$=22.39, $p \leq 0.001$). There were no significant differences between pre-test and post test measures for either the NTS or the TS group in VJ height, concentric peak torque, concentric angle of peak torque, concentric time to peak torque, eccentric peak torque, eccentric angle of peak torque, and eccentric TTPT and the observed power for these tests was less than 0.12.

Research question four examined the relationship between anterior pelvic tilt (r= 0.235, p=.12), hip extension ROM (r= -0.256, p=0.09), and concentric (r= -0.05, p= 0.77 and eccentric (r= -0.05, p= 0.74strength. There was no significant relationship between hip flexor tightness and anterior pelvic tilt, hip flexor tightness and ROM, hip flexor tightness and concentric peak torque or hip flexor tightness and concentric peak torque.

CHAPTER FIVE-DISCUSSION AND CONCLUSIONS

People with tight hip flexors appear to exhibit decreased hip extension range of motion (ROM) than those without tight hip flexors. People with muscle tightness have been shown to have a decreased stretch tolerance than their not-tight counterparts. Those with and without hip flexor tightness do not appear to differ on anterior pelvic tilt, hip extension range of motion (ROM), SEMO agility time, vertical jump height, or hip extensor concentric peak torque, angle of concentric peak torque, concentric time to peak torque (TTPT), eccentric peak torque, eccentric angle of peak torque, and eccentric TTPT. Clark (2001) [5] theorized that having a tight muscle would cause strength deficits in its antagonist counterpart due to a change in the force-length relationship. This was not clearly demonstrated in this study, but observed power was low ($1-\beta \leq .12$). The tight control (TC) group exhibited significantly more anterior pelvic tilt than the not tight stretch (NTS) group and the tight stretch (TS) group at pretest. Both the TS and TC groups had an equal number of subjects and similar standard deviations for the anterior pelvic tilt measurements before stretching, but there may have been an unknown covariate that caused the TS group to have a lower pelvic tilt than the TC group. While it seems logical that tight hip flexors would cause the pelvis to tilt anteriorly, other factors such as neuromuscular control of the abdominal muscles may contribute to pelvic tilt more than muscular tightness. Since the TC group exhibited more anterior pelvic tilt than the TS and NTS groups at pretest, future research should be performed to examine how hip flexor tightness affects posture as it may affect performance.

Acute stretching of the hip flexors did not affect tight and not tight subjects differently. The stretching protocol effectively increased hip extension ROM by an average of 5.56 degrees in the NTS groups and 5.20 degrees in the TS group which suggests that acute PNF stretching will effectively increase active hip extension. Marek et al. (2005) [58] found a 1.8 degree increase knee extensor ROM following PNF stretching. Increases in ROM due to stretching have been recently attributed to an increase in stretch tolerance rather than a change in muscle elasticity [56, 57]. The stretching protocol also decreased anterior pelvic tilt by an average of 3.09 degrees in the NTS group and 4.08 degrees in the TS group. Although the TC group had more anterior pelvic tilt, a Tukey post hoc analysis revealed that this group did not change from pre-test to post-test. The group by test interaction effect for anterior pelvic tilt suggests that stretching the hip flexors will lower anterior pelvic tilt values in both a tight and not tight populations. There was a main effect for test in SEMO time. This is likely due to a learning effect, as all groups improved in the post test condition.

Stretching a muscle has been shown to decrease muscle strength in that muscle [1, 13, 58], but there has been limited research on how stretching an agonist would affect the strength of the antagonist muscle. The results of this study suggest that a single session of PNF stretching does not have a large enough effect to change the isokinetic strength of the antagonist muscle. This study measured hip extension strength though mid-range hip extension. There could have been strength differences if the strength testing had taken place at the end-range hip extension, where tight hip flexors may have limited the ability of the hip extensors. Additionally, some subjects probably exhibited a learning effect for the Biodex testing. This increase could have offset the decreases seen in other subjects in the NTS group.

There were no changes in vertical jump height after PNF stretching of the hip flexors, which differs from Church et al (2001) [73]. However, Church et al (2001) and Power et al (2004) did not find differences in vertical jump height after stretching the thigh muscles [17]. Church employed PNF stretching in the quadriceps and hamstrings which help propel the body upward during jumping. Since hip extensor strength was not affected by our stretching protocol, functional performance in the SEMO and VJ did not change. Additionally, our study stretched the hip flexors, which are not the prime movers in a jumping maneuver, in hopes of increasing the function of the hip extensors. Perhaps utilizing a longer stretching protocol would allow the body to adjust to the increased stretch tolerance of the hip flexors. Another possibility for not finding significant differences in vertical jump height after stretching is that only the dominant limb was stretched and both legs were active during the vertical jump and the SEMO drill. In subjects with bilateral hip flexor tightness, stretching both hip flexors may change vertical jump height and agility speed.

Research question 4 examined the relationship between hip flexor tightness as measured by a modified Thomas test, anterior pelvic tilt, hip extension ROM, concentric peak torque and eccentric peak torque. This supports the findings of previous studies by Schache and Heino [3, 27] that found no significant relationship between anterior pelvic tilt and hip extension ROM measured by a Thomas test. Additionally, other studies have found low correlations with hip extension available for the Thomas test and hip extension in functional activities such as running and kicking [3,28].

Hip flexor tightness likely contributes to anterior pelvic tilt as stretching the hip flexors effectively reduced anterior pelvic tilt measures. Goeger found an increased anterior pelvic tilt correlated with significantly lower hamstring strength. He concluded this was because the hamstrings were placed on more of a stretch than the gluteal muscles due to muscle fiber orientation [80]. Stretching of the hip flexors may have changed hamstring strength more than gluteal strength. However, if hamstring strength was increased or decreased by stretching, it was not significant enough to change the results of the SEMO time or vertical jump height. Since both of these tests utilized both legs, hamstring strength could have been improved and not been detected. Research needs to be done to determine if hip flexor stretching affects the strength of the hamstring muscles.

Limitations

One of the strengths of this study was that we compared tight subjects to not tight subjects to see if there were differences in the way these two groups responded to a clinically relevant stretching protocol. However, there were several limitations. First, hip flexor strength was not measured. Stretching may have reduced the hip flexor strength, even though no changes were seen in gluteal strength. Since the SEMO drill and VJ test were chosen to assess the ability of the hip extensors in a functional setting, reduced hip flexor strength may not have been demonstrated. Second, the standard deviations for the strength variables were large, causing the effect sizes to be very small. More research needs to examine how stretching one muscle affects its antagonist's function. Third, only one limb was stretched. Bilateral stretching may have caused more of a change in the performance variables as these employed both legs.

Clinical Significance

The results of this study suggest that people with tight hip flexors and unrestricted hip flexors do not perform differently on hip extensor strength variables, vertical jump height or agility speed. Perhaps those with tight hip flexors have adapted to their shortened muscles and would improve their scores if their hip flexors were stretched on a regular basis for an extended period of time. However, at this time, it appears that those who are tight are not negatively affected by right hip flexors as their scores were similar to those who were in the NTS group.

This study indicates that those who have hip flexor tightness as measured by the Thomas test have less active hip extension ROM. PNF stretching is utilized in a clinical setting on a regular basis to increase ROM. This study shows that hold-relax PNF stretching will improve ROM. Whether this is due to an increase in stretch tolerance or a change in the mechanical properties of the muscle, an addition of five degrees of hip extension could allow for an increased stride length. Those with tight muscles have been thought to be at increased risk of injury. Additionally, anterior pelvic tilt was effectively decreased by PNF stretching in both tight and not tight subjects. Since anterior pelvic tilt has been correlated to ACL injury rates, reducing pelvic tilt and increasing hip extension ROM could reduce injury occurrence.

Summary

Athletes commonly have tight muscles and athletic trainers utilize stretching techniques to increase ROM. Although many recent studies have shown decreases in force after stretching, different results may occur in tight subjects. Our study showed that PNF stretching of the hip flexors effectively increased ROM and decreased anterior pelvic tilt without affecting gluteal strength or performance variables.

Appendix A: Manuscript

The Effects of Acute Proprioceptive Neuromuscular Facilitation (PNF) Stretching of the Hip Flexors on Selected Performance Parameters

Context: Stretching is commonly utilized in the clinical setting. Our findings may assist the clinician decide who to stretch using a PNF technique.
Objectives: To determine how those with and without tight hip flexor musculature respond to an acute bout of PNF stretching on hip extensor strength, anterior pelvic tilt, hip extension range of motion, speed on an agility drill and vertical jump height. To determine how an acute bout of PNF stretching affects those with and without tight hip flexors on these measures.
Design: A counter-balanced 3x2 Repeated measures ANOVAs and correlation analysis
Setting: Sports Medicine Research Laboratory
Patients: 45 (22 males and 23 males) recreationally active subjects were tested.
Intervention: A 1 minute 50 second PNF stretching protocol
Main Outcome Measures: Hip extensor concentric peak torque, concentric angle of peak torque, concentric time to peak torque (TTPT), eccentric peak torque, eccentric angle of peak torque, eccentric TTPT were tested at 60°/sec. Strength variables, anterior pelvic tilt, hip extension ROM, vertical jump height, and agility speed were tested before and after the stretching protocol.
Results: There was a main effect for group and test for anterior pelvic tilt as well as a significant interaction. There was a main effect for test for ROM. Post-hoc analysis revealed that the tight subjects had less ROM than the not tight subjects. There was a main effect for agility speed for test. There were no differences on strength variables or vertical jump height between group or test.
Conclusions: Those with and without hip flexor tightness do not differ on ROM, strength, or performance variables. The tight control group exhibited more anterior pelvic tilt than either the tight stretch or not tight stretch groups. Stretching decreased anterior pelvic tilt and hip extension ROM.
Key Words: Hip flexor tightness, reciprocal inhibition, force-length relationship

Introduction: Hip flexor tightness is commonly noticed in athletes, possibly because athletes neglect stretching these muscles and/or spend a lot of time with their hips flexed in athletics. This may limit hip extension and cause increases in anterior pelvic tilt as a compensatory motion [3]. In theory, increases in anterior pelvic tilt, will cause elongation of the hip extensor musculature due to the hamstring and gluteal muscle's attachment on the pelvis. Muscle length has been shown to affect muscle strength, [4] and if muscles are shortened or lengthened beyond their optimal length, the amount of tension the muscle can produce will decrease [5]. This phenomenon is known as reciprocal inhibition [5]. The gluteus maximus is the strongest hip extensor muscle, but if this muscle is elongated, the gluteus maximus may become weakened [5]. Because hip extensor strength is vital to jumping and sprinting, a decrease in hip extensor strength could cause a decrease in agility and vertical jump height [6, 7].

Athletic trainers commonly use proprioceptive neuromuscular facilitation (PNF) stretching to increase ROM and lengthen tight muscles. Recent studies investigating acute stretching have shown decreases in force, strength, and power output [1, 9, 10, 13-16] following stretching. This has led some clinicians to advise athletes against acute stretching before athletic activity. Because these studies have not reported ROM statistics for their subjects [1, 14, 17, 18], it is unclear if their subjects exhibited tight musculature. Those with tight musculature may respond differently to acute stretching than those who are not tight, but no research has investigated this theory. The purpose of this study was to determine how people with and without tight hip flexors differ on posture and performance parameters and how PNF stretching affects those with and without tight hip flexors.

Methods:

Subjects: Forty-five recreationally active at least three hours per week (18-25 years, 23 males and 22 females) students were recruited from the University of North Carolina Chapel Hill. Average height was 174.78 ± 11.08 centimeters and average weight was 80.98 ±15.55 kilograms. Subjects were excluded if they have had a lower extremity injury within the past three months which restricted activity for more than one day, lower extremity surgery within the last six months, current participation in a formal rehabilitation program for a lower extremity problem, or previous diagnosis of a leg length discrepancy greater than 0.5 cm.

Subjects were placed into one of three groups based on the results of a modified Thomas test performed by a research assistant (see Figure 1). If the angle was between the table and the thigh was less than 10 degrees or more from the horizontal plane of the table, then the subject was placed in the tight hip flexor group. Tight subjects were randomly assigned to the tight stretch (TS) group or tight control (TC) group. If the subjects' leg was parallel or below the plane of the table, the subject was placed in the normal hip flexor group, which would be stretch (NTS).

Figure 1

Modified Thomas Test

The subject rode a stationary bike for 5 minutes at 50% of what the subject felt was their maximum speed. Then hip extension ROM, hip extensor strength, anterior pelvic tilt, speed on an agility drill and vertical jump height were measured. Testing order was counterbalanced. For hip extension ROM, the subject actively extended his/her hip as far as they could without lifting their pelvis off the table, while keeping their knee flexed to 30 degrees (see Figure 2). The average of the three measurements was recorded. The ICC (2,1) for anterior pelvic tilt was .99 with an SEM of .258 degrees. The ICC (2,k) for the TC group was .989 with an SEM of .621 degrees

Figure 2

Hip Extension ROM

Anterior pelvic tilt measurements were taken with the subject standing in a neutral position, after bending to touch their knees 5 times. Calipers were placed on the PSIS and the ASIS and the angle between the two was measured using a digital inclinometer. An average of the three measurements was recorded. The ICC (2,1) for the ROM measurement was .99 with an SEM of .641 degrees. The ICC (2.k) for the TC group was .996 with an SEM of .57 degrees.

Figure 3

Anterior Pelvic Tilt

Agility was measured using the Southeastern Missouri (SEMO) test. The test was performed on a tile floor (see Figure 4). Subjects walked through two warm-up trials. The subject ran the test twice with a one minute rest in between. The average of the two trials was recorded. The test was timed using a handheld Accusplit Eagle Memory 100 stopwatch.

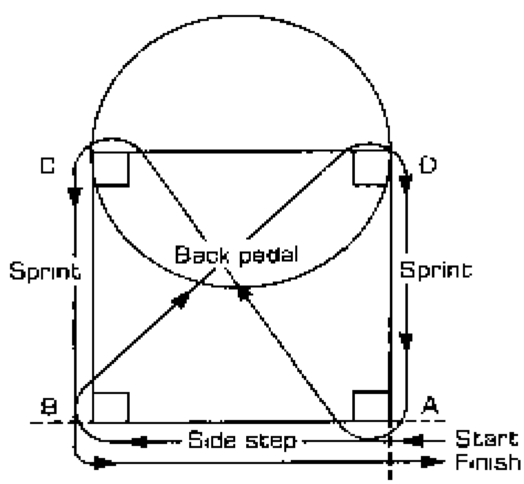


Figure 4

SEMO Drill

Countermovement jump height was recorded with the Ver-Tec (Sports Imports, Hilliard, OH). Each subject performed two warm-up counter-movement jumps. During the jump, subjects moved at a self-selected speed as they bent their knees and maximally jumped up to tap as many markers over as possible. The markers were not replaced after each attempt and the highest of three trials was recorded. In between each jump, the subject rested thirty seconds. Hip extensor strength testing was performed on the Biodex isokinetic dynamometer, system three (Biodex Inc, Shirley, NY). Each subject was tested on eccentric and concentric hip extensor strength through forty degrees of hip extension where the starting position was ninety degrees of hip flexion (see figure 5).

Figure 5

Biodex Testing

Each subject was allowed to practice the motion five times with resistance after set up. Although the manufacturer does not use this testing position, this method has been shown to be reliable and valid [35]. Peak torque, angle of peak torque and time to peak torque of eccentric and concentric contractions was recorded at 60 degrees/second. Concentric was measured first, then eccentric contractions. Each subject performed five repetitions of concentric and eccentric contractions. The middle three contractions values were used for data analysis.

After all of the above testing is completed, subjects in a stretching group were stretched by the researcher. Stretching was done with the subject side-lying on their non-dominant leg. The subject's knee was bent to 90 degrees and the examiner stabilized the subject's pelvis on his/her posterior ilium. The examiner's other hand was placed on the subject's anterior thigh (see Figure 3). The examiner pulled posteriorly against the subject's thigh while stabilizing the subject's pelvis for 10 seconds (see Figure 6)[79]. The subject exerted an isometric force they felt was 50% of their maximal voluntary contraction for 10 seconds [21, 79]. This was repeated five times. Those not stretched rested for 1 minute and 50 seconds, which is the stretch duration of the stretch group. Testing was repeated in the same order as the pre-testing.

Figure 6

Stretching Intervention

For all statistical analysis, SPSS 13.0 (SPSS Inc, Chicago, Illinois) was used. A 3x2 repeated measures ANOVA was run for each of the ten dependent variables. A Tukey post hoc analysis was run to determine if there was a significant difference in any of the ten omnibus ANOVAs for group. A correlation analysis was performed to determine if there were relationships among anterior pelvic tilt, hip extension ROM, and hip extensor strength. Correlations were determined between degrees of hip flexor tightness and degrees of hip extension ROM and hip extension peak torque.

Results:

A summary of the results can be found in Tables 2 and 3. There was a main effect for test in hip extension ROM ($F_{1,42}$=75.40, p≤.001), but not for group. The TS and NTS groups improved active ROM by 5.2 degrees and 5.56 degrees respectively. The observed power for the NTS group was greater than .94 and was greater than .84 for the TS group. There was a main effect for test in SEMO time ($F_{1,42}$=22.39, p≤.001), but not for group. There was a main effect for group ($F_{2, 42}$=10.28, p≤ .001) and test ($F_{2, 42}$ =74.01, p≤ .001) for anterior pelvic tilt. Post-hoc analysis revealed that the TC group exhibited significantly more anterior pelvic tilt than the TS and NTS in pretest measures (p≤.001). There were no significant differences between group or test for vertical jump height, concentric peak torque (PT), eccentric PT, concentric time to peak torque (TTPT), eccentric TTPT, concentric angle of PT, or eccentric TTPT.

There was no relationship between hip flexor tightness and anterior pelvic tilt, hip flexor tightness and ROM, hip flexor tightness and concentric peak torque or hip flexor tightness and eccentric peak torque.

Discussion:

People with tight hip flexors appear to exhibit decreased hip extension range of motion (ROM) than those without tight hip flexors. People with muscle tightness have been shown to have a decreased stretch tolerance than their not-tight counterparts {Magnusson, 1998 #138. Those with and without hip flexor tightness do not appear to differ on anterior pelvic tilt, hip extension range of motion (ROM), SEMO agility time, vertical jump height, or hip extensor concentric peak torque, angle of concentric peak torque, concentric time to peak torque (TTPT), eccentric peak torque, eccentric angle of peak torque, and eccentric TTPT. Clark (2001) [5] theorized that having a tight muscle would cause strength deficits in its antagonist counterpart due to a change in the force-length relationship. This was not clearly demonstrated in this study, but observed power was low ($1-\beta \leq .12$). The tight control (TC) group exhibited significantly more anterior pelvic tilt than the not tight stretch (NTS) group and the tight stretch (TS) group at pretest. Both the TS and TC groups had an equal number of subjects and similar standard deviations for the anterior pelvic tilt measurements before stretching, but there may have been an unknown covariate that caused the TS group to have a lower pelvic tilt than the TC group. While it seems logical that tight hip flexors would cause the pelvis to tilt anteriorly, other factors such as neuromuscular control of the abdominal muscles may contribute to pelvic tilt more than muscular tightness. Since the TC group exhibited more anterior pelvic tilt than the TS and NTS groups at pretest, future research should be performed to examine how hip flexor tightness affects posture as it may affect performance.

Acute stretching of the hip flexors did not affect tight and not tight subjects differently. The stretching protocol effectively increased hip extension ROM by an average of 5.56 degrees in the NTS groups and 5.20 degrees in the TS group which suggests that acute PNF stretching will effectively increase active hip extension. Marek et al. (2005) [58] found a 1.8 degree increase knee extensor ROM following PNF stretching. Increases in ROM due to stretching have been recently attributed to an increase in stretch tolerance rather than a change in muscle elasticity [56, 57]. The stretching protocol also decreased anterior pelvic tilt by an average of 3.09 degrees in the NTS group and 4.08 degrees in the TS group. Although the TC group had more anterior pelvic tilt, a Tukey post hoc analysis revealed that this group did not change from pre-test to post-test. The group by test interaction effect for anterior pelvic tilt suggests that stretching the hip flexors will lower anterior pelvic tilt values in both a tight and not tight populations. There was a main effect for test in SEMO time. This is likely due to a learning effect, as all groups improved in the post test condition.

Stretching a muscle has been shown to decrease muscle strength in that muscle [1, 13, 58], but there has been limited research on how stretching an agonist would affect the strength of the antagonist muscle. The results of this study suggest that a single session of PNF stretching does not have a large enough effect to change the isokinetic strength of the antagonist muscle. This study measured hip extension strength though mid-range hip extension. There could have been strength differences if the strength testing had taken place at the end-range hip extension, where tight hip flexors may have limited the ability of the hip extensors. Additionally, some subjects probably exhibited a learning effect for the Biodex testing. This increase could have offset the decreases seen in other subjects in the NTS group.

There were no changes in vertical jump height after PNF stretching of the hip flexors, which differs from Church et al (2001) [73]. However, Church et al (2001) and Power et al (2004) did not find differences in vertical jump height after stretching the thigh muscles [17]. Church employed PNF stretching in the quadriceps and hamstrings which help propel the body upward during jumping. Since hip extensor strength was not affected by our stretching protocol, functional performance in the SEMO and VJ did not change. Additionally, our study stretched the hip flexors, which are not the prime movers in a jumping maneuver, in hopes of increasing the function of the hip extensors. Perhaps utilizing a longer stretching protocol would allow the body to adjust to the increased stretch tolerance of the hip flexors. Another possibility for not finding significant differences in vertical jump height after stretching is that only the dominant limb was stretched and both legs were active during the vertical jump and the SEMO drill. In subjects with bilateral hip flexor tightness, stretching both hip flexors may change vertical jump height and agility speed.

Research question 4 examined the relationship between hip flexor tightness as measured by a modified Thomas test, anterior pelvic tilt, hip extension ROM, concentric peak torque and eccentric peak torque. This supports the findings of previous studies by Schache and Heino [3, 27] that found no significant relationship between anterior pelvic tilt and hip extension ROM measured by a Thomas test. Additionally, other studies have found low correlations with hip extension available for the Thomas test and hip extension in functional activities such as running and kicking {Schache, 2000 #4;Young, 2003 #72}.

Hip flexor tightness likely contributes to anterior pelvic tilt. Goeger found an increased anterior pelvic tilt correlated with significantly lower hamstring strength. He concluded this was because the hamstrings were placed on more of a stretch than the gluteal muscles due to muscle fiber orientation [80]. Stretching of the hip flexors may have changed hamstring strength more than gluteal strength. However, if hamstring strength was increased or decreased by stretching, it was not significant enough to change the results of the SEMO time or vertical jump height. Since both of these tests utilized both legs, hamstring strength could have been improved and not been detected. Research needs to be done to determine if hip flexor stretching affects the strength of the hamstring muscles.

Appendix B – Figures and Tables

Figure 7
Anterior Pelvic Tilt

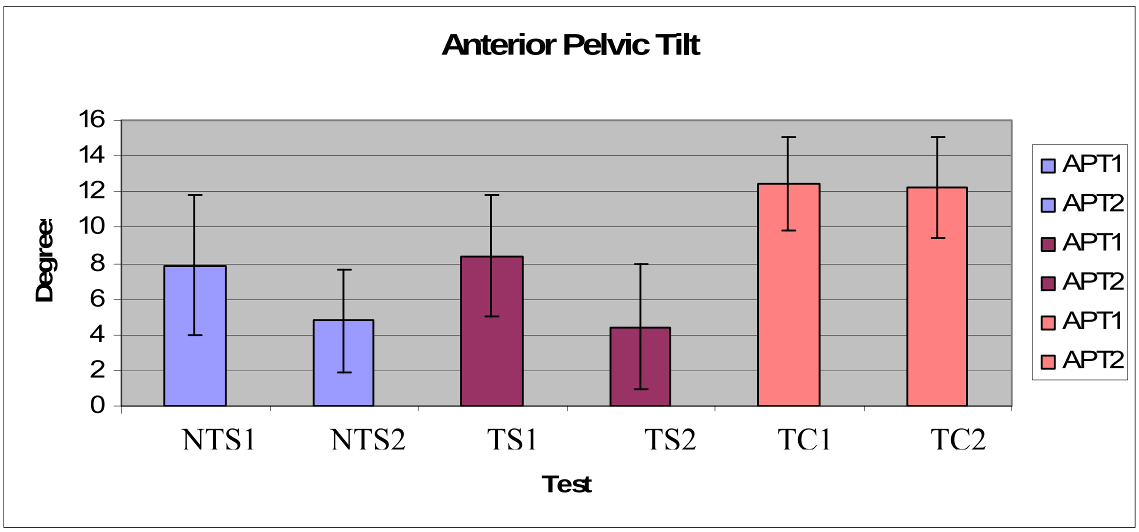


Figure 8
Hip Extension Range of Motion

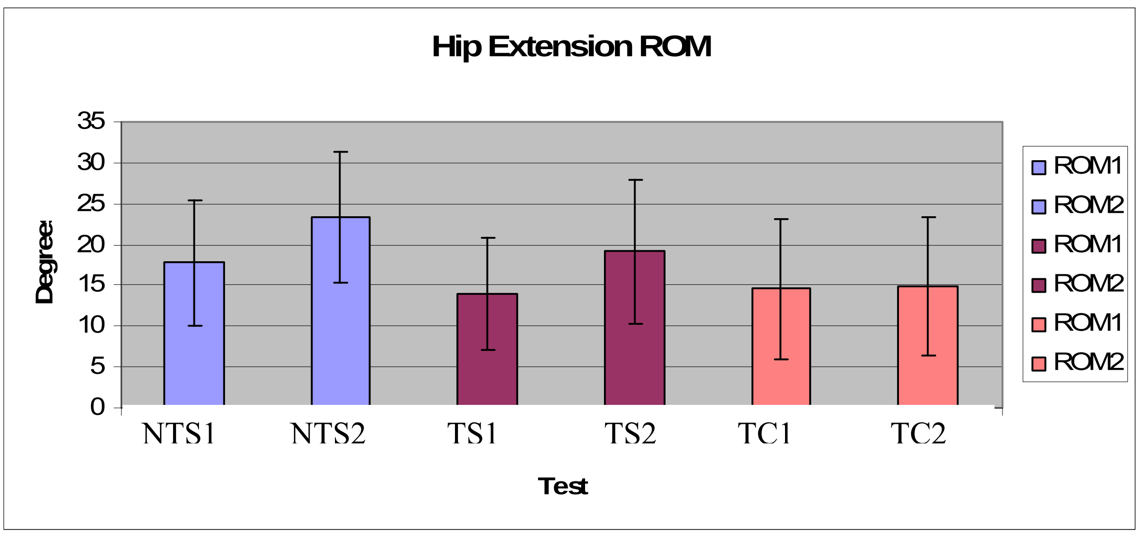


Figure 9
SEMO Agility Drill Time

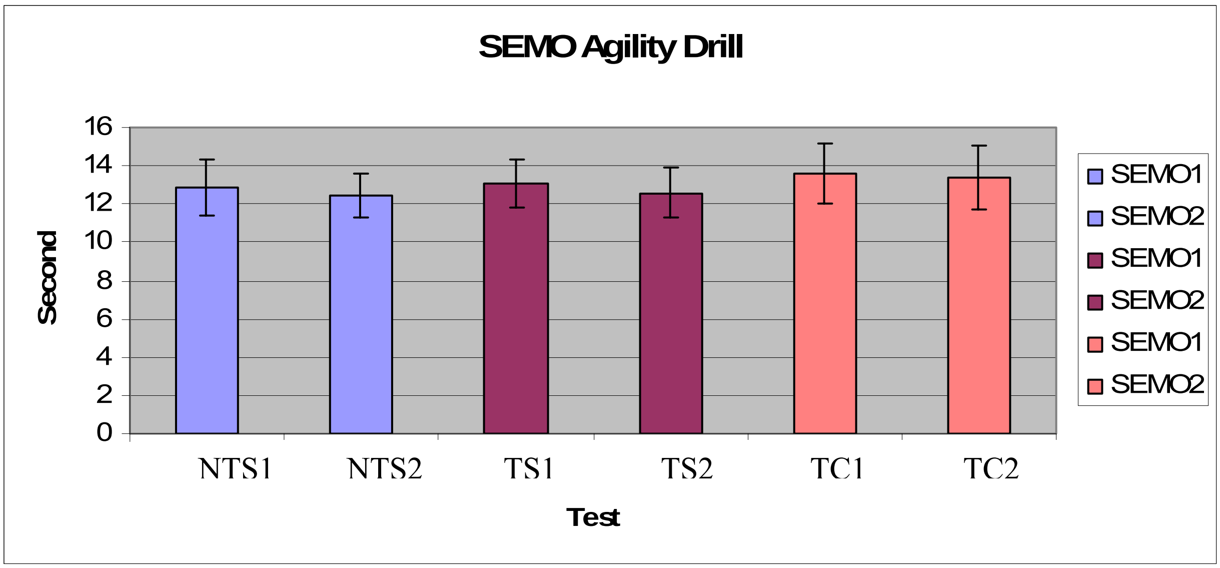


Figure 10
Vertical Jump Height

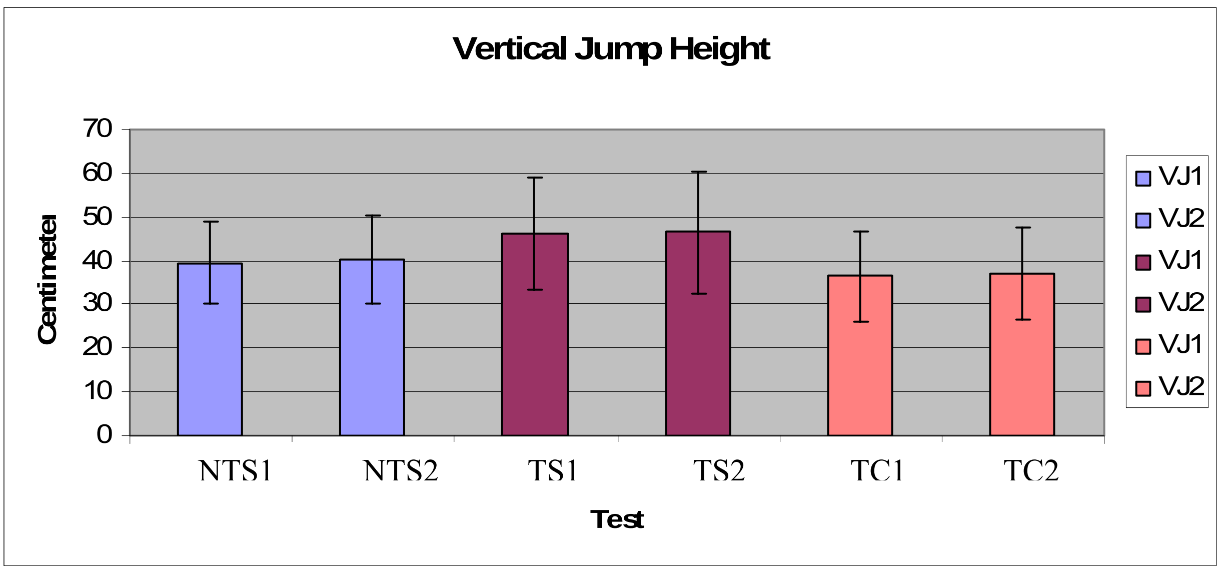


Figure 11
Concentric Peak Torque

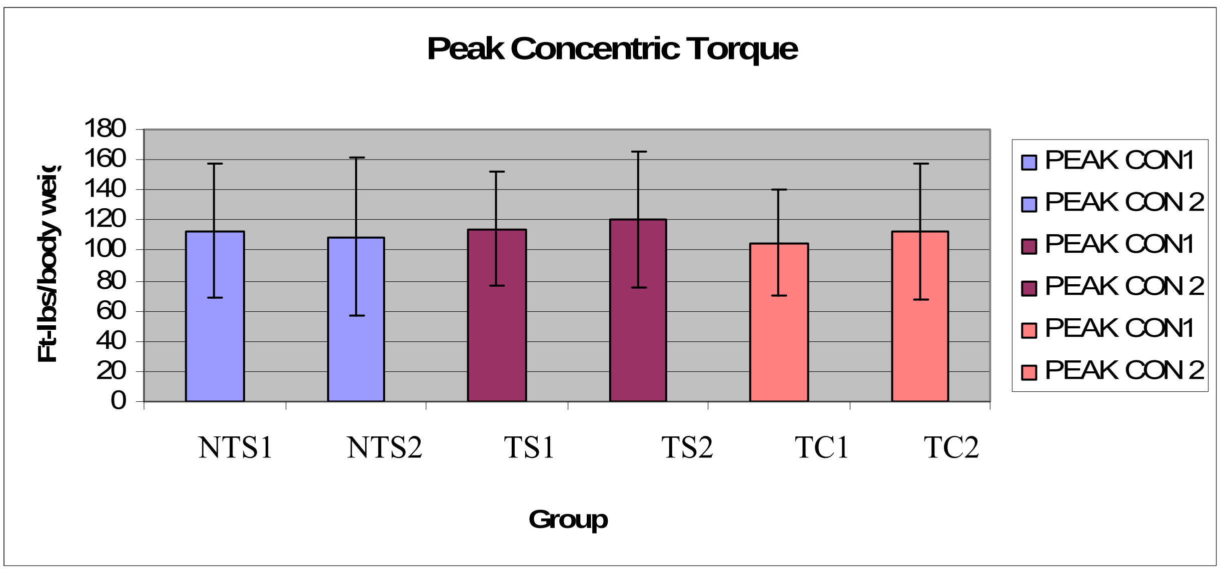


Figure 12
Concentric Angle of Peak Torque

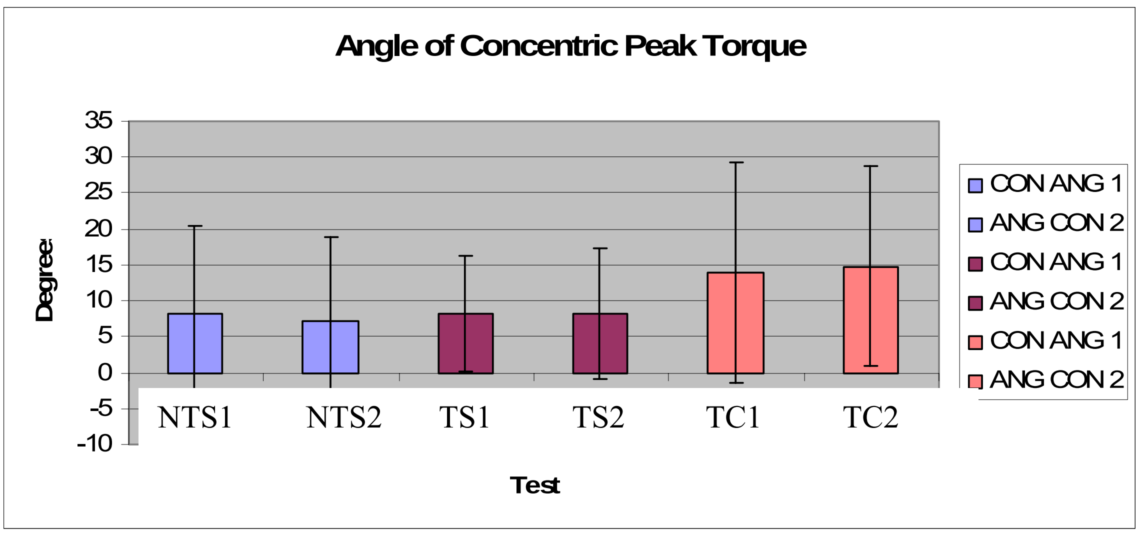


Figure 13
Concentric TTPT

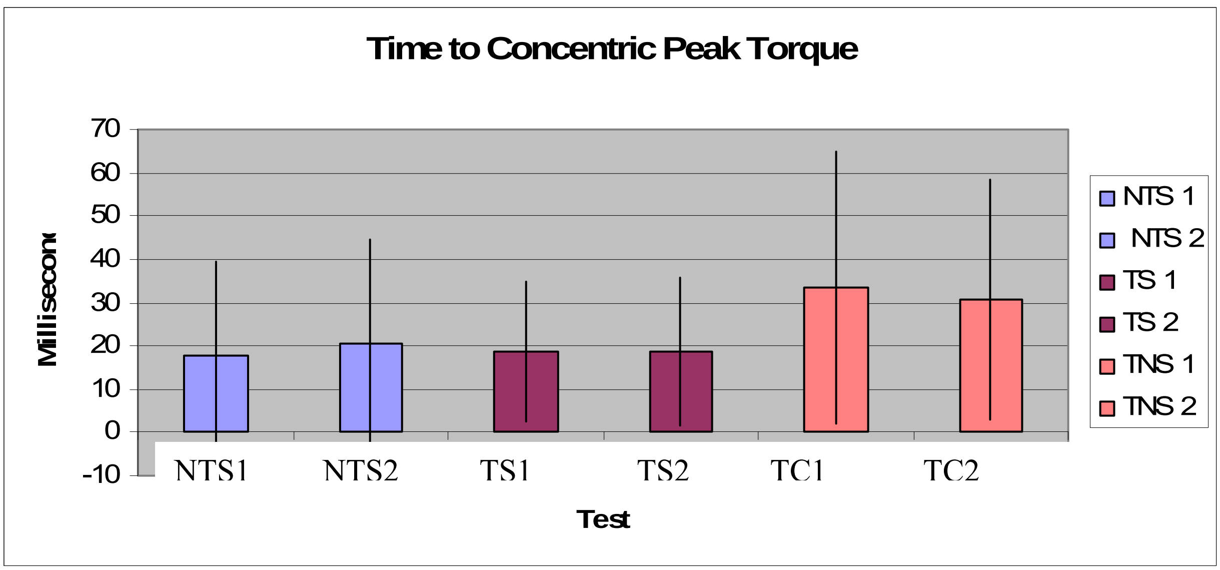


Figure 14
Eccentric Peak Torque

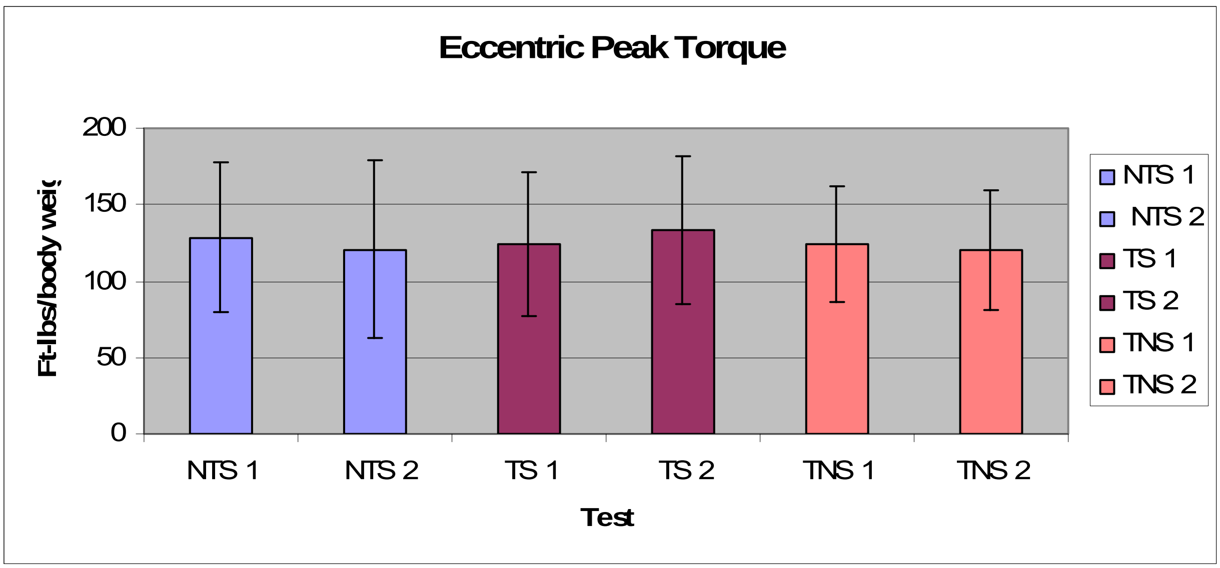


Figure 15
Eccentric Angle of Peak Torque

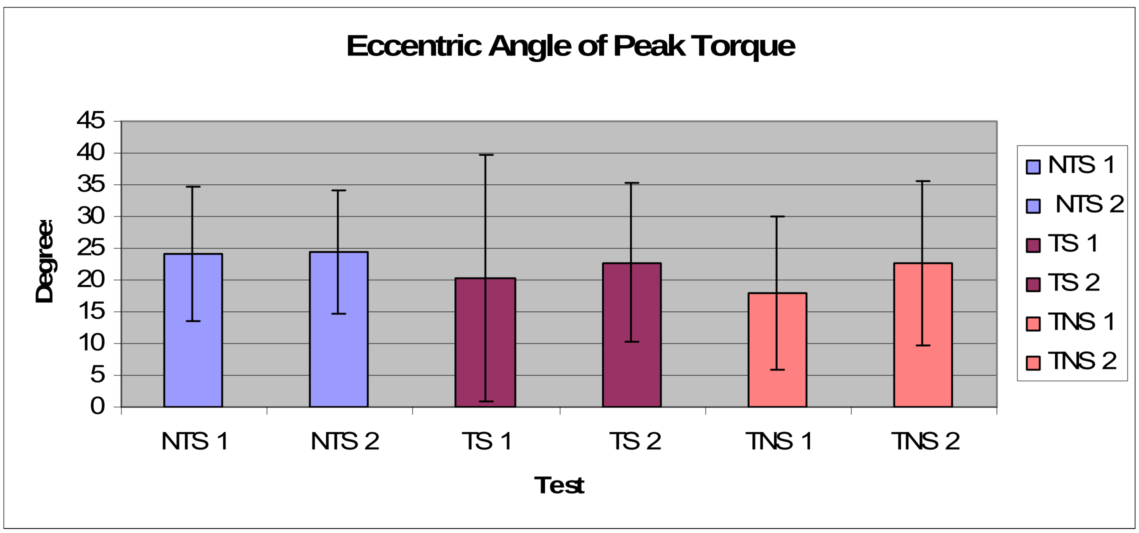


Figure 16
Eccentric TTPT

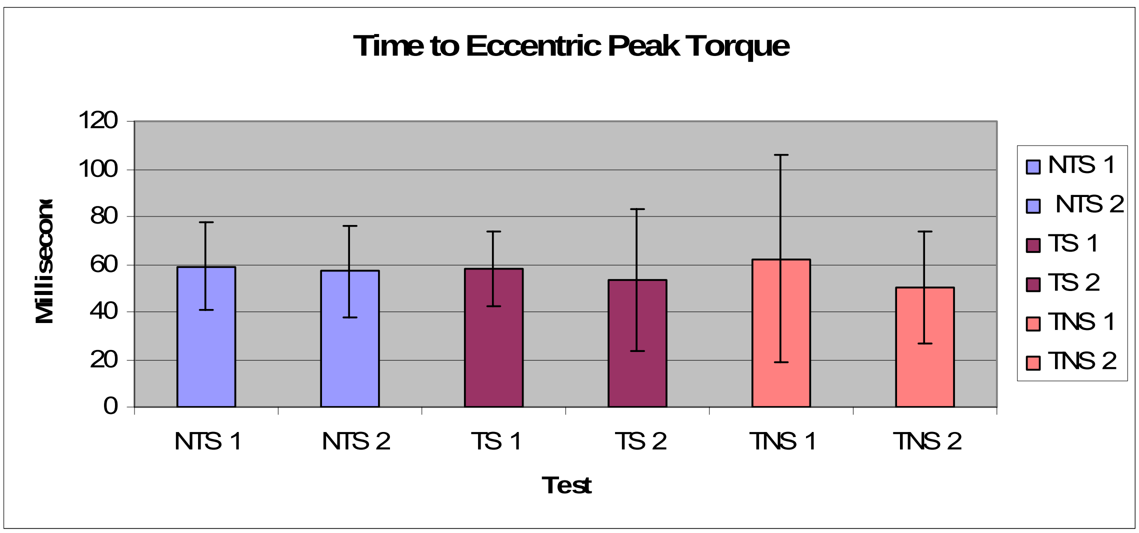


Table 2
Anterior Pelvic Tilt, Hip Extension ROM, SEMO, and Vertical Jump

	Pre-Test	Post-Test	Group Effect	Test Effect	Interaction	Effect Size
APT (°)						
NTS	7.89 ± 3.92	4.80 ± 2.88	$F_{2, 42}$=10.28*	$F_{1, 42}$=74.01*	$F_{1,2}$=18.77*	.79
TS	8.42 ± 3.37	4.44 ± 3.55	p≤.001	p≤.001	p≤.001	1.12
TC	12.47 ± 2.60	12.28 ± 2.83				.067
ROM (°)						
NTS	17.76 ± 7.67	23.31 ± 8.00	$F_{2, 42}$=2.44	$F_{1, 42}$=75.40*	$F_{1,2}$=17.14*	.69
TS	13.96 ± 6.96	19.13 ± 8.80	p=0.099	p≤.001	p≤.001	.59
TC	14.61± 8.60	14.83 ± 8.46				.03
SEMO (seconds)			$F_{2, 42}$=0.78			
NTS	12.86 ± 1.44	12.48 ± 1.14		$F_{1\ 42}$=22.39*	$F_{1,2}$=1.83	.26
TS	13.06 ± 1.26	12.59 ± 1.32		p≤.001	P=0.172	.35
TC	13.59 ± 1.60	13.37 ± 1.66	p=0.46			.13
VJ (cm)						
NTS	39.47 ± 9.49	40.13±10.07	$F_{2, 42}$=1.76	$F_{1\ 42}$=2.57	$F_{1,2}$=0.20	.07
TS	46.25±12.98	46.50±13.79	p=0.185	p=.116	p=.820	.02
TC	36.42±10.36	37.00±10.37				.06

* indicates a significant finding at the p ≤ 0.05 level.

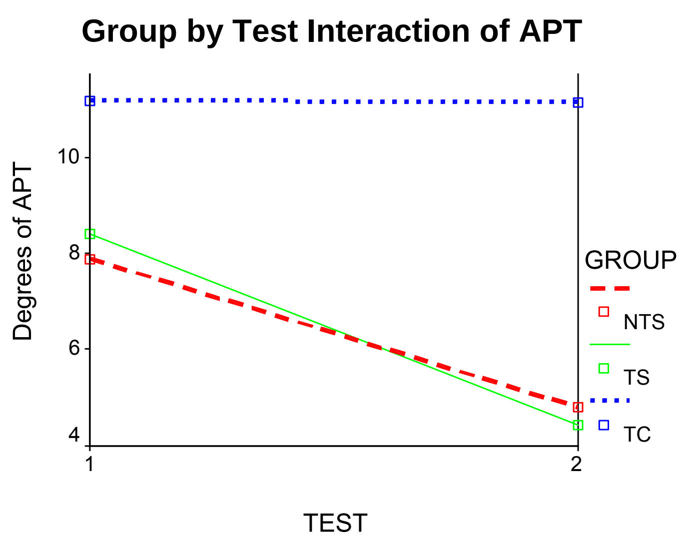
APT: anterior pelvic tilt
ROM: hip extension range of motion
SEMO: Southeastern Missouri agility drill
VJ: vertical jump

Table 3
Strength Variables

CON PT						
NTS	112.92±44.39	109.07±52.18	$F_{2, 42}=.402$	$F_{1\ 42}=2.02$	$F_{1,2}=1.76$	.07
TS	114.19±37.70	120.55±45.27	$p=0.67$	$p=0.16$	$p=0.185$	.14
TC	104.87±34.80	112.24±45.11				.16
CON angle PT (°)						.
NTS	8.29 ± 12.26	7.22 ± 11.64	$F_{2, 42}=1.55$	$F_{1\ 42}=.05$	$F_{1,2}=.265$	09
TS	8.27 ± 8.07	8.10 ± 9.12	$p=0.22$	$p=0.83$	$p=0.768$	.02
TC	13.83 ± 15.37	14.75 ± 13.90				.06
CON TTPT (ms)						
NTS	17.60 ± 21.65	20.42 ± 24.30	$F_{2, 42}=2.23$		$F_{1,2}=.449$	.12
TS	18.72 ± 16.24	18.62 ± 17.21	$p=0.12$	$F_{1\ 42}=.046$	$p=0.641$	.01
TC	33.50 ± 31.35	30.72 ± 27.90		$p=0.83$		.09
ECC PT						
NTS	128.35±49.25	120.44±58.13	$F_{2, 42}=0.36$	$F_{1\ 42}=0.10$	$F_{1,2}=1.41$	.14
TS	124.52±46.97	133.31±48.44	$p=0.70$	$p=0.92$	$p=0.256$	.18
TC	124.37±37.81	119.95±38.94				.11
ECC angle PT (°)						
NTS	24.11±10.62	24.33±9.69	$F_{2, 42}=1.73$	$F_{1\ 42}=0.24$	$F_{1,2}=1.38$	.02
TS	20.33±19.45	22.79±12.60	$p=0.19$	$p=0.63$	$P=0.263$	.13
TC	15.58±11.96	22.51±13.62				.51
ECC TTPT (ms)						
NTS	59.11 ± 18.59	57.04 ± 19.10	$F_{2, 42}=1.73$	$F_{1\ 42}=0.24$	$F_{1,2}=1.38$	.11
TS	57.75 ± 15.64	53.21 ± 29.56	$p=0.19$	$p=0.63$	$p=0.263$	.15
TC	62.28 ± 43.23	50.31 ± 23.27				.28

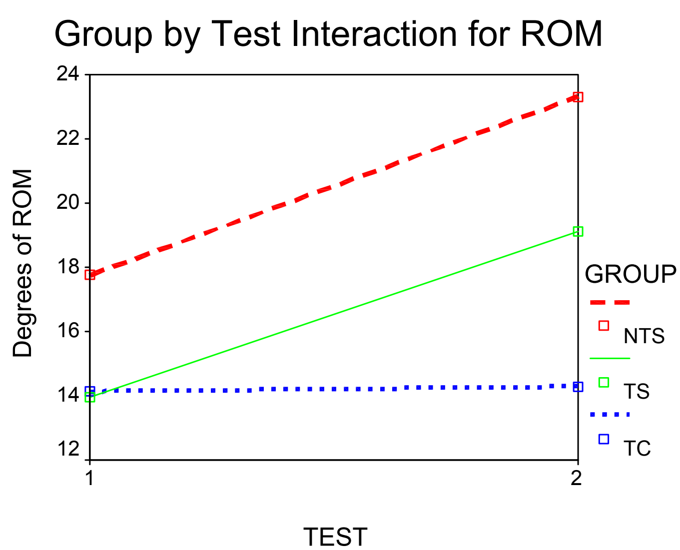
CON PT: Concentric peak torque
CON angle PT: Concentric angle of peak torque
CON TTPT: Concentric time to peak torque
ECC PT: Eccentric peak torque
ECC angle PT: Eccentric angle of peak torque
ECC TTPT: Eccentric time to peak torque

Figure 17



*Significant group by test interaction at the p≤ 0.05 level

Figure 18



* Sigificant group by test interaction at the p≤ 0.05 level

Figure 19

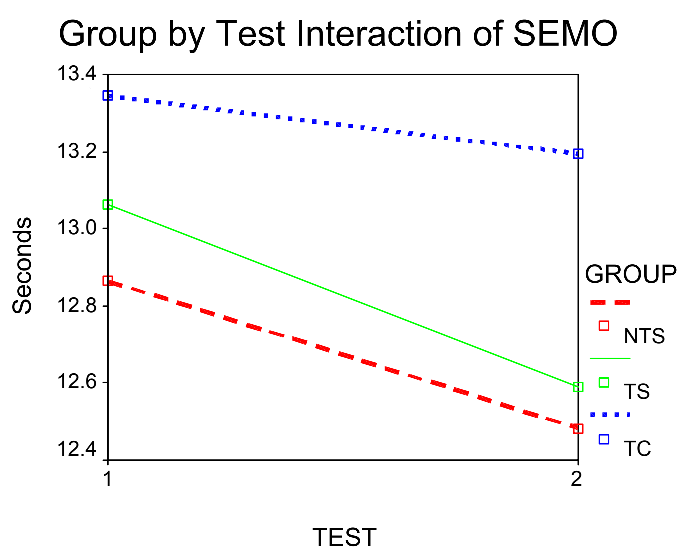
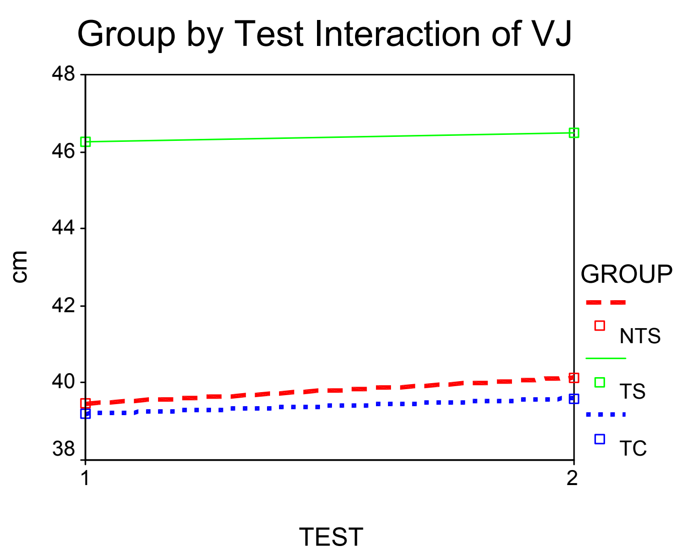

Group by Test Interaction of SEMO
13.4
13.2
13.0
12.8
12.6
12.4
Seconds
1
2
TEST
GROUP
NTS
TS
TC

Figure 20



Group by Test Interaction of VJ
48
46
44
42
40
38
cm
1
2
TEST
GROUP
NTS
TS
TC

Figure 21

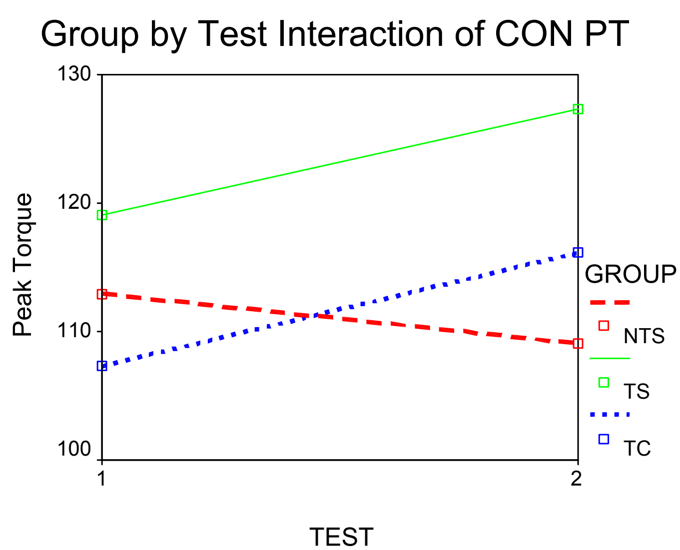

Group by Test Interaction of CON PT
130
120
110
100
Peak Torque
1
2
TEST
GROUP
NTS
TS
TC

Figure 22

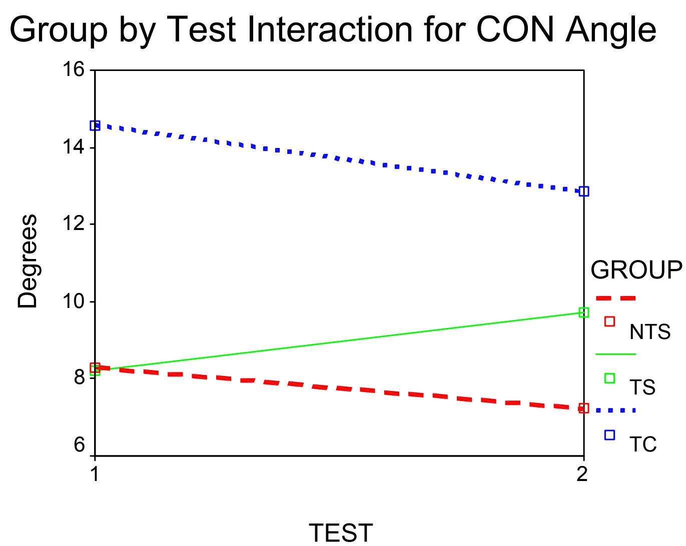
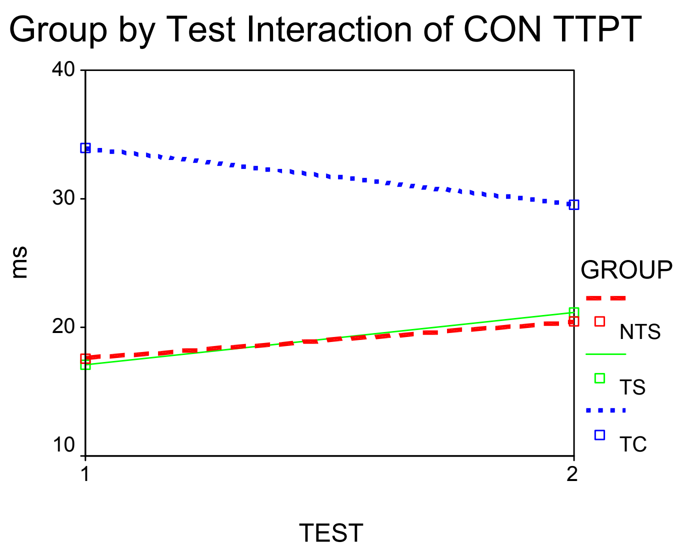

Group by Test Interaction for CON Angle
16
14
12
10
8
6
Degrees
1
2
TEST
GROUP
NTS
TS
TC

Figure 23



Group by Test Interaction of CON TTPT
40
30
20
10
ms
1
2
TEST
GROUP
NTS
TS
TC

Figure 24

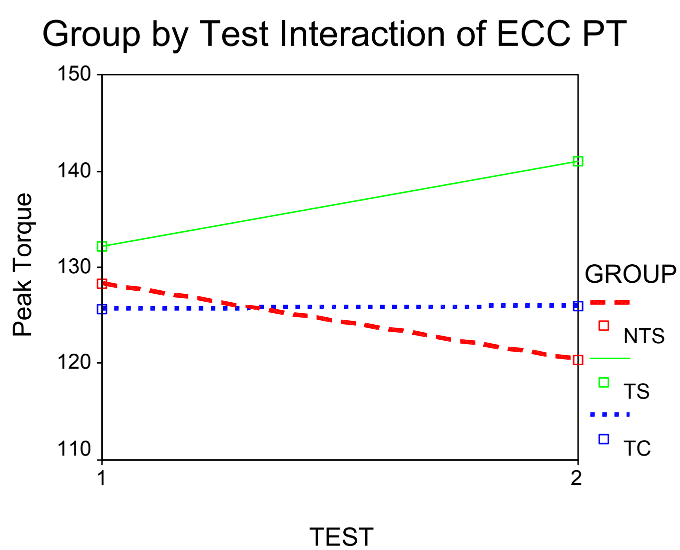

Group by Test Interaction of ECC PT
150
140
130
120
110
Peak Torque
1
2
TEST
GROUP
NTS
TS
TC

Figure 25

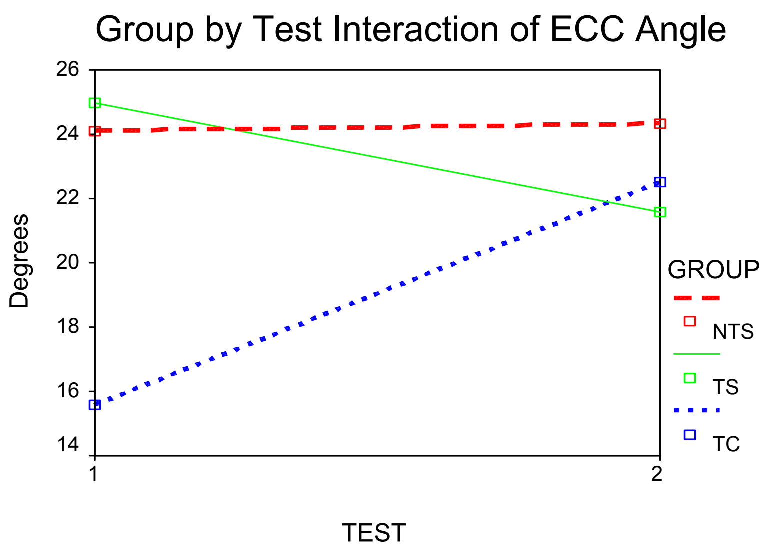
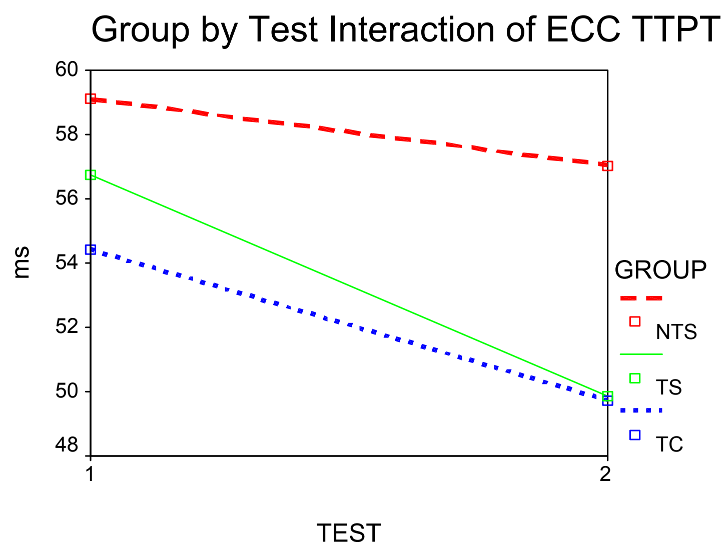

Group by Test Interaction of ECC Angle
26
24
22
20
18
16
14
Degrees
1
2
TEST
GROUP
NTS
TS
TC

Figure 26



Appendix C – Consent Form

University of North Carolina-Chapel Hill

Consent to Participate in a Research Study
Adult Subjects
Biomedical Form

IRB Study #__05-EXSS-698___________________
Consent Form Version Date: 11/22/05

Title of Study: The Acute Effects of Proprioceptive Neuromuscular Facilitation (PNF) Stretching on Selected Performance Parameters

Principal Investigator: Julie Gage ATC, LAT
UNC-Chapel Hill Department: Exercise and Sport Science
UNC-Chapel Hill Phone number: 933-4471

Co-Investigators: William Prentice, PhD, ATC
Darin Padua, PhD, ATC
Cathy Brown, MA, ATC
Michelle Boling MS, ATC
Johna Register, ATC

Funding Source: None

Study Contact telephone number: 933-4471
Study Contact email: gageja@email.unc.edu

<u>What are some general things you should know about research studies?</u>
You are being asked to take part in a research study. To join the study is voluntary. You may refuse to join, or you may withdraw your consent to be in the study, for any reason.

Research studies are designed to obtain new knowledge that may help other people in the future. You may not receive any direct benefit from being in the research study. There also may be risks to being in research studies.

Deciding not to be in the study or leaving the study before it is done will not affect your relationship with the researcher, your health care provider, or the University of North Carolina-Chapel Hill. If you are a patient with an illness, you do not have to be in the research study in order to receive health care. As a student, your grade will not be affected if you do or do not participate in this study.

Details about this study are discussed below. It is important that you understand this information so that you can make an informed choice about being in this research study. You will be given a copy of this consent form. You should ask the researchers named above, or staff members who may assist them, any questions you have about this study at any time.

<u>What is the purpose of this study?</u>
The purpose of this research study is to learn about how people with tight hip muscles

perform exercise tasks differently than those without tight hip muscles. Also, this study will look at how those with and without tight hip muscles respond to an acute stretching regimen. If people with tight muscles perform better on the tasks after being stretched, then this research will support the use of stretching for those with muscle tightness. If those without muscle tightness perform worse on the exercise tasks after stretching, then this study may decrease unnecessary stretching for those who are not tight.

You are being asked to be in the study because you are between the ages of 18 and 25, participate in physical activity for at least three hours per week, and do no have any lower extremity injury.

Are there any reasons you should not be in this study?
You should not be in this study if any of the following apply to you:

- You have had a lower extremity injury within the last three months that has prohibited normal physical activity for at least one day
- You are currently participating in a formal rehabilitation program for a lower extremity injury or are currently experiencing pain from a previous lower extremity injury
- You have had lower extremity surgery in the last six months.
- You are not between the ages of 18-25
- You have one leg that is greater than .5 cm longer than the other
- You have Charcot-Marie-Tooth disorder or a hereditary nerve disorder.

How many people will take part in this study?
If you decide to be in this study, you will be one of approximately 30 people (15 men and 15 women) in this research study.

How long will your part in this study last?

Your participation will last approximately 60 minutes.

What will happen if you take part in the study?

If you take part in this study, you will be asked to report to the Sports Medicine Research Laboratory for one testing session. You will be asked to wear athletic shorts, a t-shirt and running shoes. You will be measured for a leg length discrepancy and your height and weight will be taken. You will fill out a short questionnaire about your stretching activities, and previous injuries to your lower extremities.

1. You will be measured to determine if you have tight hip flexors by a research colleague. If you have tight hip flexors, you will be randomly assigned to a stretch or a no-stretch group. If you do not have tight hip flexors, then you will in a stretching group.
2. First, You will ride a stationary bike for 5 minutes for a warm-up . You will then participate in 5 exercise tasks. The order of these will be randomized by the examiner. Your standing pelvic tilt position will be measured and your hip extension range of motion will be measured while you are lying on your stomach.

Your hip extension strength will be tested using the Biodex Isokinetic Dynamometer. Isokinetic testing is a form of strength testing used to objectively evaluate the strength of specific muscles or motions. Your hip strength will be tested by contracting against a moveable arm and resisting the moveable arm. Before strength testing you will be given five practice trials before the testing will take place. You will be tested on agility by timing your running of a predetermined pattern on the gymnasium floor upstairs. The course is the size of the free throw lane on a basketball court. You will also perform several vertical jumps.

3. If you were assigned to either stretch group, then your hip flexors will be stretched by the investigator. You will be asked to exert a small amount of resistance for 10 seconds and then relax so your muscles can be stretched. This will happen 5 times. If you are not in a stretch group, you will rest for several minutes
4. After stretching or resting for several minutes, your pelvic position, hip extension range of motion, hip extensor strength, agility and vertical jump will be measured once more.

What are the possible benefits from being in this study?

Research is designed to benefit society by gaining new knowledge. You will not benefit personally from being in this research study.

What are the possible risks or discomforts involved with being in this study?

This study involves strength testing, agility testing and vertical jumping which might involve the following risks and/or discomforts to you:
* Possibility of muscle strains/pulls/soreness in your lower extremities similar to those encountered during exercise.
*Possibility of sprains to the joints of the lower extremities.
*In addition, there may be uncommon or previously unknown risks that might occur. You should report any problems to the researchers.

How will your privacy be protected?

No subjects will be identified in any report or publication about this study. All data will be collected under your subject identification number so no one can identify you by name except the researcher. The data will be kept in a locked office and on password protected computers. After the study is completed, this list will be destroyed. All information shared between researchers will be password protected. Although every effort will be made to keep research records private, there may be times when federal or state law requires the disclosure of such records, including personal information. This is very unlikely, but if disclosure is ever required, UNC-CH will take all the steps allowable by law to protect the privacy of personal information. In some cases, your information in this research study could be reviewed by representatives of the University, research sponsors, or government agencies for purposes such as quality control or safety.

What will happen if you are injured by this research?

All research involves a chance that something bad might happen to you. This may include the risk of personal injury. In spite of all safety measures, you might develop a reaction or injury from being in this study. If such problems occur, the researchers will help you get medical care, but any costs for the medical care will be billed to you and/or your insurance company. The University of North Carolina at Chapel Hill has not set aside funds to pay you for any such reactions or injuries, or for the related medical care. However, by signing this form, you do not give up any of your legal rights.

What if you want to stop before your part in the study is complete?
You can withdraw from this study at any time, without penalty. The investigators also have the right to stop your participation at any time. This could be because you have had an unexpected reaction, or have failed to follow instructions, or because the entire study has been stopped. Your relationship with any UNC instructor will not be affected if you or the researcher decides to stop your participation.

Will you receive anything for being in this study?
You will not receive anything for taking part in this study.

Will it cost you anything to be in this study?
It will not cost you anything to be in this study except the normal costs associated with travel

to campus and possibly parking

What if you are a UNC student?

You may choose not to be in the study or to stop being in the study before it is over at any time. This will not affect your class standing or grades at UNC-Chapel Hill. You will not be offered or receive any special consideration if you take part in this research.

What if you are a UNC employee?
Taking part in this research is not a part of your University duties, and refusing will not affect your job. You will not be offered or receive any special job-related consideration if you take part in this research.

What if you have questions about this study?
You have the right to ask, and have answered, any questions you may have about this research. If you have questions, or if a research-related injury occurs, you should contact the researchers listed on the first page of this form.

What if you have questions about your rights as a research subject?
All research on human volunteers is reviewed by a committee that works to protect your rights and welfare. If you have questions or concerns about your rights as a research subject you may contact, anonymously if you wish, the Institutional Review Board at 919-966-3113 or by email to IRB_subjects@unc.edu.

- -

<u>Subject's Agreement:</u>

I have read the information provided above. I have asked all the questions I have at this time. I voluntarily agree to participate in this research study.

_______________________________________ ________________

Signature of Research Subject Date

____

Printed Name of Research Subject

_______________________________________ ________________

Signature of Person Obtaining Consent Date

____

Printed Name of Person Obtaining Consent

Appendix D-IRB Application

OFFICE OF HUMAN RESEARCH ETHICS

Institutional Review Board

APPLICATION FOR IRB APPROVAL OF
HUMAN SUBJECTS RESEARCH
Version 18-Apr-2005

For IRB Use				
Behav	Bio	Dent	Nurs	PH
IRB Study #________________				
Rec'd______________________				
Full	Expedited	Exempt		

Part A.1. Contact Information, Agreements, and Signatures

Title of Study: The Acute Effects of Proprioceptive Neuromuscular Facilitation (PNF) Stretching on Selected Performance Parameters
Date: 09/08/2005

Name and degrees of Principal Investigator: Julie Gage
Department: Exercise and Sport Science c/o Cindy Atkins
Mailing address/CB #: CB# 8700
Chapel Hill, NC 27599
UNC-CH PID: 710984072 Pager:
Phone #: 933-4471 Fax #: 919-962-0489 Email Address: gageja@email.unc.edu

For trainee-led projects: __ undergraduate X graduate __ postdoc __ resident __ other

Name of faculty advisor: William Prentice, PhD
Department: Exercise and Sport Science Mailing address/CB #: CB 8700
Phone #: 962-5174 Fax #: 919-962-0489 Email Address: prentice@email.unc.edu

Name, phone number, email address of project manager or coordinator, if any: N/A

List **all other project personnel** including co-investigators, and anyone else who has contact with subjects or identifiable data from subjects:

Dr. William Prentice
Dr. Darin Padua
Cathy Brown
Michelle Boling
Johna Register

Name of funding source or sponsor:
_X not funded __ Federal __ State __ industry __ foundation __ UNC-CH
__ other (specify): **Sponsor or award number**:

Include following items with your submission, where applicable. Check the items below and **include in order listed**.

- □ This application. One copy must have original PI signatures.
- □ Consent and assent forms, fact or information sheets; include phone and verbal consent scripts
- □ HIPAA authorization addendum to consent form
- □ All recruitment materials including scripts, flyers and advertising, letters, emails
- □ Questionnaires, scripts used to guide phone or in-person interviews, etc.
- □ Focus group guides
- □ Data use agreements (may be required for use of existing data from third parties)
- □ Addendum for Multi-Site Studies where UNC-CH is the Lead Coordinating Center
- □ Documentation of reviews from any other committees (e.g., GCRC, Oncology)
- □ Documentation of training in human research ethics for all study personnel
- □ Investigator Brochure if a drug study
- □ Protocol, grant application or proposal supporting this submission; (e.g., extramural grant application to NIH or foundation, industry protocol, student proposal)

Principal Investigator: I will personally conduct or supervise this research study. I will ensure that this study is performed in compliance with all applicable laws, regulations and University policies regarding human subjects research. I will obtain IRB approval before making any changes or additions to the project. I will notify the IRB of any other changes in the information provided in this application. I will provide progress reports to the IRB at least annually, or as requested. I will report promptly to the IRB all unanticipated problems or serious adverse events involving risk to human subjects. I will follow the IRB approved consent process for all subjects. I will ensure that all collaborators, students and employees assisting in this research study are informed about these obligations. All information given in this form is accurate and complete.

____ __________________
Signature of Principal Investigator Date

Faculty Advisor if PI is a Student or Trainee Investigator: I accept ultimate responsibility for ensuring that this study complies with all the obligations listed above for the PI.

____ __________________
Signature of Faculty Advisor Date

Department or Division Chair, Center Director (or counterpart) of PI: (or Vice-Chair or Chair's designee if Chair is investigator or otherwise unable to review): I certify that this research is appropriate for this Principal Investigator, that the investigators are qualified to conduct the research, and that there are adequate resources (including financial, support and facilities) available. I support this application, and hereby submit it for further review.

____ __________________
Signature of Department Chair or designee Date

____ __________________
Print Name of Department Chair or designee Department

Part A.2. Summary Checklist

Are the following involved?

	Yes	No
A.2.1. Existing data, research records, patient records, and/or human biological specimens?	__	X
A.2.2. Surveys, questionnaires, interviews, or focus groups with subjects?	X	___
A.2.3. Videotaping, audiotaping, filming of subjects?	__	X
A.2.4. Do you plan to enroll subjects from these vulnerable or select populations:		
a. UNC-CH students or UNC-CH staff?	X	
b. Non-English-speaking?	__	X
c. Decisionally impaired?	__	X
d. Patients?	__	X
e. Prisoners, parolees and other convicted offenders?	__	X
f. Pregnant women?	__	X
g. Minors (less than 18 years)? **If yes**, give age range: to years	__	X
A.2.5. a. Is this a multi-site study (i.e., involves organization(s) outside UNC-CH)?	__	X
b. Will any of these sites be outside the United States? *__If yes__*, provide contact information for the foreign IRB.	__	__
c. Is UNC-CH the sponsor or lead coordinating center? *__If yes__*, include the ***Addendum for Multi-site Studies where UNC-CH is the Lead Coordinating Center***.	__	__
A.2.6. Will there be a data and safety monitoring committee (DSMB or DSMC)?	__	X
A.2.7. a. Are you collecting sensitive information such as sexual behavior, HIV status, recreational drug use, illegal behaviors, child/physical abuse, immigration status, etc?	__	X
b. Do you plan to obtain a federal Certificate of Confidentiality for this study?	__	__
A.2.8. a. Investigational drugs? (provide **IND #**)	__	X
b. Approved drugs for "non-FDA-approved" conditions? *All studies testing substances in humans must provide a letter of acknowledgement from the UNC Health Care Investigational Drug Service (IDS).*	__	__
A.2.9. Placebo(s)?	__	X
A.2.10. Investigational devices, instruments, machines, software? (provide **IDE #**)	___	X
A.2.11. Fetal tissue?	__	X
A.2.12. Genetic studies on subjects' specimens?	__	X
A.2.13. Storage of subjects' specimens for future research? *__If yes__, see instructions within the form* ***Consent for Stored Samples***.	__	X
A.2.14. Diagnostic or therapeutic ionizing radiation, or radioactive isotopes, which subjects would not receive otherwise? *__If yes__, approval by the* ***UNC-CH Radiation Safety Committee*** *is required.*	__	X
A.2.15. Recombinant DNA or gene transfer to human subjects? *__If yes__, approval by the* ***UNC-CH Institutional Biosafety Committee*** *is required.*	__	X
A.2.16. Does this study involve UNC-CH cancer patients? *__If yes__, submit this application directly to the* ***Oncology Protocol Review Committee***.	__	X
A.2.17. Will subjects be studied in the General Clinical Research Center (GCRC)? *__If yes__, obtain the* ***GCRC Addendum*** *from the GCRC and submit complete application (IRB application and Addendum) to the GCRC.*	__	X

Part A.3. Potential Conflict of Interest

The following questions apply to **all investigators and study staff involved with this research, and/or their immediate family members (spouse, dependent children, parents, significant others).** With respect to this study, will any of the study investigators or study staff or their immediate family members:

A.3.1. Have an intellectual property interest in any technology or invention used in this study, including patent rights, copyright, etc.?	__ yes	X no
A.3.2. Receive support from a non-UNC source (**other than through a sponsored research agreement**) for this research study?	__ yes	X no
A.3.3. Receive any form of personal compensation (**other than as specified in the budget of a sponsored research agreement**) from a Sponsor of this study, including salary, consulting fees, honoraria, royalties, equipment, gifts, etc.?	__ yes	X no
a. **If yes**, does or will that personal compensation exceed $10,000?	__ yes	__ no
b. **If yes**, is that personal compensation tied to any performance within this study such as enrollment goals for the study?	__ yes	__ no
A.3.4. Have an ownership interest of any nature in the Sponsor or a product used in this study, including equity, stock options, etc?	__ yes	X no
a. **If yes**, does or will that interest exceed $10,000 in value or 5% equity in a publicly traded Sponsor?	__ yes	__ no
b. **If yes**, does that interest include any equity interest in a non-publicly traded Sponsor?	__ yes	__ no
A.3.5. Hold any position with the Sponsor, including officer, employee, director, trustee, consultant, member of advisory board, etc.?	__ yes	X no
A.3.6. Have a conflict of interest previously disclosed through the University's conflict of interest evaluation process that relates to this research study?	__ yes	X no

If the answer is "yes" to any of the questions above, please include an explanation with this application. As with any changes to the research itself, relationships or interests that develop later should be brought to the attention of the IRB for further consideration. Please contact the Office of University Counsel for guidance or assistance regarding the University's Conflict of Interest Policy. See http://www.unc.edu/campus/policies/coi.html for the policy.

Part A.4. Questions Common to All Studies

A.4.1. **Brief Summary**. Provide a *brief* non-technical description of the study, which will be used for internal and external communications regarding this research. Include purpose, methods, and participants. Typical summaries are 50-100 words.

The purpose of this study is to determine if a specific type of muscle stretching will increase performance in certain measures of athletic performance. If the stretching does increase performance indicators, it should be used by athletes before competition. This study will compare healthy recreationally active people with and without tight hip flexors before and after stretching on measures of anatomical alignment, hip range of motion, hip strength measured on an isokinetic machine, speed on an agility drill, and vertical jump height. Additionally, this study will determine the effects of a bout of proprioceptive neuromuscular facilitation stretching on those with and without tight hip flexors on the previous parameters.

A.4.2. **Purpose and Rationale**. Provide a summary of the background information, state the research question(s), and tell why the study is needed. If a complete rationale and literature review are in an accompanying grant application or other type of proposal, only provide a brief summary here. If there is no proposal, provide a more extensive rationale and literature review.

Hip flexor muscle tightness and anterior pelvic tilt are noted in athletes, especially in lower-extremity intensive sports. Tight hip flexor muscles will anteriorly rotate the pelvis and cause excessive lumbar lordosis (low back curvature) because of the hip flexors' attachments on the spine and pelvis [19]. Excessive lordosis can cause back pain. It has been suggested that when the pelvis is chronically anteriorly rotated, the hamstrings and gluteus maximus will be held on stretch **(**Clark, 2001**)**. Muscle length has been shown to affect muscle strength [4] and if muscles are shortened or lengthened beyond their optimal length, the amount of tension the muscle can produce will decrease [5]. This phenomenon is known as reciprocal inhibition [5]. The gluteus maximus is the strongest hip extensor muscle, but if this muscle is elongated, the gluteus maximus may become weakened [5]. If the gluteus maximus muscle is not functioning normally because of the altered length-tension relationship between the hip flexors and hip extensors, abnormal movement patterns may result. Because hip extensor strength is vital to jumping and sprinting, a decrease in hip extensor strength could cause a decrease in agility and vertical jump height [6, 7].

If tight hip flexors inhibit the performance of the hip extensors, then elongation of the hip flexor muscles may correct the imbalance in the length tension relationship between the hip flexors and hip extensors. This may decrease anterior pelvic tilt, increase hip extension range of motion (ROM), increase hip extensor strength, and improve vertical jump and agility. Additionally, if the hip flexors are not restricted, then the elongation of these muscles will also alter the length-tension relationship between the hip flexors and hip extensors but cause different outcomes. If unrestricted hip flexors are lengthened, it may cause the pelvis to rotate posteriorly, shortening the hip extensors. Because this would also alter the length of the hip extensors, a decrease in hip extensor strength could cause decreases in vertical jump height and agility performance.

If the hip extensors are stretched in someone with tight hip flexors, then the length-tension relationship between the hip flexors and hip extensors will be altered and may result in abnormal movement patterns, which could decrease performance and increase risk of injury.

Certified athletic trainers need to be able to identify athletes with tight hips flexors and anterior pelvic tilt to correct muscular imbalances which may lead to injury due to abnormal force transmission. Additionally, recreational and competitive athletes want to maximize performance, so normal length-tension relationships should be maintained.

Tight musculature is often treated through stretching. Three main types of stretching include static, dynamic and proprioceptive neuromuscular facilitation (PNF). Static stretching involves taking the muscle of interest to maximal length and holding it in that position. Dynamic stretching involves actively moving a muscle through a range of motion (ROM) to increase flexibility. PNF stretching involves a series of muscular contractions followed by static stretches to increase ROM. Limited research has been done investigating the effects of dynamic stretching, but one study found that while dynamic stretching produced significant increases in ROM, static stretching produced significantly greater increases in ROM. PNF stretching is effective in increasing ROM and most studies have demonstrated that PNF stretching produced greater ROM gains than static stretching [21-23].

While there is a great body of research on the chronic and acute effects of static stretching, more research needs to be done on the effects of PNF stretching on performance. PNF stretching could increase athletic performance, especially in those with tight hip flexors and anterior pelvic tilt by restoring optimal function of the muscles about the hip. In those without hip flexor tightness, stretching the hip flexor musculature could decrease performance by the same mechanisms.

Research Questions:

1. Is there a difference between individuals with and without hip flexor tightness on the following measures:
    - a. Anterior pelvic tilt
    - b. Hip extension range of motion
    - c. Hip extension strength
    - d. Speed in a multi-directional agility drill
    - e. Vertical Jump height
2. Does PNF stretching of the hip flexor musculature in those with hip flexor tightness affect the following variables:
    - a. Anterior pelvic tilt
    - b. Hip extension range of motion
    - c. Hip extension strength
    - d. Speed in a multi-directional agility drill
    - e. Vertical Jump height
3. Does PNF stretching of the hip flexor musculature in individuals without hip flexor tightness affect the following variables:
    - a. Anterior pelvic tilt
    - b. Hip extension range of motion
    - c. Hip extension strength
    - d. Speed in a multi-directional agility drill

e. Vertical Jump height

4. Is there a correlation between hip flexor tightness and anterior pelvic tilt, hip extension ROM and hip extensor strength?

A.4.3. **Full description of the study design, methods and procedures.** Describe the research study. Discuss the study design; study procedures; sequential description of what subjects will be asked to do; assignment of subjects to various arms of the study if applicable; doses; frequency and route of administration of medication and other medical treatment if applicable; how data are to be collected (questionnaire, interview, focus group or specific procedure such as physical examination, venipuncture, etc.). Include information on who will collect data, who will conduct procedures or measurements. Indicate the number and duration of contacts with each subject; outcome measurements; and follow-up procedures. If the study involves medical treatment, distinguish standard care procedures from those that are research. If the study is a clinical trial involving patients as subjects and use of placebo control is involved, provide justification for the use of placebo controls.

Thirty recreationally active (age = 18-25 years) students from the University of North Carolina Chapel Hill will be recruited for the study. Subjects will regularly participate in physical activity at least three hours per week. All subjects will be instructed to wear personal shorts, t-shirts, and athletic shoes during the testing procedure. All testing will be done in the Sports Medicine Research Laboratory and Fetzer gymnasium at the University of North Carolina Chapel Hill. Testing for each subject will be done in a single session. Upon arrival, subjects will read and sign an informed consent form as approved by the Biomedical IRB. Additionally, subjects will complete a short questionnaire about activity type, previous medical history, and their height and weight will be measured. Subjects will perform a 5 minute warm-up on a stationary bike at a self-selected pace.

A modified Thomas test will be used to determine whether the subject has tight hip flexors [19] (see figure 1 below). The subject will sit on the edge of the table and hold one knee to their chest. They will then lie back so they are supine on the table, allowing the leg they are not holding to fall towards the table. A research assistant, also a Certified Athletic Trainer licensed to practice sports medicine in the state of North Carolina, will perform the Thomas test. They will use a goniometer to determine the angle of the subject's dominant leg with the horizontal table. If the subject's leg is greater than 10 degrees off the table, then they will be placed in the tight hip flexor group. Those subjects with tight hip flexors will be randomly assigned without replacement to a stretch or no-stretch group. Those without tight hip flexors will be assigned to a not-tight-stretch group. For each of the three groups, ten subjects will be assigned. The principle investigator will be blinded to the results of the modified Thomas test. This will ensure the PI has no researcher bias regarding the stretch and no stretch protocol effects. The PI will complete the rest of the testing.

Figure 1 Modified Thomas Test

Hip extension range of motion (ROM), anterior pelvic tilt, hip extensor strength, vertical jump height and agility will be measured. The testing order for these measures will be counterbalanced. The subject's dominant hip as defined by which leg they would kick a soccer ball will be tested.

To measure hip extension ROM the subject will lie prone on the examiner's table and bend their knee thirty degrees. The subject will then actively extend their hip as far as they can without lifting their pelvis off the table. (See Figure 2) The examiner will ensure that the subjects' anterior superior iliac spine (ASIS) is in contact with the table. The examiner will measure their hip extension ROM using an inclinometer. This will be measured three times. The average of the three measurements will be used.

Figure 2 Measuring Hip Extension ROM

Anterior Pelvic Tilt

Anterior pelvic tilt will be measured using a digital inclinometer. Calipers will be placed on the PSIS and the ASIS. (See Figure 3) The digital inclinometer will be placed on the straight edge of the calipers and the angle will be measured. This measurement will be taken with the subject standing in a neutral position. To enssure posture is neutral, each subject will be instructed to first reach their hands to their knees five times and then return to a comfortable upright position. This measurement will be taken three times and the average of the three times will be used.

Figure 3 Measurement of anterior pelvic tilt with calipers and digital inclinometer

Agility

Agility will be measured using the Southeast Missouri (SEMO) test (see Figure 4 below). The SEMO test consists of a timed run in a pre-determined pattern emphasizing speed and change in movement direction. The pattern and movements are similar to what subjects would experience participating in recreational activities. This will be tested in the gymnasium (see figure 4). Subjects will perform two warm-up trials. The subject will then run the test two times with a one minute rest in between. The average time of the two trials will be recorded. The test will be timed using a handheld Accusplit Eagle Memory 100 stopwatch.

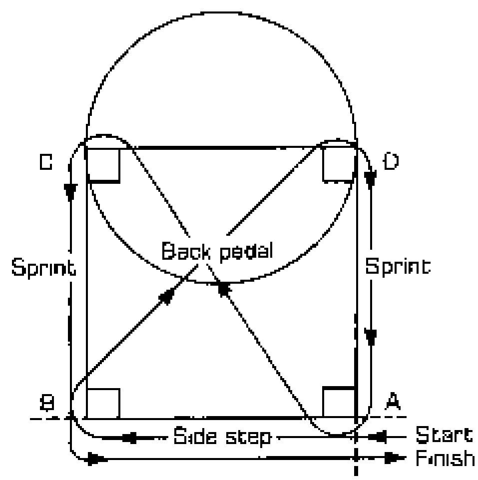


Figure 4 SEMO agility drill

Vertical Jump

Vertical jump will be measured with the Ver-Tec. It is an adjustable height stand with moveable vanes indicating height. Each subject will have two warm-up jumps and three test jumps. The subjects will stand with their feet shoulder width apart with their arms at their sides. No steps will be allowed. They will move at a self-chosen speed as they will maximally jump up and move as many vanes over as possible. Arm movement will not be control. The vanes will not be re-set after each attempt. The highest jump will be recorded. In between each jump, the subject will rest one minute.

Hip Extensor Isokinetic Strength

All strength testing will be done using the Biodex isokinetic dynamometer (Biodex, Shirley, NY). The subjects will be shown the Biodex prior to signing the consent form. Each subject will be tested on eccentric and concentric leg extensor strength through a pre-determined range of motion at 60 degrees/second. The Biodex will log the peak torque, time to peak torque and angle of peak torque for both concentric and eccentric strength.

Each subject will face the chair of the Biodex, which will be level with the subject's anterior superior iliac spine. The subject's trunk will be flexed to ninety degrees and the subject's arms will hold the support grips of the chair of the Biodex for stabilization. The non-dominant leg will support the body and will be bent at the knee to 30 degrees (see Figure 5). This method has been shown to be reliable and valid [35]. This is the same method used in 03-EXSS-417. This method will be utilized because it may be more related to functional tasks, such as sprinting [40]. The researcher will ensure the range of motion set is comfortable and safe for the subject to perform. The subject will not be able to move beyond this range during testing. Each subject will be allowed to practice the motion three times after set up. The subject will perform five repetitions of each contraction and the middle three will be recorded.

Figure 5 Hip extensor strength testing

Stretching Protocol

After the previous measures are taken, those without tight hip flexors and the tight-hip flexor-stretch group will be stretched. Stretching will be done with the subject side-lying and the subject's test side up. The subject's knee will be bent at 90 degrees and the examiner will stabilize their pelvis (see figure 6). With their other hand, they will pull back on the subject's thigh for 10 seconds. The subject will exert an isometric force they feel is 50% of their MVC for 10 seconds [21, 79]. This will be repeated five times. Those in the tight-hip flexor-control will not be stretched and will rest for 1 minute and 40 seconds, which is the duration of the stretching for the stretch group. After the stretching protocol or resting protocol, anterior pelvic tilt, hip extension ROM, hip extensor strength, vertical jump and speed on an agility drill will be retested in all subjects.

Figure 6 Stretching Protocol

A.4.4. Benefits **to subjects and/or society.** Describe any potential for direct benefit to individual subjects, as well as the benefit to society based on scientific knowledge to be gained; these should be clearly distinguished. Consider the nature, magnitude, and likelihood of any direct benefit to subjects. If there is no direct benefit to the individual subject, say so here and in the consent form (if there is a consent form). Do not list monetary payment or other compensation as a benefit.

There are no direct benefits to the individual subjects. The benefits to society will be an increased knowledge about how acute PNF stretching alters postural and performance differences between those with and without tight hip flexors.

A.4.5. **Full description of risks and measures to minimize risks.** Include risk of psychosocial harm (e.g., emotional distress, embarrassment, breach of confidentiality), economic harm (e.g., loss of employment or insurability, loss of professional standing or reputation, loss of standing within the community) and legal jeopardy (e.g., disclosure of illegal activity or negligence), as well as known side effects of study medication, if applicable, and risk of pain and physical injury. Describe what will be done to minimize these risks. Describe procedures for follow-up, when necessary, such as when subjects are found to be in need of medical or psychological referral. If there is no direct interaction with subjects, and risk is limited to breach of confidentiality (e.g., for existing data), state this.

There is a small risk of musculoskeletal injury during isokinetic strength testing, agility testing, vertical jump, and PNF stretching just as there is risk with any physical activity. Subjects will be recreational athletes who perform jumping and cutting maneuvers on a regular basis and the testing will be similar to the maneuvers they perform in sporting and recreational activity. Subjects must wait at least 4 hours following strenuous activity to be tested. Subjects with a lower extremity injury within the last three months will be excluded. Additionally, subjects will be excluded if the cause of the tightness in their hip flexors is due to active iliopsoas trigger points that have limited normal activity for at least one day due to hip pain. Subjects with a history of hereditary nerve disease will be excluded.

Subjects will perform warm-up trials on isokinetic strength testing, agility testing, and vertical jump to familiarize themselves with the test and reduce the risk of injury. A certified athletic trainer will perform all testing procedures. Any subjects sustaining an injury during testing will be referred to student health as necessary by the certified athletic trainer. None of the testing procedures include potential for psychosocial harm, nor are there any medications.

A.4.6. **Data analysis.** Tell how the qualitative and/or quantitative data will be analyzed. Explain how the sample size is sufficient to achieve the study aims. This might include a formal power calculation or explanation of why a small sample is sufficient (e.g., qualitative research, pilot studies).

For all statistical analysis, SPSS 12.0 (SPSS Inc, Chicago, Illinois) will be used. A 3x2 ANOVA will be run for each dependent variable, ten in all. A Tukey post hoc analysis will be run to determine if there is a significant difference in any of the ten omnibus ANOVAs.

A Pearson correlation analysis will be performed to determine if there are relationships among anterior pelvic tilt, hip extension ROM, and hip extensor strength. Correlations will be determined between degrees of hip flexor tightness and degrees of hip extension ROM and hip extension strength.

Power Calculation:

Using the same hip extension strength protocol proposed in this study, Hawkey reported significant differences between males and females in eccentric peak torque and concentric peak torque relative to body weight, (n=58, effect size 1.65 to 1.95) From this data, a total of 8 subjects would provide a power of over .80. Hawkey also examined time to peak torque for concentric and eccentric hip extension between males and females (n=58, effect size .04 to .096). From this data, over a thousand subjects would be needed to have a power of .80, but this study will utilize a stretching intervention that probably not need as many subjects [35].

Gerger (unpublished data) found significant differences in anterior pelvic tilt (n=205, effect size 2.65). From this data, a total of 8 subjects would be needed for a power of .80.

Leishout (unpublished thesis) measured the SEMO drill in 13 athletes in South Africa to establish normative data on athletes (effect size 5.75) Using the range and standard deviation from this data, a total of 8 athletes would be needed for a power of .80.

Winters et al looked at effects of stretching the hip flexors on hip extension ROM in those with limited hip extension (n=45, effect size 1.5). From this data, a total of 8 subjects would be needed for a power of .80 [42].

Church et al examined how PNF stretching affected vertical jump (n = 40, effect size .19). From this data, over 300 subjects would be needed to have a power of .80. However, the authors found a significant difference with 40 subjects [73].

Although several of these variables have a power of 80 with only 8 subjects, it is important for as many variables as possible to have a power of 80. From these calculations, a total of 30 subjects will be tested in this study.

A.4.7. **Will you collect or receive any of the following identifiers as part of the study data?** Does not apply to consent forms.

__ No __X__ Yes *If yes, check all that apply*:

a. _X_ Names
b. __ Telephone numbers
c. __ Any elements of dates (other than year) for dates directly related to an individual, including birth date, admission date, discharge date, date of death. For ages over 89: all elements of dates (including year) indicative of such age, except that such ages and elements may be aggregated into a single category of age 90 and older
d. __ Any geographic subdivisions smaller than a State, including street address, city, county, precinct, zip code and their equivalent geocodes, except for the initial three digits of a zip code
e. __ Fax numbers
f. _X Electronic mail addresses
g. __ Social security numbers
h. __ Medical record numbers
i. __ Health plan beneficiary numbers
j. __ Account numbers
k. __ Certificate/license numbers
l. __ Vehicle identifiers and serial numbers (VIN), including license plate numbers
m. __ Device identifiers and serial numbers (e.g., implanted medical device)
n. __ Web universal resource locators (URLs)
o. __ Internet protocol (IP) address numbers
p. __ Biometric identifiers, including finger and voice prints
q. __ Full face photographic images and any comparable images
r. __ Any other unique identifying number, characteristic or code, other than dummy identifiers that are not derived from actual identifiers and for which the re-identification key is maintained by the health care provider and not disclosed to the researcher

A.4.8. **Data sharing.** With whom will *identifiable* (contains any of the 18 identifiers listed in question 7 above) data be shared outside the immediate research team? For each, explain confidentiality measures. Include data use agreements, if any.

X No one
__ Coordinating Center:
__ Statisticians:
__ Consultants:
__ Other researchers:
__ Registries:
__ Sponsors:
__ External labs for additional testing:
__ Journals:
__ Publicly available dataset:
__ Other:

A.4.9. **Confidentiality of the data**. Describe procedures for maintaining confidentiality of the data you will collect or will receive. Describe how you will protect the data from access by those not authorized. How will data be transmitted among research personnel? Where relevant, discuss the potential for deductive disclosure (i.e., directly identifying subjects from a combination of indirect IDs). Describe your plan to destroy identifiers. When will identifiers be destroyed?

Names and email addresses will be collected from potential subjects to schedule them for testing. These will not be shared among research personnel and will be kept in a locked cabinet in the Sports Medicine Research Laboratory. To enter the Sports Medicine Research Laboratory, one must use their ONEcard. Faculty, staff, doctoral and master's students within the Exercise and Sports Science Department have ONEcard access to the Sports Medicine Research Laboratory. The names and email addresses of subjects will be destroyed after their testing session has been completed.

A.4.10. **Data security for storage and transmission**. Please check all that apply.

For electronic data:

__ Secure network Password access __ Encryption
__ Other (describe):
__ Portable storage (e.g., laptop computer, flash drive)
Describe how data will be protected for any portable device:

For hardcopy data (including human biological specimens, CDs, tapes, etc.):

X Data de-identified by research team (stripped of the 18 identifiers listed in question 7 above)
X _ Locked suite or office
X Locked cabinet
X Data coded by research team with a master list secured and kept separately
__ Other (describe):

Part A.5. The Consent Process and Consent Documentation (including Waivers)

The standard consent process is for all subjects to sign a document containing all the elements of informed consent, as specified in the federal regulations. Some or all of the elements of consent, including signatures, may be altered or waived under certain circumstances.

- If you will obtain consent in any manner, complete **section A.5.1**.
- If you are obtaining consent, but requesting a waiver of the requirement for a signed consent document, complete **section A.5.2**.
- If you are requesting a waiver of any or all of the elements of consent, complete **section A.5.3**.

You may need to complete more than one section. For example, if you are conducting a phone survey with verbal consent, complete sections A.5.1, A.5.2, and possibly A.5.3.

A.5.1. **Describe the process of obtaining informed consent from subjects**. If children will be enrolled as subjects, describe the provisions for obtaining parental permission and assent of the child. If decisionally impaired adults are to be enrolled, describe the provision for obtaining surrogate consent from a legally authorized representative (LAR). If non-English speaking people will be enrolled, explain how consent in the native language will be obtained. Address both written translation of the consent and the availability of oral interpretation. *After you have completed this part A.5.1, if you are not requesting a waiver of any type, you are done with Part A.5.; proceed to Part B.*

Each subject will sign an informed consent form after the orientation to the study. Subjects will be over the age of 18 and not decisionally impaired adults. Subjects will be recruited from physical activity classes as well as from intramural club athletic teams on campus. All subjects will be shown the Biodex, a picture of the SEMO drill, and ver-tec device prior to signing the informed consent form.

A.5.2. **Justification for a waiver of *written* (i.e., signed) consent**. *The default is for subjects to sign a written document that contains all the elements of informed consent.* Under limited circumstances, the requirement for a signed consent form may be waived by the IRB if either of the following is true:

a. The only record linking the subject and the research would be the consent document and the principal risk would be potential harm resulting from a breach of confidentiality (e.g., study involves sensitive data that could be damaging if disclosed). __ yes __ no
Explain.

b. The research presents no more than minimal risk of harm to subjects and involves no procedures for which written consent is normally required outside of the research context (e.g., phone survey). __ yes __ no
Explain.

If you checked "yes" to either, will consent be oral? Will you give out a fact sheet? Use an online consent form, or include information as part of the survey *itself, etc?*

A.5.3. **Justification for a full or partial waiver of consent.** *The default is for subjects to sign a written document that contains all the elements of informed consent.* A waiver might be requested for research involving only existing data or human biological specimens (see also Part C). More rarely, it might be requested when the research design requires withholding some study details at the outset (e.g., behavioral research involving deception). In limited circumstances, parental permission may be waived. This section should also be completed for a waiver of HIPAA authorization if research involves Protected Health Information (PHI) subject to HIPAA regulation, such as patient records.

__ Requesting **waiver of some elements** (specify; see SOP 28 on the IRB web site):
__ Requesting **waiver of consent entirely**
If you check either of the boxes above, answer items a-f.. To justify a full waiver of the requirement for informed consent, you must be able to answer "yes" (or "not applicable" for question c) to items a-f. **Insert brief explanations that support your answers.**

a. Will the research involve <u>no greater than minimal risk</u> to subjects or to their privacy? __ yes __ no
Explain.

b. Is it true that the waiver will *not* adversely affect the rights and welfare of subjects? *(Consider the right of privacy and possible risk of breach of confidentiality in light of the information you wish to gather.)* __ yes __ no
Explain.

c. When applicable to your study, do you have plans to provide subjects with pertinent information after their participation is over? *(e.g., Will you provide details withheld during consent, or tell subjects if you found information with direct clinical relevance? This may be an uncommon scenario.)* __ yes __ not applicable
Explain.

d. Would the research be impracticable without the waiver? *(If you checked "yes," explain how the requirement to obtain consent would make the research impracticable, e.g., are most of the subjects lost to follow-up or deceased?).* **Explain.** __ yes __ no

e. Is the risk to privacy reasonable in relation to benefits to be gained or the importance of the knowledge to be gained? __ yes __ no
Explain.
No sensitive information will be taken during this study. Additionally, the only personal information needed will be self-reported relevant medical history and names of subjects.

If you are accessing patient records for this research, you must also be able to answer "yes" to item f to justify a waiver of HIPAA authorization from the subjects.

f. Would the research be impracticable if you could not record (or use) Protected Health Information (PHI)? *(If you checked "yes," explain how* not *recording or* __ yes X no

using PHI would make the research impracticable).
Explain.

Part B. Questions for Studies that Involve Direct Interaction with Human Subjects

→ *If this does not apply to your study, do not submit this section.*

B.1. **Subjects.** Specify number, gender, ethnicity, race, and age. Specify whether subjects are healthy volunteers or patients. If patients, specify any relevant disease or condition and indicate how potential subjects will be identified.

Thirty healthy volunteers will be recruited for this study (15 males and 15 females). They will be males and females representing the ethnicities and races on the UNC-CH campus between the ages of 18-25who participate in at least three hours of physical activity per week. There will be 10 subjects per group. If the subject does not have tight hip flexors, the will be placed in the not-tight group. If the subject does not have tight hip flexors they will be randomly assigned without replacement to a tight-hip flexor-control group, or a tight-hip flexor-stretch group.

B.2. **Inclusion/exclusion criteria.** List required characteristics of potential subjects, and those that preclude enrollment. Justify exclusion of any group, especially by criteria based on gender, ethnicity, race, or age. If pregnant women are excluded, or if women who become pregnant are withdrawn, specific justification must be provided.

Inclusion Criteria:

Subjects participate in physical activity at least three hours per week

Subjects in the tight hip flexor control and tight hip flexor stretch groups lack at least 10 degrees of hip extension from the table in a modified Thomas test.

Subjects in the normal hip flexor group have their leg at least parallel with the table in the modified Thomas test

Exclusion Criteria:

Knowingly pregnant women because hormonal changes that occur during pregnancy alter muscular flexibility

Any subject with a leg length discrepancy of .5 cm or more as this can influence pelvic position and alter test results.

History of lower extremity surgery in the last year because surgery and the rehabilitation process will alter a subjects ability to perform testing

Current participation in a formal rehabilitation program for a lower extremity injury because any formal rehabilitation program may inhibit a subject's performance on athletic testing

Active hip flexor myofascial trigger points because hip ROM deficits may not be from muscular tightness but from pain due to myofascial trigger points

Any injury causing the subject to withdrawal from physical activity for one day of more in the past three months to exclude subjects who may have a condition which may put the subject at risk for an injury during athletic testing

Any subject with Charcot-Marie-Tooth or any other hereditary nerve disorders because they may respond to stretching differently than subjects without these conditions.

Subjects not between the ages of 18 and 25 as muscle flexibility is altered as aging occurs

B.3. **Methods of recruiting.** Describe how and where subjects will be identified and recruited. Indicate who will do the recruiting, and tell how subjects will be contacted. Describe efforts to ensure equal access to participation among women and minorities. Describe how you will protect the privacy of potential subjects during recruitment. *For prospective subjects whose status (e.g., as patient or client), condition, or contact information is not publicly available (e.g., from a phone book or public web site), the initial contact should be made with legitimate knowledge of the subjects' circumstances. Ideally, the individual with such knowledge should seek prospective subjects' permission to release names to the PI for recruitment. Alternatively, the knowledgeable individual could provide information about the study, including contact information for the investigator, so that interested prospective subjects can contact the investigator.* Provide the IRB with a copy of any document or script that will be used to obtain the patients' permission for release of names or to introduce the study. Check with your IRB for further guidance.

Subjects will be recruited by the principle investigator out of physical activity classes on campus which have equal numbers of males and females as well as minority students. Subjects will also be recruited out of club and intramural athletic teams on campus. Additionally, flyers will be placed on the bulletin board in Fetzer and Woollen gymnasium. Potential subjects will be asked to give their names and email addresses to the principle investigator for scheduling purposes. If subjects do not wish to give their information at the time of the principle investigator's presentation, the principle investigator's e-mail address and phone number will be accessible.

B.4. **Protected Health Information (PHI).** If you need to access Protected Health Information (PHI) to identify potential subjects who will then be contacted, you will need a *limited waiver of HIPAA authorization*. If this applies to your study, please provide the following information.

a. Will the information collected be limited only to that necessary to contact the subjects to ask if they are interested in participating in the study?

b. How will confidentiality/privacy be protected prior to ascertaining desire to participate?

c. When and how will you destroy the contact information if an individual declines participation?

B.5. **Duration of entire study and duration of an individual subject's participation, including follow-up evaluation if applicable.** Include the number of required contacts and approximate duration of each contact.

Each subject's participation will last approximately 1 ½ hours. This will be in one contact session.

B.6. **Where will the subjects be studied?** Describe locations where subjects will be studied, both on and off the UNC-CH campus.

The subjects will be tested in the Sports Medicine Research Lab as well as the gymnasium in Fetzer Gym.

B.7. **Privacy.** Describe procedures that will ensure privacy of the subjects in this study. Examples include the setting for interviews, phone conversations, or physical examinations; communication methods or mailed materials (e.g., mailings should not indicate disease status or focus of study on the envelope).

Subjects will be emailed information about the study after they sign up for a time. All questionnaires will be completed in the Sports Medicine Research Lab.

B.8. **Inducements for participation.** Describe all inducements to participate, monetary or non-monetary. If monetary, specify the amount and schedule for payments and how this will be prorated if the subject withdraws (or is withdrawn) from the study prior to completing it. For compensation in foreign currency, provide a US$ equivalent. Provide evidence that the amount is not coercive (e.g., describe purchasing power for foreign countries). Include food or refreshments that may be provided.

There will be no inducements for participation in this study.

B.9. **Costs to be borne by subjects.** Include child care, travel, parking, clinic fees, diagnostic and laboratory studies, drugs, devices, all professional fees, etc. If there are no costs to subjects other than their time to participate, indicate this.

Subjects will be required to provide their own transportation to campus as well as cover their own parking fees. There are no other costs to the subjects.

Part C. Questions for Studies using Data, Records or Human Biological Specimens without Direct Contact with Subjects

→ *If this does not apply to your study, do not submit this section.*

C.1. What records, data or human biological specimens will you be using? *(check all that apply)*:

__ Data already collected for another research study
__ Data already collected for administrative purposes (e.g., Medicare data, hospital discharge data)
__ Medical records (custodian may also require form, e.g., HD-974 if UNC-Health Care System)
__ Electronic information from clinical database (custodian may also require form)
__ Patient specimens (tissues, blood, serum, surgical discards, etc.)
__ Other (specify):

C.2. For each of the boxes checked in 1, how were the original data, records, or human biological specimens collected? Describe the process of data collection including consent, if applicable.

C.3. For each of the boxes checked in 1, where do these data, records or human biological specimens currently reside?

C.4. For each of the boxes checked in 1, from whom do you have permission to use the data, records or human biological specimens? Include data use agreements, if required by the custodian of data that are not publicly available.

C.5. If the research involves human biological specimens, has the purpose for which they were collected been met before removal of any excess? For example, has the pathologist in charge or the clinical laboratory director certified that the original clinical purpose has been satisfied? Explain if necessary.

__ yes __ no __ not applicable (explain)

C.6. Do all of these data records or specimens exist at the time of this application? If not, explain how prospective data collection will occur.

__ yes __ no If no, explain

Appendix E
Subject Questionnaire

Order_____________ Stretch Rest

Name: __________________ Subject ID___________________

Height__________________ Weight_________________

Have you ever been diagnosed with a leg length discrepancy? YES NO

Are you currently involved in a formal rehabilitation program? YES NO

Have you experienced a lower extremity injury within the last 3 months? YES NO

Have you had any lower extremity condition (injury, pain, etc) that has caused you to limit your physical activity for more than one day in the last three months YES NO

Do you currently participate in a regular stretching program? YES NO

If so, which muscles do you stretch? Circle all that apply.

Hamstrings Shoulders Quadriceps Calves Back Hip Flexors Triceps

Which foot would you kick a ball with? RIGHT LEFT

Leg Length R_____ L______

APT 1__________ 2__________ 3___________ AVG__________

Hip ROM 1________ 2__________ 3__________ AVG_______

SEMO 1__________ 2___________ AVG_________

VJ 1_________ 2__________ 3___________

STRETCH REST

APT 1__________ 2____________3___________ AVG__________

Hip ROM 1__________2__________ 3__________ AVG_______

SEMO 1__________ 2___________ AVG_________

VJ 1_________ 2__________ 3___________

REFERENCES

1. Behm, D G, et al., *Effect of Acute Static Stretching on Force, Balance, Reaction Time, and Movement Time.* Med Sci Sports Exerc, 2004. **36**(8): p. 1397-402.

2. Kujala, U M, et al., *Subject Characteristics and Low Back Pain in Young Athletes and Nonathletes.* Med Sci Sports Exerc, 1992. **24**(6): p. 627-32.

3. Hieno, J G, JJ Carter, CL, *Relationship between Hip Extension Range of Motion and Postural Alignment.* J Orthop Sports Phys Ther, 1990. **12**(6): p. 243-247.

4. Trontelj, J V, *Muscle Fiber Conduction Velocity Changes with Length.* Muscle Nerve, 1993. **16**(5): p. 506-12.

5. Clark, M a A R, *Optimum Performance Training for the Performance Enhancement Specialist*. 1st ed. 2001.

6. Kyrolainen, H P, A Belli, *Changes in Muscle Activity Patterns and Kinetics with Increasing Running Speed.* National Strength and Conditioning Association, 1999. **13**(4): p. 400-406.

7. Young, W B, C MacDonald, and M A Flowers, *Validity of Double- and Single-Leg Vertical Jumps as Tests of Leg Extensor Muscle Function.* J Strength Cond Res, 2001. **15**(1): p. 6-11.

8. Spernoga, S G, et al., *Duration of Maintained Hamstring Flexibility after a One-Time, Modified Hold-Relax Stretching Protocol.* J Athl Train, 2001. **36**(1): p. 44-48.

9. Nelson, A G, et al., *Inhibition of Maximal Voluntary Isometric Torque Production by Acute Stretching Is Joint-Angle Specific.* Res Q Exerc Sport, 2001. **72**(1): p. 68-70.

10. Nelson, A G, et al., *Inhibition of Maximal Voluntary Isokinetic Torque Production Following Stretching Is Velocity-Specific.* J Strength Cond Res, 2001. **15**(2): p. 241-6.

11. Burke, D, CJ Culligan, LE Holt, *The Theoretical Basis for Proprioceptive Meuromuscular Facilitation.* journal of strength and conditioning research, 2000. **14**(4): p. 496-500.

12. Nelson, R, *An Update on Flexibility.* national strength and conditioning association, 2005. **27**(1): p. 10-16.

13. Cramer, J T, et al., *Acute Effects of Static Stretching on Peak Torque in Women.* J Strength Cond Res, 2004. **18**(2): p. 236-41.

14. Fowles, J R, DG Sale, JD MacDougall, *Reduced Strength after Passive Stretch of the Human Plantarflexors.* J Appl Physiol, 2000. **89**(3): p. 1179-88.

15. Kokkonen, J, AG Nelson, *Acute Stretching Exercises Inhibit Maximal Strength Performance.* Med Sci Sports Exerc, 1996. **28**(5): p. 190.

16. Kokkonen, J A G N, D A Arnall, *Acute Stretching Inhibits Strength Endurance.* Med Sci Sports Exerc, 2001. **35**(5): p. s11.

17. Power, K, et al., *An Acute Bout of Static Stretching: Effects on Force and Jumping Performance.* Med Sci Sports Exerc, 2004. **36**(8): p. 1389-96.

18. Guissard, N and J Duchateau, *Effect of Static Stretch Training on Neural and Mechanical Properties of the Human Plantar-Flexor Muscles.* Muscle Nerve, 2004. **29**(2): p. 248-55.

19. Kendall, F, Elizabethe McCreary, Patricia Provance, *Muscles Testing and Function*. 4th ed. 1993, Philidelphia: Lippincott Williams and Wilkins.

20. Prentice, W a D A, *Principles of Athletic Training*. Tenth ed. 2000, Boston: McGraw Hill.

21. Feland, J B and H N Marin, *Effect of Submaximal Contraction Intensity in Contract-Relax Proprioceptive Neuromuscular Facilitation Stretching.* Br J Sports Med, 2004. **38**(4): p. E18.

22. Osternig, L R, et al., *Differential Responses to Proprioceptive Neuromuscular Facilitation (Pnf) Stretch Techniques.* Med Sci Sports Exerc, 1990. **22**(1): p. 106-11.

23. Funk, D C, et al., *Impact of Prior Exercise on Hamstring Flexibility: A Comparison of Proprioceptive Neuromuscular Facilitation and Static Stretching.* J Strength Cond Res, 2003. **17**(3): p. 489-92.

24. Levine, M, J Lombardo, J McNeeley, T Anderson, *An Analysis of Individual Stretching Programs of Intercollegiate Athletes.* Phys Sportsmed, 1987. **15**(3): p. 130-135.

25. Harvey, D, *Assessment of the Flexibility of Elite Athletes Using the Modified Thomas Test.* Br J Sports Med, 1998. **32**(1): p. 68-70.

26. Lee, L W, DC Kerrigan, U Della Croce, *Dynamic Implications of Hip Flexion Contractures.* Am J Phys Med Rehabil, 1997. **76**(6): p. 502-8.

27. Schache, A, PD Blanch, ATMurphy, *Relation of Anterior Pelvic Tilt During Running to Clinical and Kinematic Measures of Hip Extension.* Br J Sports Med, 2000. **34**(4): p. 279-83.

28. Young, W, L Clothier, L Bruce, D Liddell, *Relationship between a Modified Thomas Test and Leg Range of Motion in Australian-Rules Football Kicking.* Journal of sport rehabilitation, 2003. **12**(4): p. 343=350.

29. Eland, D C, et al., *The "Iliacus Test": New Information for the Evaluation of Hip Extension Dysfunction.* J Am Osteopath Assoc, 2002. **102**(3): p. 130-42.

30. Kerrigan, D C, et al., *Effect of a Hip Flexor-Stretching Program on Gait in the Elderly.* Arch Phys Med Rehabil, 2003. **84**(1): p. 1-6.

31. Schwartz, M, TF Novacheck, J Trost, *A Tool for Quantifying Hip Flexor Function During Gait.* Gait Posture, 2000. **12**(2): p. 122-7.

32. Schache, A, KL Bennell, PD Blanch, TV Wrigley, *The Coordinated Movement of the Lumbo-Pelvic-Hip Complex During Running: A Literature Review.* Gait and Posture, 1999. **10**: p. 30-47.

33. Hertel, J, JDorfman, R Braham, *Lower Extremity Malalignments and Anterior Cruciate Ligament Injury History.* Journal of sports science and medicine, 2004. **3**: p. 220-225.

34. Sahrmann, S, *Diagnosis and Treatment of Movement Impairment Syndromes*. 1st ed ed. 2002, St. Louis, Missouri.

35. Hawkey, T, *A Comparison of Hip Strength and Anatomical Measures between Male and Female Basketball and Soccer Players*, in *Exercise and Sport Science*. 2004, University of North Carolina: Chapel Hill. p. 112.

36. Youdas, J W, et al., *Lumbar Lordosis and Pelvic Inclination of Asymptomatic Adults.* Phys Ther, 1996. **76**(10): p. 1066-81.

37. Norkin, C, J White, *Measurement of Joint Motion: A Guide to Goniometry*. 2nd ed. 1995, Philadelphia: F. A. Davis Company.

38. Bierma-Zeinstra, S M, et al., *Comparison between Two Devices for Measuring Hip Joint Motions.* Clin Rehabil, 1998. **12**(6): p. 497-505.

39. McClellen, E, *A Comparison of Myofascial Release and Static Stretching on Active Range of Motion and Muscle Activity*, in *Exercise and Sport Science*. 2003, University of North Carolina: Chapel Hill.

40. Guskeiwicz, K, S Lephart, R Burkholder, *The Relationship between Sprint Speed and Hip Flexion/Extension Stretngth in Collegiate Athletes.* Isokinetics in Exercise Science, 1993. **3**(2): p. 111-116.

41. Simonsen, E B, L Thomsen, and K Klausen, *Activity of Mono- and Biarticular Leg Muscles During Sprint Running.* Eur J Appl Physiol Occup Physiol, 1985. **54**(5): p. 524-32.

42. Winters, M V, et al., *Passive Versus Active Stretching of Hip Flexor Muscles in Subjects with Limited Hip Extension: A Randomized Clinical Trial.* Phys Ther, 2004. **84**(9): p. 800-7.

43. Delp, S, FE Zajac, *Force- and Moment-Generating Capacity of Lower-Extremity Muscles before and after Tendon Lengthening.* Clin Orthop Relat Res, 1992(284): p. 247-59.

44. Halbertsma, J P, et al., *Repeated Passive Stretching: Acute Effect on the Passive Muscle Moment and Extensibility of Short Hamstrings.* Arch Phys Med Rehabil, 1999. **80**(4): p. 407-14.

45. Kennedy, P M and A G Cresswell, *The Effect of Muscle Length on Motor-Unit Recruitment During Isometric Plantar Flexion in Humans.* Exp Brain Res, 2001. **137**(1): p. 58-64.

46. Muraoka, T, et al., *Length Change of Human Gastrocnemius Aponeurosis and Tendon During Passive Joint Motion.* Cells Tissues Organs, 2002. **171**(4): p. 260-8.

47. Kokkonen, J, Caroline Eldredge, Arnold Nelson, *Chronic Stretching Imporves Sport Specific Skills.* Med Sci Sports Exerc, 1997. **29**(5): p. 67.

48. Nelson, A, J Kokkonen, C Eldredge, A Cornwell, E Glickman-Weiss, *Chronic Stretching and Running Economy.* Med Sci Sports Exerc, 1997. **29**(5): p. 68.

49. Cornelius, W, Karen Hayes, *The Relationship between Isometric Contraction Durations and Improvement in Acute Hip Joint Flexibility.* Journal of applied sport science research, 1987. **1**(3): p. 39-41.

50. Handel, M, et al., *Effects of Contract-Relax Stretching Training on Muscle Performance in Athletes.* Eur J Appl Physiol Occup Physiol, 1997. **76**(5): p. 400-8.

51. Van Hatten, B, *Passive Versus Active Stretching.* Phys Ther, 2005. **85**(1): p. 80; author reply 80-1.

52. Shrier, I, *Does Stretching Improve Performance? A Systematic and Critical Review of the Literature.* Clin J Sports Med, 2004. **14**(5): p. 267-273.

53. Witvrouw, E, Nele Mahieu, Leiven Danneels, Peter McNair, *Stretching and Injury Prevention; an Obscure Relationship.* Sports Medicine, 2004. **34**(7): p. 443-449.

54. Dadebo, B, J White, and K P George, *A Survey of Flexibility Training Protocols and Hamstring Strains in Professional Football Clubs in England.* Br J Sports Med, 2004. **38**(4): p. 388-94.

55. Halbertsma, J P, A I van Bolhuis, and L N Goeken, *Sport Stretching: Effect on Passive Muscle Stiffness of Short Hamstrings.* Arch Phys Med Rehabil, 1996. **77**(7): p. 688-92.

56. Kubo, K, H Kanehisa, and T Fukunaga, *Effect of Stretching Training on the Viscoelastic Properties of Human Tendon Structures in Vivo.* J Appl Physiol, 2002. **92**(2): p. 595-601.

57. Magnusson, S P, et al., *Viscoelastic Response to Repeated Static Stretching in the Human Hamstring Muscle.* Scand J Med Sci Sports, 1995. **5**(6): p. 342-7.

58. Marek, S M, et al., *Acute Effects of Static and Proprioceptive Neuromuscular Facilitation Stretching on Muscle Strength and Power Output.* J Athl Train, 2005. **40**(2): p. 94-103.

59. Carter, A, SJ Kinzey, LF Chitwood, JL Cole, *Proprioceptive Neuromuscular Facilitation Decreases Muscle Activity During the Stretch Reflex in Selected Posterior Thigh Muscles.* J Sport Rehabil, 2000. **9**: p. 269-278.

60. Siatras, T, G Papadopoulos, D Maeletzi, V Gerodimos, P Kellis, *Static and Dynamic Acute Stretching Effect on Gymnasts' Speed in Vaulting.* Ped Ex Sci, 2003. **15**: p. 383-391.

61. Laur, D J, et al., *The Effects of Acute Stretching on Hamstring Muscle Fatigue and Perceived Exertion.* J Sports Sci, 2003. **21**(3): p. 163-70.

62. Avela, J, H Kyrolainen, and P V Komi, *Altered Reflex Sensitivity after Repeated and Prolonged Passive Muscle Stretching.* J Appl Physiol, 1999. **86**(4): p. 1283-91.

63. Avela, J and P V Komi, *Reduced Stretch Reflex Sensitivity and Muscle Stiffness after Long-Lasting Stretch-Shortening Cycle Exercise in Humans.* Eur J Appl Physiol Occup Physiol, 1998. **78**(5): p. 403-10.

64. DePino, G W W, BL Arnold, *Duration of Maintained Hamstring Flexibility after Cessation of an Acute Static Stretching Protocol.* J Athl Train, 2000. **35**(1): p. 56-59.

65. Avela, J, et al., *Reduced Reflex Sensitivity Persists Several Days after Long-Lasting Stretch-Shortening Cycle Exercise.* J Appl Physiol, 1999. **86**(4): p. 1292-300.

66. Schilling, B, *Stretching: Acute Effects on Strength and Power Performance.* National Strength and Conditioning Association, 2000. **22**(1): p. 44-47.

67. Kubo, K, H Kanehisa, T Fukunaga, *Effects of Transient Muscle Contractions and Stretching on the Tendon Structures in Vivo.* Acta Physiologica Scandinavia, 2002. **175**(2): p. 157-164.

68. Cornwell, A, AG Nelson, *The Acute Effects of Passive Stretching on Active Musculotendinous Stiffness.* Med Sci Sports Exerc, 1997. **29**(5): p. 281.

69. Rosenbaum, D and E M Hennig, *The Influence of Stretching and Warm-up Exercises on Achilles Tendon Reflex Activity.* J Sports Sci, 1995. **13**(6): p. 481-90.

70. Luhtanen, P and R V Komi, *Segmental Contribution to Forces in Vertical Jump.* Eur J Appl Physiol Occup Physiol, 1978. **38**(3): p. 181-8.

71. Brown, M E, J L Mayhew, and L W Boleach, *Effect of Plyometric Training on Vertical Jump Performance in High School Basketball Players.* J Sports Med Phys Fitness, 1986. **26**(1): p. 1-4.

72. Bobbert, M, A Van Soest, *Effects of Muscle Strengthening on Vertical Jump Height: A Simulation Study.* Med Sci Sports Exerc, 1994. **26**(8): p. 1012-1020.

73. Church, J B, et al., *Effect of Warm-up and Flexibility Treatments on Vertical Jump Performance.* J Strength Cond Res, 2001. **15**(3): p. 332-6.

74. Voigt, M, et al., *Mechanical and Muscular Factors Influencing the Performance in Maximal Vertical Jumping after Different Prestretch Loads.* J Biomech, 1995. **28**(3): p. 293-307.

75. Johns, B, Jack Nelson, *Practical Measurement for Evaluation in Physical Education*. 1979, Minneapolis, MN: Burgess Publishing Company.

76. Markovic, G, et al., *Reliability and Factorial Validity of Squat and Countermovement Jump Tests.* J Strength Cond Res, 2004. **18**(3): p. 551-5.

77. Hunter, J P and R N Marshall, *Effects of Power and Flexibility Training on Vertical Jump Technique.* Med Sci Sports Exerc, 2002. **34**(3): p. 478-86.

78. Liebermann, D, L Katz, *On the Assessment of Lower Limb Muscular Power Capability.* Isokinetics in Exercise Science, 2003. **11**: p. 87-94.

79. Rowlands, A, VF Marginson,J Lee, *Chronic Flexibility Gains: Effect of Isometric Contraction Duration During Proprioceptive Neuromuscular Facilitation Stretching Techniques.* Res Q Exerc Sport, 2003. **74**(1): p. 47-51.

80. Georger, B, *The Effect of Pelvic Inclination on Lower Extremity Strength*, in *Exercise and Sports Science*. 2004, University of North Carolina: Chapel Hill.