

ASSESSING THE RELIABILITY OF TWO ORTHOPEDIC SPECIAL TESTS TO
DETERMINE HIP FLEXOR CONTRACTURE WITH THE ASSESSMENT OF PELVIC TILT
ANGLE DURING A BACK SQUAT

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ABSTRACT

Orthopedic specialists use Special Tests to determine a pathology's presence. Hip flexor contracture is linked to injury predisposition and postural anomalies. This research examined reliability for the Modified Thomas and Ely's Special Tests when evaluating hip flexor contracture, and its effect on dynamic exercise. Twenty adults were randomized in a study and analyzed for hip flexor contracture. Dartfish Motion Analysis measured hip and knee flexion angles. Participants performed isometric squats to determine their maximal voluntary isometric contraction, which was later used to calculate exercise prescription for the eight-repetition dynamic back squat. Inter-rater reliability was slight to fair for iliopsoas contracture during the Modified Thomas Test. Overall analysis of pre-/post-test pelvic tilt and dynamic pelvic tilt between repetitions was not statistically significant ($p < .05$). Hip flexion between repetitions was statistically significant ($p = .016$). Clinicians should exert caution when defining pathology utilizing Special Tests and the effect of hip flexor contracture on dynamic movement.

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TABLE OF CONTENTS

ABSTRACT.....	iii
ACKNOWLEDGEMENTS.....	iv
LIST OF TABLES.....	viii
LIST OF FIGURES.....	ix
CHAPTER 1. INTRODUCTION.....	1
Overview of the Problem.....	1
Statement of Purpose.....	2
Research Questions.....	3
Hypotheses.....	3
Overview of the Study.....	3
Limitations.....	4
Delimitations.....	4
Assumptions.....	5
Significance of Current Study.....	5
Definition of Terms.....	6
CHAPTER 2. LITERATURE REVIEW.....	8
Introduction.....	8
Defining Anterior Pelvic Tilt.....	10
Muscles and Their Effect on Pelvic Kinematics.....	14
Injury Risks from Anterior Pelvic Tilt.....	16
Impact of Gender Differences on Injury.....	17
Importance of Special Tests in an Orthopedic Practice.....	20
Ely’s Test.....	21
Thomas Test.....	25

Assessment between Special Tests of Reliability.....	37
Reliability of the Ely’s Test.....	38
Reliability of the Thomas Test.....	39
Assessment of Hip Strength Through Dynamic Exercise	42
Purpose of the Isometric Squat	42
Exercise Load and Prescription.....	43
Motion Analysis in the Two-Dimensional View	45
Conclusion	50
CHAPTER 3. METHODOLOGY	52
Research Design	52
Participants.....	52
Instrumentation	53
Procedures.....	54
Statistical Analysis.....	58
CHAPTER 4. MANUSCRIPT	60
Abstract.....	60
Introduction.....	60
Methods	62
Design	62
Participants.....	62
Procedures.....	63
Statistical Analysis.....	67
Results.....	67
Discussion.....	73
Inter-rater Reliability.....	73

Range of Motion for Modified Thomas and Ely's Tests	75
Anterior Pelvic Tilt	78
Hip Flexion	79
Pelvic Tilt.....	81
Conclusion	81
References.....	82
REFERENCES	85

LIST OF TABLES

<u>Table</u>	<u>Page</u>
1. Descriptions of the Multiple Thomas Tests/Modified Thomas Tests Broken Down	31
2. Participant Demographics (Mean and SD)	67
3. Hip and Knee Angle Measures for Modified Thomas Test (MTT) and Ely's Test (Mean and SD)	68
4. Indications for Modified Thomas Test (MTT) and Ely's Test to Determine Presence of Hip Flexor Contracture (+) or Non-existence (-)	69
5. Ratio/Percentage for Modified Thomas Test (MTT) and Ely's Test Per Examiner	69
6. Fleiss' Kappa Coefficients to Determine Inter-rater Reliability of Modified Thomas Test (MTT) and Ely's Test (Ely)	70
7. Mean Values Collected During Pelvic and Hip Analysis for Each Repetition of Dynamic Back Squat (Mean and SD)	72

LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
1. Thomas Test positioning as described by Vigotsky et al. ⁶ , Shultz et al. ¹⁵ , Lee et al. ³⁹ , and Lee et al. ³⁸	27
2. Shultz et al. ¹⁵ 's interpretation of a Positive Thomas Test.....	27
3. Lines used by Lee et al. ³⁹ and Lee et al. ³⁸ to measure the amount of hip flexor contracture.....	27
4. Placement of Markers for Two-Dimensional Motion Analysis.....	56
5. The Modified Thomas Test as described by Starkey et al. ⁸	57
6. The Ely's Test as described by Starkey et al. ⁸	57
7. Estimated Anterior Pelvic Tilt Means for Every Squat Repetition.....	71
8. Estimated Hip Flexion Means for Every Squat Repetition.....	73

CHAPTER 1. INTRODUCTION

Overview of the Problem

Resistance training for both recreational and competitive athletes has become increasingly popular. Research in these areas has also increased greatly in recent years. Today's elite athletes are specializing early with their training, therefore possibly creating postural imbalances due to neglect of antagonist musculature. These imbalances in muscles become present as athletes train to perform certain tasks, specific to their own sport. For example, linemen in football push for their primary job, therefore the chest musculature is strengthened perhaps more often than the back. Another example may be a volleyball player that is always leaned forward to dive for a ball, yet experiences impingement through her hips due to tight hip flexors and weak hip extensors.

The focus of this study involves anterior muscular dominance of the hip flexor complex and its effect on anterior pelvic tilt. Anterior muscular dominance, mainly in the hip flexor complex have been generally measured with the Modified Thomas Test and Ely's Test by orthopedic clinicians to establish a lack of hip flexor flexibility. The Modified Thomas Test is an orthopedic special test that measures for rectus femoris and iliopsoas muscle contractures, however the validity or methods to perform this special test are not consistent over a wide range of studies including textbooks.¹⁻⁸ The Ely's Test is intended to determine rectus femoris tightness, however there is very little literature that defends its ability to do so.^{8,9} Therefore, the reliability and validity of these orthopedic Special Tests must be measured to determine if they are suitable for clinical practice.

Presently, many individuals sit at a desk all day or in a forward-leaned position which creates a perfect environment for the condition.¹⁰ Therefore, anterior pelvic tilt, along with a

weakness in trunk flexor musculature, places the participant at an increased risk for injuries such as hamstring strain, groin injury, ankle sprains, knee ligament injury (such as ACL sprain) and low back pain.⁶⁻¹¹ In addition, hip strength influences the presence of anterior pelvic tilt. Ideally, the pelvis would be in perfect positioning at 0° of pelvic tilt. However, the amount of muscular power created will depend upon the change in kinematics which results from muscular dominance. Muscular activation via electromyography during anterior pelvic tilt determined that the rectus femoris shows greater activation when in this position, as discovered by Workman et. al¹². Furthermore, their rationale proposed that this phenomenon occurs due to a shortening of the rectus femoris, therefore increased contractile force during normal movement.¹² In conclusion, it is pertinent to recognize shortening of the rectus femoris and how this position affects the rest of the body.

Statement of Purpose

The chief purpose of this study is to determine the utility of two orthopedic special tests, Modified Thomas Test and Ely's Test, and how reliable the special tests are to determine hip flexor contracture. Additionally, to evaluate how hip flexor contracture affects dynamic performance. We took a multifactorial approach to analyze these commonly used special tests to: 1) determine inter-rater reliability between three certified athletic trainers and 2) analyze the relationship between a static special tests and dynamic activity. The focus of this study will be to determine hip flexor contracture, which is an indication factor to the presence of anterior pelvic tilt, the reliability of the Modified Thomas Test and Ely's Test, and how dynamic performance; specifically a back squat, changes in response to this condition.

Research Questions

1. What is the inter-rater reliability of the Modified Thomas and Ely's Tests in determining the presence of a hip flexor contracture?
2. How does pelvic tilt and hip flexion vary before, during and post back squat?

Hypotheses

1. The Modified Thomas Test and Ely's Tests will have low intra-rater reliability.
2. There will be a significant increase in the amount of pelvic tilt present after the back squat exercises in relation to the measures before the back squat measures.
3. Also, they will have increasing hip flexion angles during the back squat from repetition one to eight.

Overview of the Study

The participants will be exposed to a variety of tests in this study. During the first portion of the study, three clinicians with at least five years of orthopedic evaluation experience will perform the Modified Thomas and Ely's Tests. Each clinician will perform a randomized order of the Modified Thomas Test and the Ely's Test. In addition, the order in which the clinicians will be selected to perform these orthopedic special tests will be randomized. The clinicians will be blinded to each other's results in order to maintain unbiased measures. Next, an Accupower force plate (American Medical Technologies Incorporated, Watertown, MA) will be used to collect the initial weight of the person and their estimated one-repetition maximum (1RM). A squat rack loaded with enough weight to prevent the individual from lifting the bar will be used while the subjects will be videoed by a camera (Casio EX-FH20, Tokyo, Japan) and the angles of the pelvis will be measured later using Dartfish Motion Analysis ver. 8.0 (Dartfish, Fribourg, Switzerland). Following a five-minute rest period, the participants will be required to perform

eight repetitions at 80% of their 1RM for the back squat exercise while images are taken to later evaluate anterior pelvic tilt and hip flexion during the squat via Dartfish Motion Analysis

Limitations

Several limitations in this study are present. First of all, there are limitations with the use of two-dimensional motion analysis instead of the gold standard of three-dimensional motion analysis. A three-dimensional motion analysis gives the examiner three different viewing planes that allows for analysis of rotation. However, two-dimensional motion analysis only provides two planes of viewing, therefore, it is difficult to determine if there is rotation at the joint. The inability to access three-dimensional motion analysis software was another limitation in the study. Therefore, two-dimensional motion analysis was used with the understanding that it is not the gold standard software for measuring biomechanical movements. The final limitation of this study is the quality of lifting form while the participant performs the back squat. This may vary due to learned procedures from coaches and whether those coaches taught proper techniques for the back squat. Perhaps, some individuals have been performing a back squat for years without ever consulting with a strength and conditioning specialist. Therefore, techniques for performing a back squat may vary in between participants.

Delimitations

Three experienced orthopedic clinicians will perform the Modified Thomas and Ely's Tests. The special tests will be performed similar to the Starkey et al.⁸ method, since these are the special tests that are taught to many Athletic Training students, who will then use these practices in their own evaluations. Therefore, it is critical to ensure that these special tests that are taught to future Athletic Trainers are accurate. The 1RM is used for measuring strength.¹³ Bazzyler et al.¹³, determined the validity of using the isometric squat to measure a 1RM. The

researchers revealed dynamic 1RM squats to be similar to isometric squats at 90° and 120° of knee flexion.¹³ To determine exercise prescription for the back squat, the National Strength and Conditioning Association (NSCA) protocol is used, therefore requiring eight repetitions.¹⁴ The load is determined as 80% of the participant's 1RM to train for basic strength.¹⁴

Assumptions

It was assumed participants are truthful when they state their amount of experience with resistance training and about their health profile. Furthermore, it was assumed participants have been taught the proper technique to perform a back squat exercise. In addition, it was assumed that the athletic trainers had the same training and followed the same protocol to administer the special tests.

Significance of Current Study

As the demand for elite performance increases, we will need to develop more research to determine the optimal anatomical characteristics for the body. This study provided more evidence to determine whether there are differences in posture due to muscular dominance. Furthermore, the information can be used in future studies to determine whether posterior dominance will affect posture or the potential for different lifting techniques utilizing pelvic tilt.

In order to provide the most effective care, orthopedic clinicians must perform the most efficient tests to determine if a hip flexor contracture is present. Since the reliability of the Thomas and Ely's Tests will be measured, clinicians will have evidence to give their patients the most thorough evaluation and an accurate assessment. In addition, with a wide variance in the literature on the reliability and validity of the Modified Thomas Test and little evidence on the Ely's Test and its efficacy, the results from this study may provide a model for continued research to follow.

Definition of Terms

Acetabular Anteversion: the excessive anterior angulation of the femoral neck that results in a toe-in gait.¹⁵

Anterior Pelvic Tilt: when the distance between the midpoint of both anterior-superior iliac spines and the coronal plane is greater than the distance from the symphysis pubis and the coronal plane.¹⁶

Ely's Test: a special orthopedic test used to evaluate rectus femoris tightness. Performed prone with the clinician at the patient's side. Passively flexes one knee to allow the foot to reach the buttocks. If the hip flexes from the table, there is an implication of rectus femoris tightness.⁸

Genu recurvatum: excessive hyperextension of the knee.¹⁷

Genu valgum: "excessive lateral angulation of the tibia relative to the femur."¹⁵

Inter-rater reliability: reliability that describes the consistency of results for an examination technique practiced on one patient by many examiners.⁹

Intrarater reliability: the consistency of results over the course of several examinations of the same patient by the same clinician.⁹

Myositis ossificans: "a condition that occurs when the body's inflammatory response during absorption of a hematoma causes calcification or bony deposits to form in the muscle."¹⁵

1-repetition maximum (IRM): the greatest amount of weight that may be lifted for one repetition using proper technique.¹⁴

Q-angle: "the angle created by a line from the anterior superior iliac spine through the midpoint of the patella and a line from the tibial tubercle through the midpoint of the patella."¹⁵

Sensitivity: defined as "the ability of a test to yield a positive result when the condition is truly present."¹⁵

Specificity: defined as "the ability of a test to yield a negative result when the condition is truly absent"¹⁵

Modified Thomas Test: an orthopedic special test used to evaluate hip flexor contracture. The patient sits on the edge of the table, grasps one knee to their chest and rolls back onto the table, leaving the opposite limb extended off the table. Positive implications include the extended thigh rising from the table (iliopsoas contracture indicated) or the knee moving into extension (rectus femoris contracture indicated).⁸

Thomas Test: a special orthopedic test used to evaluate hip flexor contracture. The patient lies supine and passively flexes the knee to the chest and holds with their hands while the opposite leg resting flat on the table. Positive implications include the transition of the extended leg to a flexed position, therefore lifting the knee from the table. This indicates an iliopsoas contracture.⁸

CHAPTER 2. LITERATURE REVIEW

Introduction

The primary goal of sports injury prevention is to reduce the incidence or recurrence of injury through a combination of patient history, physical examination, strength and cardiovascular endurance training, stretching protocols, and Special Tests.^{1,2,18-20} Fulfilling this objective requires accurate diagnosis of the injury, proper implementation of rehabilitation protocols, and sufficient research to confirm the reliability of measures.⁹ If the orthopedic clinician were to fail at the diagnosis or prescription, then the goal of treatment would be unachievable. With an ever-increasing emphasis on athletes performing at their greatest potential, clinicians need to accurately diagnose injuries. In addition, the proper measures must be taken to treat and rehabilitate athletes, so they can continue to perform at elite levels.

Anatomical structures affect an individual's posture, which exposes them to potential injury. In addition, it is well known that patient posture and prevalence to injury is impacted by change in flexibility and strength in the muscles surrounding the body's joints.^{1,2,11,19,21-25} Extrinsic factors can have an effect on rectus femoris tightness.²⁶ The factors include immobilization of the hip while in a flexed position, immobilization of the knee in an extended position or injuries to other structures connected to the kinetic chain (ankle/knee injuries).²⁶ It is certain that traumatic incidences such as muscle strains, myositis ossificans, and avulsion fractures of the anterior superior iliac spine (ASIS) contribute to rectus femoris tightness.²⁶ More specifically, where there is a general deficiency in range of motion (ROM) for a joint structure, the surrounding areas are subject to altered biomechanical movement, thereby increasing the energy expended and predisposition to injury.^{19,21,26} Furthermore, an analysis of an athlete's function and biomechanical movements can reveal critical information about the

importance of the pelvis for posture.²⁴ Indeed, analysis of hip flexor tightness and lack of hip extension are reported to increase anterior pelvic tilt in individuals.^{11,25 26}

Anterior pelvic tilt is diagnosed when the distance between the midpoint of both anterior-superior iliac spines and the coronal plane is greater than the distance from the symphysis pubis and the coronal plane.¹⁶ Therefore, the anterior-superior iliac spines move away from the coronal plane, as the pubic symphysis transitions closer. This phenomenon describes the anterior tilting of the pelvis. Anterior pelvic tilt predisposes the body to injury such as anterior cruciate ligament (ACL) sprains, hamstring strain, low-back pain, and many more musculoskeletal pathologies.^{6,10,17,27} Anterior pelvic tilt may be caused by lack of flexibility in the iliopsoas complex (iliacus, psoas major, and psoas minor) and the rectus femoris, weakness or insufficient length of the hamstring muscle complex, or weakness in the trunk musculature.^{22,28}

Many different special tests are used by orthopedic specialists to determine a pathology from a differential diagnosis. A differential diagnosis allows the clinician to narrow down a pathology from a list of possible pathologies that may be present. To determine a pathology, it is necessary that the Special Tests reproduce consistent results through multiple measures. The terms sensitivity and specificity are used by clinicians to define the results that have been found. Sensitivity is defined as the ability of a test to yield a positive result when the condition is truly present.¹⁵ This is known as a true positive rate because it describes a proportion of the positive results as compared to the number of positives for the condition.⁸ Specificity is defined as "the ability of a test to yield a negative result when the condition is truly absent."¹⁵ This is also known as a true negative rate because it detects the number of individuals who do not have the condition at that time.⁸ The Modified Thomas and Ely's Tests are used to test for the lack in hip flexor (iliopsoas and rectus femoris) flexibility, in turn determining potential anterior pelvic tilt.

While we know that these special tests are used widely by clinicians, we still are not educated of their effectiveness. This is due to a lack of consistent measures to determine their validity and reliability. In conclusion, to know whether the Modified Thomas and Ely's Test show criteria for anterior pelvic tilt is a necessity. Therefore, it is also pertinent to establish parameters for anterior pelvic tilt to determine whether or not it is present.

Defining Anterior Pelvic Tilt

Objective measurements enable clinicians to determine parameters for establishing the presence of anterior pelvic tilt, as well as the extent of the tilt. Numerous studies have incorporated a measurement of pelvic tilt using the anterior pelvic plane.^{16,27,29,30} Yet, while these researchers incorporate a measure of pelvic tilt using the anterior pelvic plane, they define the actual plane in various ways. For example, Loppini et al.²⁹ defined anterior pelvic plane as the angle between a vertical reference line and another line that is tangent to the ASIS and the pubic symphysis. In contrast, Kanazawa et al.³⁰ described the measure of the anterior pelvic plane as the area that lies between the line that connects both ASIS and the superior area of the pubic symphysis. In yet another definition, Zahn et al.²⁷ determined anterior pelvic plane with a 3-dimensional model of a pelvis in which they marked the ASIS bilaterally and both pubic tubercles. Zhu et al.¹⁶ also marked the ASIS and both pubic tubercles in the same manner as Zahn; they used pelvic tracking software to achieve their measurements from markers. According to a textbook by Shultz et al.¹⁵, there are normalized measurements to determine anterior pelvic tilt. In females, 7 to 17° is the general range for anterior pelvic tilt, while men experience a general range of 5 to 13°. These protocols for measurement give clinicians a baseline and help standardize a measure for anterior pelvic tilt.

The placement of markers for imaging has been performed in many ways to measure pelvic tilt.²⁹ A 2-dimensional radiographic analysis of pelvis in the sagittal plane were conducted in two postures, standing and sitting.²⁹ Landmarks of reference for pelvic tilt included the upper plate in S1 and a midpoint of the femoral heads.²⁹ For example, in a study by Vigotsky et al.⁶ pelvic tilt was calculated between an intercrystal line fashioned from the ASIS to the PSIS and a horizontal plane that was offset by 90°. Marker placement varies between studies for motion analysis. Researchers for Vigotsky fixed markers to the iliac crests parallel to the Anterior Superior Iliac Spine (ASIS) and the Posterior Superior Iliac Spine (PSIS), lateral femoral epicondyle and greater trochanter.⁶ In another situation, Zahn et al.²⁷ provided marker locations along the rim of the acetabular rim, bilateral ASIS and both pubic tubercles. On the other hand, a study compared the obturator foramina heights and widths with the anterior pelvic plane to establish sagittal pelvic tilt.³⁰ Kanazawa et al.³⁰ and Zahn et al.²⁷ did not perform traditional motion analysis, but measured the differences through computed tomography (CT) analysis. Computer navigation was used in a study to determine pelvic tilt with a pelvic tracker administered to the participant.¹⁶ In order to register the landmark, small stab wounds were made over both ASIS and close to the pubic tubercles.¹⁶ The stab wounds served as the “markers” in this study, as they gave the researchers guidelines for measure with the use of motion analysis.

Motion analysis and radiographic imaging in the following studies determined the potential range of pelvic tilt in athletic populations.^{16,27,29} A study by Loppini et al.²⁹ focused on 2-dimensional imaging of the pelvis from the sagittal angle in individuals following a hip arthroplasty. Patients underwent radiographic assessment in both standing and sitting positions. Pelvic tilt was determined from the angle created by the vertical reference line and a line tangent

to the ASIS and the pubic symphysis.²⁹ Pelvic tilt measurements were $11^{\circ} \pm 8.3$ in the standing position and $34^{\circ} \pm 11.8$ for the sitting position.²⁹ Since the measurements are positive, they describe the anterior tilt of the pelvis, whereas negative numbers would indicate a posterior tilt of the pelvis. Loppini et al.²⁹ did not describe whether these values are excessive or normalized, but did describe that a neutral (0°) pelvic tilt does not exist and that the participants will either experience an anterior or posterior tilt of the pelvis. Therefore, whenever a surgeon is performing total hip arthroplasty, they must take into account the amount of pelvic tilt, and then account for how much femoral anteversion may need to be manipulated for best kinematics of the body.

Another method using computed tomography (CT) scans of the pelvis were used to calculate mean pelvic tilt.²⁷ Pelvic tilt was determined by the angle between the anterior pelvic plane and the horizontal plane created by the CT scanner. Measurements of both men and women were conducted where all positive values attributed to anterior pelvic tilt. The mean difference within measures was $-0.1^{\circ} \pm 5.5^{\circ}$ of pelvic tilt.²⁷ No differences between genders or age were found.²⁷ The study did not provide information to determine a gender prevalence among individuals with anterior pelvic tilt, however, the measurements provided will assist in the provision of a standardized range of measure for this condition.

A study by Zhu et al¹⁶ discovered the effects on how pelvic tilt affects femoral anteversion. The researchers determined from 216 men and 220 women that femoral (acetabular) anteversion increases with anterior pelvic tilt.¹⁶ Femoral anteversion is defined as excessive femoral angulation that is often characterized with a 'toe-in' gait pattern, increased quadriceps angle (Q-angle), and genu valgus at the knee (knock-kneed).¹⁵ It may cause further pathologies such as hip dysplasia or femoro-acetabular impingement.²⁷ Their measurements of

pelvic tilt fell within a range of 1° to $+20^{\circ}$, thereby highlighting the amount of pelvic tilt present.¹⁶ In this study no gender differences were found. During pelvic tilt there are subsequent alterations to the body's biomechanical posturing where femoral anteversion is influenced by anterior pelvic tilt.^{16,23,27} Bagwell et al.²³ noted a considerable cause and effect between internal rotation of the femur and the anterior tilt of the pelvis. As reported by Zhu et al.¹⁶, for every degree of pelvic tilt, either anteriorly or posteriorly, femoral anteversion changed by 0.8° . Bagwell et al.²³ stated that the phenomenon may be caused by the posterior rotation of the femoral head into the posterior acetabulum, which in turn, will guide the pelvis into an anterior tilt.^{23,27,31} Zhu et al.¹⁶ determined that the change in femoral anteversion may contribute to the changes in posture of the hips, thereby placing different forces on the knee joint. These forces may change the kinematics of the knee, thereby predisposing the individual to injury or re-injury.¹⁶ Therefore, a reliable technique must be determined in order to assess patients for changes in pelvic tilt. However, females display a stronger correlation of anterior pelvic tilt with acetabular anteversion compared to males.²⁷ Therefore, females may show more predisposition to anterior pelvic tilt than men.

The preceding studies yielded different measurements of pelvic tilt that fall into a particular range. This range is important as it describes the presence of anterior pelvic tilt to the clinician. Based on the studies' results, anterior pelvic tilt values fall between 1° and just above 20° .^{16,27,29} Utilizing this range, a clinician may make an informed decision regarding the excessive degree of the anterior pelvic tilt and how this may affect the kinematics of the individual since there are no established norms at this time. As noted prior by Shultz et al.¹⁵, there is a general range of anterior pelvic tilt ($7-17^{\circ}$) in females and ($5-13^{\circ}$) in males. In summation, a clinician may use these norms to help track anterior pelvic tilt and implement

options to decrease the angle of anterior pelvic tilt to optimize posture for the patient and increase performance. The measurements may assist the clinician in their determination for causation of the tilt.

Muscles and Their Effect on Pelvic Kinematics

The pelvis is acted on by a wide variety of muscular structures that may change the direction of pelvic tilt due to differences in strength and tension. The length of the musculature will affect the muscle's contractile force.¹ Muscles that have experienced changes in their positioning (lengthened or shortened) are at risk for decreased development of maximum tension due to the changes in resting length.¹ Weakness of the hamstrings or inadequate lengthening also contribute to anterior pelvic tilt, as the anterior hip musculature dominates.²² Among the dominant anterior hip musculature is the rectus femoris, which becomes tight during anterior pelvic tilt. It is related to changes in knee joint biomechanics, pain within the knee joint, and restricts the ability to complete full functional movements.¹⁸ The rectus femoris may be accompanied by the iliopsoas complex in its contracted state. During this contracture, the spine may be guided into further extension creating low back pain.⁶ Rectus femoris tightness is prevalent among individuals, therefore, many members of society are predisposed to injury or joint-related pain.¹⁸

Mills et al.³² describes that lower extremity injury is derived from overactivation of the hip flexor complex due to reciprocal inhibition. Whenever the hip flexors over-activate, there is a theory by Mills et al.³² that secondary hip extensors activate in order to compensate for the lack of activation in the gluteus maximus. The effect on lower extremity injury from this biomechanical deficiency has been thought to be caused by synergistic domination.³² When a prime mover exhibits weakness, synergistic musculature will engage in an attempt to handle the

work load, leading to over-activation of the muscle(s).³³ This over-activation of the synergistic musculature results in over-use of the muscle and consequently in gait changes.³³ Injury will occur whenever the dominant muscle is not engaged, yet the synergistic musculature activates in order to compensate for the load.³² For example, in the case of a hamstring strain, the gluteus maximus may not be properly firing to achieve peak hip extension, therefore, the hamstring complex may activate to handle the load, leading to damage of the muscle tissue.³²

Workman et al.¹² determined which muscles are activated during various exercises that place the pelvis in different positions. During this study, the 14 male participants were tested performing two separate exercise while electromyography (EMG) measured muscle activation. To test abdominal activation, the participant performed the Janda sit-up. This exercise was created by Vladimir Janda and is often referred to as a heel-press sit up.¹² It is performed similarly to a normal sit-up with the exception that the feet are held by a second person. However, to ensure complete hamstring contraction during the duration of the Janda sit-up, a bar was placed behind their heel while a member of the research team held the bar.¹² The idea is to eliminate hip flexor activation during the exercise through the active contraction of the hamstring muscles.¹² While EMG was measuring the rectus femoris, upper and lower rectus abdominis, external obliques, and hamstrings, the participant was asked to perform the Janda sit-up and hold the position of 45° of trunk flexion while simultaneously contracting the hamstrings.¹² In addition, the second exercise involved a double straight leg lift, during which the participant was instructed to perform anterior and posterior pelvic tilts and neutral pelvic position.¹² They defined an anterior tilt of the pelvis as tilting the pelvis as far forward as possible to make as much space as possible between the lower back and the plinth that they were laying on.¹² Additionally, a neutral pelvic tilt was defined as the comfortable resting position of the pelvis.¹²

Finally, posterior pelvic tilt was achieved by flattening the back against the plinth.¹² For each exercise position, there was a five second contraction and continued for two more tests with a 30 second rest period in between exercises.¹² Activation of the muscles were then measured by EMG to determine what muscles were activated at particular points of pelvic tilt (anterior, posterior, neutral).¹² The Janda sit-up yielded the greatest activation of the upper rectus abdominis and biceps femoris (approximately 0.65-0.7 millivolts) according to EMG data. During the exercise of anterior pelvic tilt, the rectus femoris yielded the highest EMG activity (approximately 0.4 millivolts).¹² According to Workman et al.¹², with the rectus femoris in a favorable position due to anterior pelvic tilt, there will be higher contractile forces. The higher contractile force during anterior pelvic tilt may show the relation between anterior pelvic tilt and rectus femoris contracture. The relationship of rectus femoris activation with anterior pelvic tilt may support that contracture of the rectus femoris promotes anterior pelvic tilt.

Injury Risks from Anterior Pelvic Tilt

Determining changes in pelvic tilt may aid clinicians in eliminating risks for injury because there are several risks for a variety of injuries due to improper lower body kinematics. For example, anterior tilt of the pelvis contributes to an increase in injury risk due to tight hip flexor muscles or tightness within the joint capsule of the hip.¹¹ In addition to anterior pelvic tilt, there are a plethora of anatomical characteristics that contribute to injury, such as anteverted hips, tight hamstrings, genu recurvatum (hyperextension of the knee while standing), and subtalar joint pronation, all of which lead to further hyperextension of the knee and increases the risk of lower extremity injury.¹⁷ Anteversion of the hip is defined as the excessive anterior angulation of the femoral neck that results in a toe-in gait, thereby increasing the quadriceps angle and genu valgum of the knee.¹⁵ Therefore, hip anteversion leads to internal rotation of the

femoral head in the acetabulum, which over time will cause repetitive trauma and will wear down the acetabular labrum placing the individual at great risk for degenerative hip disease.³⁴ In addition to risks caused by femoral anteversion, weakness in the hip extensors (gluteus medius and hamstring complex) remains a risk because it occurs with hip flexor shortening or abdominal weakness.²⁸ Additionally, while abdominal weakness is not a primary risk factor, a deficit of abdominal control may lead to an increased angle during anterior pelvic tilt, especially during hip extension when lying in the prone position.³⁵ Therefore, a lack of trunk and hip strength increases incidences of injuries to the lower extremity and lumbo-pelvic region, such as hamstring strain, groin injury, ankle sprains, ACL injury, and low back pain. This risk may be amplified in men and women differently due to biomechanical changes exhibited with rectus femoris tightness and anterior pelvic tilt.^{6,20,32}

Impact of Gender Differences on Injury

Due to changes in body position and kinematics, there is a likelihood that men and women may present contrasting predispositions to injury. It has been stated that women are more likely to experience patellofemoral (knee) pathology due to the position of the pelvis, thigh, knee, and tibia.¹⁵ The text by Shultz et al. claimed that women experience greater amount of anterior pelvic tilt than males, which may increase their likelihood of experiencing injury.¹⁵ In addition, injuries have increased since there has been greater participation by women in competitive sports.¹⁷ Men and women alike are affected by changes in muscle flexibility.¹⁹ For example, women may be predisposed to non-contact ACL injury due to anatomic characteristics of an increased anterior pelvic tilt, internal rotation of the hip, an increase in knee valgus, recurvatum of the knee and excessive subtalar joint pronation.^{17,36} Loudon et al.¹⁷ noted positions that these female athletes were found clinically in this position which supported their

study about the prevalence of female athletes to ACL injury. Another example of gender difference from Krivickas et al.¹⁹ provides evidence of a correlation between muscle tightness with increased injury in males affecting both injured and non-injured candidates.¹⁹ However, women experience greater flexibility in general than men, which decreases their risk for injury.¹⁹ Gender differences were compared in a study by Ristolainen et al.³⁷ to determine prevalence in injuries between several participants. The researchers sent 1200 questionnaires to athletes in soccer, swimming, distance running and cross-country skiers.³⁷ The questionnaire included information such as acute and overuse injuries that were experienced over the past 12 months.³⁷ Additionally, statistics were run where 1000 hours of exposure to training and competition were calculated to determine injury rates.³⁷ Then, separate statistics via analysis of variance (ANOVA) were used to calculate the injury rates for acute, overused and total injuries.³⁷ Finally, Poisson regression calculated the risk of injury with the adjustment for the sport participated in with both genders.³⁷ Within the acute injuries category, more males reported injury, especially in soccer players.³⁷ However, no gender differences were discovered after sport-specific calculations during the 1000 hours were evaluated.³⁷ However, females had greater acute injury at the heel, where more men reported back injury and overall acute muscle injury.³⁷ For overuse injuries, there was more prevalence in male runners, however, there was not a statistically significant difference to describe when the overuse injuries were calculated during the 1000 hours of activity.³⁷ Finally, after some calculations involving posterior thigh pain in male soccer players, there was a prevalence for men to have posterior thigh overuse injuries over women, as well as upper back, and toe injuries.³⁷ In contrast, women tended to have greater risk for overall ankle injury which was also statistically significant ($p < .05$) as well as the heel when measured

against cross-country skiers.³⁷ This study highlights that men and women have prevalence to many different types of injury, but does not give evidence to hypothesize the cause of the injury.

Hip flexor tightness was correlated in multiple instances in which anterior pelvic tilt was the cause and positioned the knee in inadvertent positions leading to further injury.^{17,19} One study by Krivickas et al.¹⁹ determined differences in ligamentous laxity and muscular tightness between men and women and their relation to lower extremity injuries. Measurement of ligamentous laxity was assessed with a 9 point scale used in another study cited by Krivickas et al.¹⁹ The measurements included areas of passive thumb opposition, passive hyperextension of the fifth metacarpal phalangeal joint, hyperextension of the knees by 10° or more, and anterior flexion of the trunk with the knees straight and the palms down on the floor.¹⁹ Muscular tightness was assessed by the Modified Ober Test, the Thomas Test, goniometric measurement of the hamstrings at the popliteal angle, and gastrocnemius tightness through measurements of ankle dorsiflexion.¹⁹ Next, a TIGHT scale of 0 (all muscles loose) to 10 (all muscles tight) was assigned.¹⁹ The TIGHT scale's purpose was to classify the laxity or tightness of muscle tissue, then adding the amount of tight muscles in each lower extremity. The results were calculated through logistic regression, which determined the relationship between muscular tightness and injury.¹⁹ Also, a Spearman's rank correlation coefficient measured a significant correlation ($p < 0.05$) between muscular tightness and ligamentous laxity for men ($p=.001$) and women ($p=.02$).¹⁹ The results determined that men experienced a mean ligamentous laxity of 1.8 ± 2.0 and 3.3 ± 2.2 for women.¹⁹ In addition, scores for muscular tightness for men were 3.5 ± 2.1 , whereas women were found to have scores of 1.5 ± 1.6 ($p < .01$).¹⁹ This showed that women experience less muscular tightness than men and that men may experience a higher rate of injury due to muscular

tightness.¹⁹ However, there were no statistically significant relationships that describe the laxity of ligaments, muscular tightness or injury rate between men and women.¹⁹

These studies provide evidence that there are few significant differences between men and women as far as their risk of injury. However there were differences noted that women experience greater ligamentous laxity which may predispose them to injury, along with sport-specific injuries of the heel and ankle.^{19,37} Men on the other hand, experience greater muscular tightness and may be predisposed in a sport-specific environment to overuse muscular injuries of the posterior thigh and back.^{19,37} In conclusion, based on a particular area, there may be gender differences, especially in the lower body.

Importance of Special Tests in an Orthopedic Practice

Special tests are often used in orthopedic assessment of the body to determine pathologies. These tests assist the clinician with making the appropriate differential diagnosis. This differential diagnosis process allows the clinician to narrow down the possibilities in order to develop an accurate diagnosis or determine the necessity for further assessment (imaging, exploratory arthroscopy, etc.). When a method to determine a pathology results in consistent results across examiners, it can be considered reliable. This reliability describes the extent that a particular result is repeated without error, and determines whether or not the same results may be repeated under constant, controlled scenarios.⁹ Intrarater and interrater reliability are two ways to determine the consistency of special tests. Intrarater reliability is the consistency of results over the course of several examinations of the same patient by the same clinician.⁹ Interrater reliability describes the consistency of results for an examination technique practiced on one patient by many examiners.⁹ To perform a test without reliable or consistent results to support a diagnosis, a clinician may not properly establish or treat the condition.⁹

Ely's Test

There is not a “gold standard” special test to determine hip flexor tightness; therefore, in order to determine whether a test is efficient, reliability and validity must be established.³⁸ In order to establish that an individual may or may not exhibit hip flexor tightness, clinicians generally use the Ely's Test to examine range of motion.¹⁸ The literature records several techniques associated with the procedure for the Ely's Test^{8,9,18,26}.

One such technique for the Ely's Test was used by Iversen et al.¹⁸ in a study involving ligamentous laxity and its effect on knee osteoarthritis as a part of the physical examination protocol to differentiate criteria for knee osteoarthritis. Three examiners performed the Ely's Test on 87 subjects.¹⁸ This protocol involved a subject lying prone with the examiner next to the subject at the side of the leg that was tested. The examiner placed one hand on the participant's lower back with the other holding near the ankle. Passive flexion in a rapid maneuver of the knee allowed the heel to move towards the buttocks. The test was deemed positive if the heel could not physically touch the buttocks, the hip of the ipsilateral side being tested rose from the table, or the patient felt pain or tingling in their back or legs.¹⁸ The examiners determined that muscle inflexibility, especially in the rectus femoris was present in 91% (79/87 people) of the population evaluated.¹⁸ However, statistics were not conducted to determine the interrater reliability or the intrarater reliability for measuring rectus femoris tightness. Since there were no tests conducted to analyze intrarater reliability or interrater reliability of the Ely's Test, it is difficult to determine whether the positive results achieved by the examiners were authentic since there was an absence of raw data and knee flexion measurements for the Ely's Test. The only data for the Ely's Test included the ratio of participants with a positive test and the total

number of participants. Without a measure to validate the Ely's Test, these results may not be accurate.

Similar to the Iversen et al.¹⁸ study, a textbook by Chad Starkey, used in many Athletic Training education programs, describes the Ely's Test as a prone test.⁸ However, there are differences between the descriptions on how to complete the Ely's Test by these two authors. Starkey's text describes the procedure of the Ely's Test with the patient in the prone position and the clinician standing beside the patient.⁸ The clinician then passively flexes the knee towards the buttocks.⁸ This is in contrast to the Iversen et al.¹⁸ technique that requires a rapid movement of the knee towards the buttocks. A positive result as described by Starkey for the Ely's Test occurs when rectus femoris tightness is elicited if the heel does not make contact with the buttocks or if the ipsilateral hip rises from the table.⁸ In addition, the maneuver by Starkey⁸ does not note passive knee flexion in a rapid fashion, nor does he mention pain or tingling sensations in the buttocks. These qualities are what separates the Starkey⁸ method of Ely's Test from Iversen et al.¹⁸. However, everything outside of these two qualities is the same between the two publications. Starkey does mention that the literature on Ely's Test is not conclusive.⁸ The lack of a primary method for conducting the Ely's Test mandates that tangible evidence be found to rationalize the use of this special test. This difference in technique may mean the difference between a few degrees of knee flexion. With the variance in procedure, there will be a variance in the degrees measured. If there are variances in measures, then a standard may be skewed, thereby allowing the potential for misdiagnosis of pathologies. There should be a standard procedure of the Ely's Test that achieves the most efficient, and consistent results.

Another version in the application of the Ely's Test has been demonstrated by Peeler et al.⁹ who sought to determine the test's intrarater and interrater reliability, which were determined

by goniometric measurements. In this study, 54 participants (108 limbs) were placed in the prone position on a plinth (platform).⁹ Then, they were instructed to actively flex one knee to their buttocks while maintaining neutral pelvic position on the plinth.⁹ The exam required active knee flexion instead of passive knee flexion due to the need to perform goniometric measurements which required the examiner to use both hands to measure, therefore they were unable to flex the knee passively.⁹ In this pass/fail test, if the hip remained in its stationary position against the plinth, then the test was considered passed.⁹ If the anterior hip rose from the table during active knee flexion on the ipsilateral side, then the test was considered failed.⁹ To determine the intrarater and interrater reliabilities for this test, an intraclass correlation coefficient (ICC) measured for intrarater reliability while a chance corrected Kappa statistic measured for interrater reliability.⁹ Across the three examiners, the goniometric reliability values ranged from .50-.83, which range from moderate to good measures of reliability.⁹ In addition, the Kappa statistic for the Ely's Test ranged from .46-.62 which were considered only moderate levels of reliability.⁹ However, there was an unfortunate discovery using measurement error values (SEM); the researchers determined there was a range of 20° between each clinician's measures.⁹ This variance in measures could produce inaccurate results. The data shows that the Ely's Test may not be as effective as goniometric measuring, if goniometer usage is consistent.⁹ Interrater results for the pass or fail scoring produced a mean of .52 within the three examiners, while the goniometric rating discovered a mean of .69. The variances between examiners was determined by a two-way ANOVA with a p value < .01.⁷ However, the variation in goniometric measurement may have been caused by slight differences in placement of the goniometer on bony landmarks.⁹ In conclusion, the data implies that the Ely's Test may not be as effective as goniometric measurement, but the lack of effectiveness may be due to inconsistent technique for

the test. Perhaps better measures would have occurred with two examiners present: one passively flexing the knee, while the other provides goniometric measurement.⁹ In order to determine reliability for this test, there must be a standard of performance to obtain consistent measures.

Comparable to the Ely's Test is the Active Knee Flexion Test, used for the examination of rectus femoris tightness.²⁶ A study by Gajdosik et al²⁶ used this test to examine active movement.²⁶ Twenty men, tested in the prone position with the ankle off of the table were in a relaxed, plantarflexed position.²⁶ The pendulum goniometer was placed along lines between the fibular head and the lateral malleolus of the fibula, which was used as the longitudinal axis.²⁶ The goniometer measured in response to gravity, therefore the angle measures are in response to movement.²⁶ A belt maintained pelvic stabilization while the participant actively flexed their knee to their buttocks.²⁶ The patient flexed to a point of initial resistance (inability to continue motion) and then measurements were obtained.²⁶

The examiners determined norms based off of multiple repetitions that the knee's range of motion for the right extremity was 98-125° and 85-125° for the left extremity.²⁶ Pearson product moment correlation determined the intrarater reliability of the active knee flexion test.²⁶ The coefficients for both lower legs were .97 measured with $p < .05$. This test could provide evidence to support that the prone position knee flexion as a reputable position to measure rectus femoris tightness. These results are considered very high by the author, deeming this test potentially credible for use.²⁶ Although, this test is not performed exactly as the Ely's Test, a clinician that follows the same protocol or pelvic restriction and understanding of goniometric placement, may achieve similar results.

From four separate references, there are noticeable differences among applications. Despite an exhaustive literature review, an article describing the original Ely's Test could not be found. Therefore, one must choose from the preceding methods for the purpose of study. Peeler et al.⁹, obtained their protocol from a textbook of their choosing, Starkey⁸ chose his own findings, and Iversen et al.¹⁸ does not describe a major published source for their use of Ely's Test. While Gajdosik et al.²⁶ did not necessarily use Ely's Test, they still performed a similar range of motion test in an active movement to determine rectus femoris tightness. Due to the differences in application, there is a need for evidence to recommend one procedure over another. For purposes of this study, the Starkey⁸ method will be performed. This method was chosen due to its publication in a textbook generally used by many Athletic Training education programs. If the reliability and validity of such a test does not match what Starkey claims, then one has the right to question whether the future orthopedic clinicians of tomorrow are using the best tools in their practices. However, to justify using one technique over another requires joint angle measures that provide the clinician with the best available evidence to promote the use of that special test. Potentially, this may leave room for comparison of the Ely's Test to the active knee flexion test in a study to determine if passive or active movements are more beneficial for measuring flexibility within a joint. These tests may add to the clinician's arsenal of hip flexor assessment tools and allow for combination with other Special Tests to pinpoint an injury or condition.

Thomas Test

The Thomas Test, named after Dr. Hugh Owen Thomas, was developed to assist clinicians with determining the presence of hip flexor contracture.^{6,38} Like the Ely's Test and many other orthopedic special tests, the Thomas Test has been published in many variations by

separate clinicians and is considered the gold standard for measuring limited hip extension and hip flexor contracture.³ Each clinician has their own opinion on the effectiveness of this Special Test to determine hip flexor contracture. Thus, there are several different studies incorporating a variety of interpretations of the Thomas Special Test.

The Thomas Test is performed on a bed or table with a supine patient to evaluate hip flexor contracture.^{6,15,38,39} The participants are instructed to lay on the table with their legs straight on its surface, resulting in a position where no limbs are hanging from any edges.^{6,15,39} In order to maintain neutral pelvic positioning for the participant, the uninvolved hip is flexed maximally, while the participant holds onto the knee, therefore flattening the back^{6,15,38,39} (See Figure 1). Vigotsky et al.⁶ stated that the Thomas Test was positive if the contralateral leg separates from the table, as the hip moves into flexion, forming a gap.⁶ Contrasting Vigotsky was Shultz et al.¹⁵ in his textbook, described a positive Thomas Test as the transition of the extended leg to a flexed position, therefore lifting the knee from the table¹⁵ (See Figure 2). This positive test is indicative of a hip flexor contracture.^{6,8,15,38,39} Two studies by Lee et al.³⁸ and Lee et al.³⁹ used the hip angle created by the longitudinal axis of the thigh, or the line connecting the lateral femoral condyle and greater trochanter is intersected by a horizontal line (the table) to measure the amount of hip flexion contracture^{38,39} (See Figure 3). Due to the hip's ability to hyperextend, this test is futile in measuring extension deficits in individuals.³⁸



Figure 1. Thomas Test positioning as described by Vigotsky et al.⁶, Shultz et al.¹⁵, Lee et al.³⁹, and Lee et al.³⁸

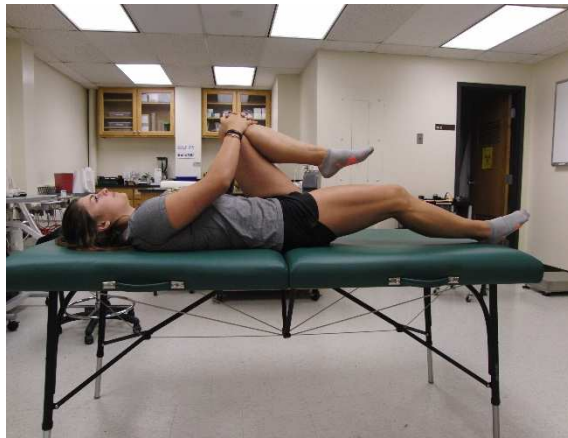


Figure 2. Shultz et al.¹⁵'s interpretation of a Positive Thomas Test.



Figure 3. Lines used by Lee et al.³⁹ and Lee et al.³⁸ to measure the amount of hip flexor contracture.

The Thomas Test is described in several instances as “modified”, but is used as a stepping stone for other areas of study.^{2 1,4,6,7} For instance, a textbook by Starkey et al.⁸ describes a method for a modification of the Thomas Test where the patient hangs one leg off the

edge of a table, the examiner passively flexes the opposite knee and pulls it to the participant's chest. This test position is also described in Shultz et al.¹⁵'s text, which describes a Rectus Femoris Contracture Test. As the participants are performing this movement, they fall backwards, such that the participant is laying supine on a treatment table.⁸ An indication of rectus femoris tightness is present if the lower leg moves into extension and an indication of iliopsoas tightness is present if the involved leg rises from the table.⁸ Additionally, Shultz et al.¹⁵ indicated a positive Rectus Femoris Contracture Test as the knee moving into extension, away from 90° of knee flexion. Starkey et al.⁸ also mentions that they participant may passively flex their own knee and that hip position may be measured with a goniometer.

The following paragraphs describe ways that the Thomas Test has been used with variables that are unrelated to the proposed study, however, it provides the reader with information about the wide variety of techniques used. For instance, in a study by Winters et al.¹ the Modified Thomas Test was used to determine hip flexor contracture. The individuals that were tested also exhibited lower extremity injury. The researchers incorporated an active and passive stretching protocol to determine which would be more effective for alleviating hip flexor contracture and decreasing the injury of these participants. Furthermore, Winters et al.¹ performed the Modified Thomas Test in a seated position at the edge of the examination table. Then, they were instructed to grasp both hands around their knees and pull them to their chest while falling backwards onto the table. As they remained in this position, the participants were then instructed to release one of their knees and lay that hand from that side onto their opposite shoulder. The released leg would fall and hang off of the table without any support. The researchers would check the lumbar spine to ensure that it was flattened against the table while the other examiner would measure via goniometer for hip extension.

Similarly, the Modified Thomas Test was used in a study by Harvey et al.², to measure muscle flexibility in the iliopsoas, quadriceps, and tensor fascia latae muscles. The Modified Thomas Test was performed similarly to the protocol by Winters et al.¹ with the exception that during the release of the tested leg, there was no instruction for the patient to place the ipsilateral arm.² The researchers in Harvey et al.² measured hip flexion to determine the length of the iliopsoas, knee flexion for quadriceps length and abduction angle for the length of the tensor fascia latae. An intraclass correlation coefficient was measured for collected lengths and were rated extremely high (.91-.94). In addition, the average muscle lengths were found at -11.9° of hip flexion, 52.5° for quadriceps, and 15.6° for tensor fascia latae.² The measures would determine the flexibility around the joint and allow the clinician to make a judgement regarding predisposing factors for injuries as it is well known that poor flexibility is related to musculoskeletal injury.²

In conjunction with the studies by Winters¹ and Harvey², Eland et al.³ used a method of the Thomas Test that was very similar to the previously discussed studies in this section. The purpose of the Eland et al.³ was to determine the efficiency of the iliacus test versus the Thomas Test. The results did not appear to reflect the content represented in this literature review, yet showed another version (a mislabeled one) of the Modified Thomas Test. Like the previous studies, the participant began with both legs off of the edge of a table, however Eland et al.³ started the patient in the supine position and instructed them to maximally flex one knee to their chest and hold while measurements were taken. The limb being measured was relaxed onto a stool, which was removed after the patient laid back. Unlike Harvey², Eland³ used a goniometer to measure hip flexion, but it was adhered to the thigh by a Velcro strap, where the axis of rotation was over the greater trochanter. The procedure is similar to the hip flexion measurement

by Winters¹, with the exception that it could be performed by one researcher instead of two.³ Independently, Eland et al.³ used a pneumatic bladder to measure lumbar pressure during range of motion testing. A hip flexor contracture was deemed present if the angle of knee flexion was not near 90° during the final phase of the test where the researcher removed the stool, prior to their application of overpressure. This test by Eland et al.³ mimics parts of the Modified Thomas Test, but does not follow the same guidelines as the studies discuss prior in this section. In addition, Eland et al.³ mislabeled the test as the “Thomas Test” when most of the characteristics followed the guidelines of the “Modified Thomas Test”.

In comparison, a study by Young et al.⁴ measured how static stretching affected the hip flexor complex and quadriceps flexibility using the Modified Thomas Test. They also determined the range of motion and the ability to determine the speed in which a kicker kicked a football.⁴ The method for the Modified Thomas Test was very similar to the one by Eland et al.³, by which the subject was laid in a supine position with the legs hanging off of the table and instructed to maximally flex one knee to the chest and hold it there.⁴ However, Young et al.⁴ measured hip angle with two-dimensional motion analysis software, where the thigh was said to be in hyperextension if it was lower than a horizontal line drawn by the iliac crest and the trochanterion. In addition, knee flexion determined knee angle measures.⁴ There were no pass/fail criteria for the Modified Thomas Test, therefore it was used for general ROM measures for the hip and knee.

In contrast, Schache et al.⁵ described the “Thomas Test” in the same fashion of Harvey², Winters et al.¹, and Eland et al.³, but with the clinician in a different position. Instead of allowing the participant to grasp their knee solely, one clinician would add additional force to maintain maximum flexion and maintain a posteriorly tilted pelvis.⁵ Measurements were taken

by a second clinician and positive values were assigned to those whose thigh extended below the horizontal reference line that was used (the table).⁵ In addition, studies by Vigotsky et al.⁶ and Peeler et al.⁷ described a procedure of the Modified Thomas Test that involves a supine patient with knees bent over the edge of a table.^{6,7} Instruction to manually flex the knee to the chest and measurement of the contralateral hip is constant.^{6,7} Participants were encouraged to keep their hip and posterior thigh flat to the table and maintain 90° of knee flexion.⁷ The test was marked as a pass with maintenance of the 90° of knee flexion through the entirety of the test.⁷ A fail was indicated when the knee moved into extension or raises above parallel to the knee.^{6,7} As the Thomas Test is used frequently throughout the previous studies, it is obvious that there is much variation in between techniques. The Thomas Test is also more than a pass/fail test for some clinicians, the subsequent section reveals other means of using a Thomas Test application.

Table 1. Descriptions of the Multiple Thomas Tests/Modified Thomas Tests Broken Down

Author	Patient Position	Clinician Position	Pass/Fail Criteria Hip	Pass Fail Criteria Knee
Winters et al. ¹	Subject sits at edge of table, grasps hands around knees and bring both to chest. Subject lays on their back. Test leg is released while ipsilateral arm rests on contralateral shoulder.	Not Specified	Thigh was higher than 0° relative to the table.	Not Measured

Table 1. Descriptions of the Multiple Thomas Tests/Modified Thomas Tests Broken Down (continued)

Harvey ²	Subject sits on the edge of table, pulls both knees to chest and lays back onto the table. Once back is flat, one leg is let go and lowered off the table, while the other leg is held maximally to the chest.	Beside patient with goniometer to measure iliopsoas, quadriceps and tensor fascia latae angle	Not Specified	Not Specified
Eland et al. ³	Supine, lower extremity off the table's edge. Measuring right hip: flex left hip and knee toward chest maximally, grasp with both hands. Foot rested on a platform. Platform removed to allow knee flexion.	Beside patient test leg.	Not Measured	Knee did not bend passively to near 90°.
Young et al. ⁴	Supine with gluteal fold at the end of table, hold both knees to chest. Lowered right leg.	Sagittal plane motion analysis	Hip lower than horizontal (line created by iliac crest and trochanterion), considered hyperextended. Angle recorded then had positive value.	Not specified, but measured knee flexion angle

Table 1. Description of Multiple Thomas Tests/Modified Thomas Tests Broken Down (continued)

Schache et al. ⁵	Sat at the edge of a plinth, rolled backwards while holding both knees to chest. Measured limb was lowered. Head and shoulders remained flat against plinth.	Tester one held leg that was not tested in passive hip flexion. Tester two measured with goniometer on lateral side of measured limb.	Positive value awarded if thigh was extended below horizontal reference line (reference line connected greater trochanter and lateral femoral epicondyle).	Not Measured
Vigotsky et al. ⁶	Participant sits on edge of the table, grasps one leg and maximally flexes it to the chest. Then, allows contralateral leg to hang off the table.	Sagittal two-dimensional motion analysis	The thigh was above parallel (the knee was higher than the hip),	Not Measured
Peeler et al. ⁷	Supine position with legs flexed over the table. Flexed one knee to chest and held it. Angle of the opposite knee was to remain at 90°. Hip and posterior thigh remained flat on table.	Lateral side of the test leg using a goniometer.	Not Measured	The assessment was scored as a pass if the test knee remained in a stationary 90° position. The assessment was scored as a fail if the test knee extended and moved to a position of less than 90°.

Table 1. Description of Multiple Thomas Tests/Modified Thomas Tests Broken Down (continued)

Starkey et al. ⁸	Patient is positioned so the knee of test leg is off the table. Passive flexion of non-tested hip to chest, opposite (test-leg) leg relaxes off of the table.	Examiner stands beside the patient.	Involved leg rises from the table, indicative of iliopsoas tightness.	Knee moves into extension, indicative of rectus femoris tightness.
Shultz et al. ¹⁵	Supine, brings one knee to chest and lays back onto the table. (Thomas Test) Supine with legs off table. Patient flexes one knee to chest with both arms (Rectus Femoris Contracture Test).	Not Described	TT: extended leg becomes flexed.	TT: knee rises from the table. Rectus Femoris Contracture Test: knee moves toward extension.
Lee et al. ³⁸	Patient in the supine position completely on the table. The uninvolved limb is adequately flexed to eliminate lumbar lordosis, and the angle between the longitudinal axis of the thigh and a horizontal line is defined as a hip flexion contracture.	Orthopedic surgeon positioned patient and measured hip angle. Second tester held patient's uninvolved limb. Goniometric measurements taken of the involved limb.	Hyperextension of knee listed as negative value. Intersecting lines created by longitudinal axis via the greater trochanter and intersecting the horizontal axis (table top)	Not Specified

Table 1. Description of Multiple Thomas Tests/Modified Thomas Tests Broken Down (continued)

Lee et al. ³⁹	Supine completely on the table, contralateral leg flexed at the hip.	Three-dimensional motion analysis	Hip flexion angle determined by the horizontal plane created by the table intersected by an estimated line that connected the greater trochanter and lateral femoral condyle.	Not Specified
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The previous methods defined a “pass/fail” protocol for the Thomas Test and the Modified Thomas Test. The following methods incorporated these tests in a more quantitative fashion to measure the iliopsoas complex beyond the traditional pass/fail protocol as indicated earlier for the Thomas Test. One study by Harvey² measured the iliopsoas with the Modified Thomas Test and goniometry. The goniometer landmarks were not specified, but Harvey² described measuring hip flexion to determine iliopsoas measurements. While there were no “positive implications” associated with this test, there were measurements for iliopsoas and quadriceps flexibility.² The mean measure for hip flexion was -11.9° and 52.5° for knee flexion.²

Another study by Krivickas et al.¹⁹ used a goniometer to assess flexibility of the iliopsoas. The angle of measurement rests between the extended hip and the table. Also, a study by Schache et al.⁵ measured the flexibility of hip extension via goniometer.⁵ The measured angle was created by two lines; a horizontal reference line, and a line that connects from the lateral femoral epicondyle to the greater trochanter.⁵ They determined that anterior pelvic tilt had

positive correlation ($p < .01$) with peak hip extension.⁵ The researcher did not provide data that showed measurements in degrees from the Thomas Test to determine how much of a deficit there was in peak hip extension.⁵ Furthermore, Vigotsky et al.⁶ measured peak hip extension with motion capture software, allowing the examiners to measure hip angle relative to the pelvis instead of the table plinth.⁶ In addition to the previous study, other techniques using motion analysis determined the hip angle in relation to pelvic tilt on the table.⁴

Young et al.⁴ placed motion analysis markers along the iliac crest, greater trochanter, tibiofemoral joint line, lateral malleolus, calcaneus, and the fifth metatarsal of the foot. The resulting diagram created through these markers was used to compare Modified Thomas Test angles with that of their study of dynamic muscle flexibility. After performing the Thomas Test, the participants performed drop-punt kicks while measured with two-dimensional motion analysis. The results used a repeated measures MANOVA to determine if there was a difference between their warm-up and flexibility over time and paired t-tests were used to note any differences in kicking variables. Their data showed that there were no significant differences in flexibility between those who performed a warmup before activity and those who did not. Also, there was no significant data supporting whether static stretching increased flexibility versus the control group.⁴ Since these studies show that the Thomas Test, in its modified form, was not used as intended in previous sections. Instead of providing a pass/fail, measurements were taken, therefore questioning what procedure is more efficient in determining hip flexor tightness.

Previously, Lee et al.³⁸ was referenced earlier on the claim that the Thomas Test cannot measure hip extension, yet many clinicians have modified this test in an attempt to measure peak hip extension. Lee et al.³⁸ also made a case regarding the hip's ability to hyperextend, stating that it is futile to measure extension deficits in the hip if there is that ability of the hip to move

beyond into hyperextension.³⁸ They determined this in their study involving hip flexor contractures in patients with cerebral palsy.³⁸ The Thomas Test and the Staheli test were used to determine hip flexor contracture.³⁸ Three examiners were incorporated in this study and were blinded to each other's performances, while an orthopedic surgeon performed measurements for each test with a goniometer.³⁸ In order to determine if the candidates qualified, psoas measurements were determined with computer software and sagittal gait analysis was used to determine if there is a potential hip flexor contracture.³⁸ For the Thomas Test, measurements of 0-20° were considered positive and 0-10° for the Staheli test.³⁸ The results were determined by an ICC with ninety-five percent confidence interval (CI) to determine the intra-observer reliability with the use of two-way random-effect model to assume that there was an absolute measurement in agreement with all examiners.³⁸ Then, Pearson correlation coefficients determined validity from three-dimensional motion analysis.³⁸ The Thomas Test yielded an intra-observer reliability of .501 in patients and .207 in control groups and a mean absolute difference of <10° in 91.6% of the cerebral palsy sample. The Thomas Test was the most valid within the control group out of the different tests.³⁸ However, there are many different incidences of what clinicians claim are the same or "similar" tests. Schache et al.⁵ and Eland et al.³, whom both claimed to be testing the Thomas Test, but were using techniques similar to the Modified Thomas Test. However, with different techniques used in many studies, it must be clarified which technique was used to determine its reliability and validity.

Assessment between Special Tests of Reliability

Without knowledge to describe the effectiveness of a special test, a clinician could not justly diagnose a pathology. Therefore, it is necessary to include evidence to suggest that the Special Test accurately assesses a specific pathology. Effectiveness of special tests can be

described with intrarater reliability and interrater reliability. To further describe how valid the tests may be, some sources use specificity and sensitivity to document the efficiency of a particular special test. Specificity is noted as the ability of a test to yield a negative result when the condition is truly absent, otherwise known as a true negative whenever it is compared to the gold standard.^{8,15} In addition, sensitivity is the ability of a particular test to produce a positive result when the condition is absolutely present, also known as a true positive whenever it is compared to the gold standard.^{8,15} The previous terms will help define the efficiency of the special test as it is discussed within each study.

Reliability of the Ely's Test

The Ely's Test has little literature published on the test itself, much less advocacy for its effectiveness. However, a few studies shed light on the potential reliability of the Ely's Test. In Iversen et al.¹⁸, three physical therapists incorporated a study protocol for the Ely's Test to determine the factors that may be present with the onset of knee osteoarthritis. The Ely's Test was performed on 87 participants with positive tests in 79 of the individuals for a 91% rate of determining rectus femoris contracture.¹⁸ However, there are gaps in this data, because there are no measures of reliability between examiners, nor are there means to measure whether or not the Ely's Test actually was positive. Measures could have included a simple goniometric analysis to determine if there was a deficit in rectus femoris flexibility. In addition, this would have been beneficial to establishing a baseline validity of the Ely's Test, because there is little information to defend its use in a study that did not perform any other special tests to determine rectus femoris flexibility.

In contrast to this study, Peeler et al.⁹ described an intrarater reliability for the Ely's Test. For this study, three experienced examiners were recruited to perform this test and all three

attended the same training seminar on the goniometric measurements process.⁹ This process involved bilateral assessment of the rectus femoris on 54 participants.⁹ In order to calculate the intrarater and interrater reliability, intraclass correlation coefficients (ICC) were used for goniometric scoring.⁹ The mean intrarater value among the three examiners was .69, while the interrater value for goniometric measure was .66.⁹ In contrast, the intrarater values for the Ely's Test was tested by chance-corrected Kappa values achieving a mean value of .52 (range of .46-.62).⁹ In addition, the interrater value for the Ely's Test was .46. According to the raw data, one would believe that goniometric analysis would be more efficient than the Ely's Test. After performing a two-way ANOVA with a $p < .01$, Peeler et al.⁹ determined that there were significant variances in the way the clinicians measured and used bony landmarks. Otherwise, the Ely's Test may be considered comparable to goniometric analysis to determine rectus femoris tightness. The skewed results may have resulted from differences in bony landmark placement for goniometric measurements and repetitive testing between each examiner for the Ely's Test, which may increase flexibility. This information gives the clinician an idea of how effective the Ely's Test is whenever they complete their assessment. These results confirm that Ely's Test is somewhat effective; however, they also indicate that human variation is wide enough to require further testing.

Reliability of the Thomas Test

The reliability of the Thomas Test, and the Modified Thomas Test, may allow clinicians to assess iliopsoas tightness in the most efficient manner. Without the information to support claims that the Thomas Test can produce consistent and accurate results, then there is little justification for its use in the clinical practice. As reported by Starkey⁸, the interrater reliability value for the Modified Thomas Test was .58. A value of 1.00 would result whenever any

clinician performs the function and achieves the same results consistently each time. The sensitivity for this Special Test is valued at .41 and a specificity value fell within a range of .33-.83. The numbers reported by Starkey⁸ indicate that the Modified Thomas test is mediocre for determining iliopsoas or rectus femoris contractures.

However, other literature does not yield the same results as Starkey. For instance, in a study by Lee et al.³⁸, intrarater measures were conducted across three examiners, who each had six or more years of experience. During the testing, the examiners were blinded to each other's results because they were placed in separate rooms; they were each supervised by a team of two orthopedic surgeons and a physician's assistant who had at least 2 years of experience.³⁸ There were two testing subgroups: a patient group with cerebral palsy and a control group with no pathology.³⁸ The three examiners examined every participant. The Thomas Test showed an intraclass correlation coefficient of .501 in patients and .207 in the control group.³⁸ While the information gives the clinician insight of how accurate findings are between examiners, the results do not show a high reliability within those examiners. This may mean that the Thomas Test is an accurate assessment tool, but only if used exactly one way, otherwise there will be differences in results.

In contrast, a study by Peeler et al.⁷ was conducted to determine the reliability of the Modified Thomas Test and the ability within clinicians to use it to examine for hip flexor contracture. For this study, they recruited three experienced examiners who had, on average, 12 years of experience as certified athletic therapists.⁷ In preparation for this study, each examiner was required to attend two instructional sessions to achieve as consistent measures as possible.⁷ As noted in previous sections, the Modified Thomas Test was assessed in contrast to goniometric measurement.⁷ Each examiner would then test the subjects blinded to their colleagues' results.

Next, ICC's with a 95% CI were used to evaluate intrarater and interrater reliability of the goniometric scoring, while pass/fail scoring for the Thomas Test used a chance-corrected k statistic (95% CI).⁷ In conclusion, the results for the intrarater reliability for the Modified Thomas Test was an average of .40 across the examiners, while the goniometer measurements achieved an average interrater reliability of .67.⁷ In addition, interrater reliability for the Modified Thomas Test was an average of .33, while the goniometer yielded an average of .50.⁷ To characterize the efficiency of the values, Peeler et al.⁷ described ICC values as .75+ as high reliability, .4-.75 as moderate level of reliability, and less than .4 as poor reliability. According to these values, the Thomas Test is barely moderate, on the verge of poor between raters.

As described earlier by Lee et al.³⁸, the Thomas Test is not an efficient evaluation tool when measuring hip extension. The Modified Thomas Test can measure hip extension due to its positioning on the table, which differs from laying directly on the table. In fact, Vigotsky et al.⁶ determined the validity of the Modified Thomas Test of measuring hip extension deficit. They selected twenty-nine participants for this study, in which the Modified Thomas Tests was performed three times upon each subject.⁶ In order to determine the validity of the modified Thomas Test, there were analyses of the sensitivity and specificity using a 95% CI.⁶ The researchers found that the Modified Thomas Test exhibited a sensitivity of 31.82% and a specificity of 57.14%.⁶ The implications from this study describe the Modified Thomas Test as an inadequate test to measure hip extension. As the Thomas Test and the Modified Thomas Test seem to lack publication of evidence to deem it a reliable test, one may only be able to make a clinical decision based on the present data. According to this data, neither test seems to be clinically reliable when assessing for hip flexor contracture.

Assessment of Hip Strength Through Dynamic Exercise

Whenever the clinician evaluates gait and pelvic positions, they may be able to discover strength deficits in certain muscle groups. However, there are no standard protocols to determine quantifiable hip strength, but there are ways to determine the quality of the musculature through screenings.²⁰

Purpose of the Isometric Squat

Many times, the effects of anterior pelvic tilt have been measured and evaluated by means of running and walking, but very little information is presented on how anterior pelvic tilt affects strength. In addition, Bazylar et al.¹³ mentions that isometric tests used to be considered suboptimal in performance versus dynamic movements due to neural and mechanical differences in individuals. Therefore, in order to determine that an isometric back squat can be measured against a dynamic back squat, joint angles and force output must be synchronized.¹³ In addition, dynamic force during a back squat appears to show peak force output around 120° of knee flexion.¹³ In this study, Bazylar et al.¹³ recruited 17 males with one year or more experience with resistance training using the back squat. During the introductory phases, the subjects trained twice a week for three weeks with squats at 90° and 120° of knee flexion to familiarize with the study's demands. The subjects were supervised during the entire study by certified strength and conditioning professionals.¹³ After the familiarization training, phase was complete, the participants moved to the dynamic strength assessment. Once it commenced, the subjects completed a dynamic warmup before testing.¹³ Then, the subjects continued to perform a protocol of increases in load while decreasing repetitions for the back squat with four minutes of rest between each attempt.¹³ In contrast, the isometric strength testing was commenced in a customized power rack that allowed height of the bar to be adjusted at will.¹³ During this test,

the subjects were required to perform a two minute dynamic warmup, followed by submaximal perceived exertion attempts of the isometric back squat.¹³ The participants pushed as hard as they physically could, and their force produced was measured by a force plate located under the bar of which they were pushing.¹³ Finally, ICC were calculated to determine the reliability between test-retest and Shapiro-Wilks test were used to track the distribution of the data.¹³ Pearson's product correlations were used to show the strength of the relationship between the correlations: .0-.01 (trivial), .1-.3 (weak), .3-.5 (moderate), .5-.7 (strong), .7-.9 (very strong) and .9-1 (nearly perfect).¹³ The results showed that the relationships between dynamic and isometric back squats were strongly correlated at 90° and 120° of knee flexion. These results also show that isometric back squats were comparable to dynamic back squats. With more research, evidence will continue to support one technique over the other.

Exercise Load and Prescription

In order to prescribe a load for exercise, there must be guidelines to follow that enables safe increases in load for the individual. Loads are defined as an amount of weight assigned to a particular exercise set.⁴⁰ Furthermore, loads may be described as heavy (1-3 repetitions to failure), maximum strength (3-8 repetitions to failure), hypertrophy (8-15 repetitions), and muscular endurance (20+ repetitions).⁴⁰ Of these load types, the greatest strength increases have been elicited after eight repetitions.⁴⁰ In addition to this statement, the NSCA recommends four to eight repetitions at 80-90% of their 1RM to achieve basic strength generally prescribed for athletes.¹⁴ In fact, a 1RM is defined as the heaviest load that can be successfully lifted one time.⁴¹ Therefore, during an eight repetition exercise, the individual needs to lift 80% of their 1RM.¹⁴ Another study by Hackett et al.⁴¹ perceived effort was utilized to determine repetitions to failure using the squat and bench press. The repetition to failure sets were performed at 5

exercise sets of ten repetitions at 70% of their 1RM.⁴¹ Since warmups are recommended, they followed the ACSM's guidelines of eight to ten repetitions with a light load, then six to eight repetitions with a moderate load and two to three repetitions with a heavy load, finally finishing with loads that were slowly increased as the subject attempted to lift it once.⁴¹ The trial was ended after failure was accomplished.⁴¹ In conclusion, they determined that perceived effort to failure correlates with that of actual sets to failure, however there was slightly less validity for perceived effort. The ICC (95% confidence interval) used in this study ranged from .92-1.0 for the bench press and .96-1.0 with the squat, therefore showing high reliability within tests. In addition, it is recommended that perceived effort to failure is used in later sets whenever the individual is more fatigued.⁴¹ The previous description of load types may become useful when determining the load for a back squat.

The back squat, along with the powerclean and deadlift, are multi-joint movements that are considered the most effective for increasing muscle strength, in comparison to single-joint exercises.⁴⁰ This claim is justified by the amount of extra weight that may be lifted during multi-joint exercises compared to single-joint.⁴⁰ However, when prescribing an exercise regimen, multi-joint exercises for large muscle groups should be performed before exercises involving small muscle groups as more energy is expended during large muscle group exercises.⁴⁰ Furthermore, in cases when energy has been expended in great quantities, it is pertinent that rest periods are prescribed in between exercise sets.

Rest periods are important in between exercises sets as they allow for recovery from the prior task. During the rest period, recovery of adenosine triphosphate (ATP) and phosphocreatine (PCr) occurs relatively within a 3-5 minute period.⁴⁰ Overall, according to a systematic review by Bird et al.⁴⁰ overall exercise prescription was determined and rest periods

were classified according to training needs. As individuals train for power, 5-8 minutes of rest in between sets are necessary, whereas for maximal strength require 1-2 minutes of rest in between sets as they are focusing on muscle hypertrophy.⁴⁰ Finally, in those who are training for muscle endurance, 30-60 seconds of rest in between exercise sets are required for recovery.⁴⁰ In conclusion, exercise prescription relies heavily on the training goals of the subject, which in turn determines work load and rest periods.

Motion Analysis in the Two-Dimensional View

Motion analysis software can be used to measure the angles of joints in the knee, hip, and pelvis, which allows a clinician to discover deficits in postural structure.^{29,30,36,42-44} Furthermore, motion analysis in a three-dimensional view is considered the gold standard for kinematic measurements.^{36,42,44} However, due to the expense of using three-dimensional motion analysis, an accurate and economic alternative must be validated.^{24,42,44} More clinicians appear to have access to two-dimensional imaging at a lesser cost, but in order to justify the economic value, there must be evidence to validate its use in place of three-dimensional motion analysis.^{36,42}

There are studies that use two-dimensional analysis for frontal plane measurements in place of three-dimensional motion analysis.^{36,43,44} One study by Gwynne et al.⁴³ measured the reliability and validity of two-dimensional motion analysis in the frontal plane while 18 participants separately performed single-leg squats. In order to compare three-dimensional with two-dimensional motion analysis, two separate trials were completed with a week's separation between them.⁴³ For the measurement of joint angles, markers were placed along bilateral ASIS, midpoint of femoral condyles, and the midpoint of the malleoli of the ankle.⁴³ While the single-leg squats were performed, instructors provided verbal instruction to squat to 60° of knee flexion with the uninvolved leg flexed to 90° of knee flexion.⁴³ During this time, the frontal plane

projection angle was calculated by the angle created from a line drawn from the ASIS marker to the knee, bisected by a line that runs through the center of the malleoli and center of the knee and continues past the pelvis.⁴³ Finally, statistics comparing two-dimensional and three-dimensional motion analysis were calculated with the use of paired samples t-tests with an alpha level of $p < .05$ for all tests. Also, Pearson correlation coefficient were used to analyze the association between the two types of motion analysis, while ICC (95% CI) were used to calculate two-dimensional frontal plane projection angle and its within-session and between-session reliability.⁴³ In conclusion, the results displayed a high correlation between two-dimension and three-dimensional methods (.64) showing “large” correlation while standing as deemed by Gwynne et al.⁴³, “very large” correlation (.78) during the single-leg squat exercise and “good” within-session (ICC .86) and between session (ICC .78) reliability. Finally, this data supports claims that there is a good correlation between two-dimensional and three-dimensional motion analysis in the frontal plane.

Maykut et al.⁴⁴ determined the validity and reliability of frontal plane two-dimensional motion analysis in 24 runners. The participants selected a speed that they were blinded to and could keep a comfortable pace for an easy 20 minute run, then measurements were taken six minutes into the run to allow for gait acclimation.⁴⁴ Dartfish Motion Analysis Software was used for this particular trial and was used simultaneously with the three-dimensional motion analysis during the run.⁴⁴ During this period, the contralateral pelvic drop, peak hip adduction, and peak knee abduction angles were measured for five two-dimensional trials and thirty, three-dimensional trials, as they correlated well by pilot data.⁴⁴ In order to measure the contralateral pelvic drop, a line connecting the bilateral ASIS bisected a second line ascending from the center of the ankle through the knee and onto the ASIS and subtracted the total measurement from

90°. ⁴⁴ Additionally, peak hip adduction was measured by an angle created by the same line connecting the bilateral ASIS to the bisecting line through the lower limb from the ASIS. ⁴⁴ Finally, knee abduction angles were created by a line that connects the ASIS of the standing limb with the middle of the knee bisecting a line that splits that medial and lateral malleoli. ⁴⁴ In order to determine the concurrent validity of two-dimensional motion analysis, comparisons were made of the data sets between the two-dimensional and three-dimensional motion analysis. ⁴⁴ Pearson product coefficients were used to determine the relationship between the measurements from both motion analysis data sets and compared them to the variables that were analyzed. ⁴⁴ To determine intra-rater reliability, ICC were performed on the two-dimensional motion analysis data. The results showed the Dartfish Motion Analysis software had high reliability for the three variables (contralateral pelvic drop .958-.966, peak hip adduction .951-.963, and peak knee abduction .955-.976), which demonstrates excellent reliability for lower extremity measurements. ⁴⁴ In addition, the results for concurrent validity demonstrated that there was moderate correlation between two-dimensional and three-dimensional motion analysis when comparing the variables. ⁴⁴ Peak hip adduction while running yielded a moderate correlation, (left extremity .539, right extremity .623), there were no significant correlations for contralateral pelvic drop but there were strong correlations for contralateral pelvic drop to peak hip adduction (left extremity .801 and right extremity .746 $p < .0001$) in the two-dimensional analysis data set. ⁴⁴ However, the data shows that only some aspects of two-dimensional motion analysis moderately correlates with three-dimensional motion analysis such as peak hip adduction, which is a key variable to measure in runners. Also, the two-dimensional motion analysis may not show the most accurate data for joint angles in the frontal plane. ⁴⁴ This does not mean that two-dimensional motion analysis is incapable of maintaining accurate measures, but more tests will

need to be ran to determine what planes and measures may provide the most accurate measurements.

An additional study by Munro et al.³⁶ describes the reliability of two-dimensional motion analysis in the frontal plane to measure dynamic knee valgus during single-leg squats, drop vertical jump, drop landing, and single-leg standing in 20 recreational athletes. In order to obtain measurements, markers were placed in the center of the femoral condyles, center of the malleoli, and proximal thigh near a line drawn from the ASIS to the knee marker.³⁶ During testing, the participants performed the exercises twice on day 1 and again a week later. To provide a reference point, the participants performed the exercises on two force plates and were allowed practice trials prior to testing.³⁶ They performed single-leg squats, drop jumps, and single-leg landing in front of a camera.³⁶ In addition, the frontal plane projection angle was measured exactly the same as mentioned previously in this section by Gwynne et al.⁴³. Also, statistical analysis was run using SPSS for Windows version 16.0 where $\alpha < .05$ for the entirety of the testing, ICC assessed within-session and between-session reliability of the two-dimensional motion analysis.³⁶ Women demonstrated a higher knee valgus than men for all tests except the single-leg squat test, within-session reliability were considered “good” for all tests except single-leg squats in women, and finally between session reliability was considered “good” to “excellent” for all tests.³⁶ In conclusion, this evidence may be used in future research to assess the dynamic movement of the lower extremities and how they play a role in injury predisposition.³⁶ However, without concrete validity established in comparison to three-dimensional motion analysis, the clinician or researcher may need to determine the amount of difference in angle measures between two and three-dimensional motion analysis in the frontal plane to determine if it is significant to their findings or not.

Frontal plane of motion has shown some effectiveness in establishing validity for two-dimensional motion analysis, however, some postural pelvic defects can only be viewed from the sagittal plane such as anterior pelvic tilt. Evidence of validity within the sagittal plane may aid clinicians to measure small measurements such as pelvic tilt. For instance, Norris et al.⁴² set out to discover the concurrent validity of two-dimensional motion analysis for the sagittal plane using Dartfish Motion Analysis Software. During the research, three researchers examined 15 adult females to eliminate differences in hip and knee kinematics, two of the researchers were students without previous exposure to Dartfish software and the third researcher was a physical therapist who had approximately 2 years of experience using the software.⁴² Furthermore, the exercise completed was a maximal lifting capacity (MLC) that was assessed with a back-leg-chest dynamometer system during two testing sessions that were 7-10 days apart. Maximal lifting capacity was performed in the squat position on the dynamometer's platform, where the participant was instructed to hold and then lift a bar that was connected to the dynamometer by a chain in an upward direction for 3 seconds.⁴² During this exercise, the participant was not allowed to leave the squat position for those 3 seconds.⁴² In addition, MLC was determined by the average of these three tests and then determined the amount of weight for their mechanical lifting task.⁴² Prior to this mechanical lifting task, the researchers fixed reflective markers on the right side of each participant at the lateral aspect of the acromion, greater trochanter, lateral femoral epicondyle, and lateral malleolus.⁴² They completed the lifting phase (after practicing five times with a five minute rest in between trials) with a weighted crate and were recorded by Dartfish Motion Analysis for the entirety of the three lifting processes, each receiving one minute of rest after each trial.⁴² Furthermore, the data was then used to determine concurrent validity, intrarater reliability and interrater reliability. In order to determine concurrent validity,

Dartfish measurements were compared to those taken by a goniometer and a constant picture was analyzed in the down phase of the lift for each measurement, which was assessed by a Pearson correlation coefficient and two-tailed t-tests. Furthermore, this was supported by high and significant associations between Dartfish and the goniometric measurements for hip and knee flexion.⁴² In addition, intrarater and interrater reliability were determined by ICC which showed high correlations for both knee and hip flexion (intrarater: .99 hip, .98 knee; interrater: .94 hip, .96 knee).⁴² In conclusion this evidence supports the claims that two-dimensional motion analysis may be valid to measure sagittal plane kinematics.

However, there are flaws in the data that may prevent two-dimensional motion analysis from becoming as valid as three-dimensional motion analysis. There is a still image that is being captured, instead of the entire movement and how forces react upon the body at different times. While there may be little evidence present in the literature to support sagittal plane measurements with two-dimensional motion analysis, Norris et al.⁴² has determined that it measures well for hip and knee flexion. Another possible flaw is whether two-dimensional motion analysis will measure pelvic tilt in such a confined amount of space and knowing when is the best time to measure for it.

Conclusion

The purpose of this review was to highlight gaps in the literature on the reliability and validity of the Modified Thomas and Ely's Tests in their diagnosis of hip flexor tightness. In addition, noting effects that muscles have on the pelvis and how this may affect an individual's performance serves another purpose of this study. There is a lack of published research and consensus in the literature for the reliability and validity of the Modified Thomas and Ely's Tests. Many exercises such as walking, running and jumping have been utilized for functional

testing during Dartfish Motion Analysis. However, there are limited studies on strength related to anterior pelvic tilt. A back squat may show clinicians that there is a deficit in strength related to the anterior pelvic tilt. This information may be used in physical rehabilitation and training to overcome deficits allowing the active population to achieve optimal performance. The lack of conclusive research for the Thomas test may limit its clinical validity. A clinician needs to be certain that when they are performing a special test to discover a pathology, the results should be repeatable through multiple trials by various testers. The use of Dartfish Motion Analysis Software will give the administrators of the test the opportunity to compare the results of the special tests with the actual measurements of pelvic tilt. If there is an anterior tilt in the pelvis that also is deemed positive by either Modified Thomas or Ely's Test, then that would solidify the claims that these special tests may be reliable for today's clinicians.

CHAPTER 3. METHODOLOGY

The chief purpose of this study is to determine the utility for two orthopedic special tests, Modified Thomas Test and Ely's Test and the reliability of these tests to diagnose hip flexor contracture. Additionally, to evaluate how hip flexor contracture affects dynamic performance. We took a multifactorial approach to analyze these commonly used special tests to: 1) determine inter-rater reliability between three certified athletic trainers and 2) analyze the relationship between a static special tests and dynamic activity. The focus of this study will be on determining hip flexor contracture, which is an indicating factor to the presence of anterior pelvic tilt, the reliability of the Thomas and Ely's test, and how anterior pelvic tilt varies while performing back squats.

Research Design

A quantitative study was performed using a causal-comparative research design. The independent variables are the Modified Thomas Test, Ely's Test, standing position prior to and after lifting, and the back squat that they perform. The dependent variables are the changes in anterior pelvic tilt, angles measured during hip flexion, and changes in anterior pelvic tilt during each repetition of the back squat. The research questions for this study are as follows:

1. What is the inter-rater reliability of the Modified Thomas and Ely's Tests in determining the presence of a hip flexor contracture?
2. How does pelvic tilt and hip flexion vary before, during and post back squat?

Participants

The participants were recruited by, word of mouth by fellow Athletic Trainers, Professors, Exercise Science staff from the population at North Dakota State University, as well as recruitment from exercise science classes, and through coaches to use volunteer out-of-season

athletes. Ten males and ten females (n=20) were selected from the population. The following inclusion criteria for the study were: a) active individuals whom are not participating in regular season competition; b) a minimum of one year of experience with performing the back squat exercise; c) regularly incorporates the back squat into their resistance training program d) ability to squat 80% of their 1RM for eight repetitions. Exclusionary criteria for this study will include: a) current musculoskeletal injuries; b) recently undergone surgery and has not been completely cleared by the surgeon; c) history of sports hernia; d) cardiovascular disease; e) asthma, unless controlled by a prescribed rescue inhaler by a physician; f) pain while squatting.

Prior to partaking in the study, the participants filled out the Health History Questionnaire (Premier Performance Inc., Decatur, Georgia) and the Physical Activity Readiness Questionnaire (Par-Q) (American College of Sports Medicine, Indianapolis, Indiana). The participants were asked to complete an informed consent form that states the procedures for the study and the potential risks involved. These risk factors include: cardiovascular and muscle fatigue, muscle strain, and injury due to improper technique. Upon completion for this study, the participants were compensated \$20 for their time.

Instrumentation

The study encompassed a wide-range of instruments that were used to collect and interpret data. An American Medical Technologies Incorporated (AMTI) Accupower (Watertown, Massachusetts) force plate was used inside of a squat rack to determine an isometric 1RM with the knees at an approximate 90° angle. Dartfish Motion Analysis Software 8.0 (Dartfish, Fribourg, Switzerland) is a two-dimensional analysis software that accurately measures hip flexion in the sagittal plane.⁴² Other studies have used two-dimensional motion analysis to determine anterior pelvic tilt.^{6,29} Two-dimensional motion analysis is generally used

as a less expensive alternative to three-dimensional motion analysis.^{36,42,44} Norris et al.⁴² noted that Dartfish was as consistent as goniometry when measuring the sagittal plane of the body. They noted that there were slight measurement variances of one to two degrees from three-dimensional motion analysis.⁴²

Procedures

Once approval was attained from the North Dakota State University Institutional Review Board, the data was collected in the Health, Nutrition, and Exercise Sciences Biomechanics and Athletic Training Exercise Science Labs located in Benson Bunker Field House Rooms 14 and 16. Data was collected in February of 2018. Prior to data collection, an email was sent out to the subjects who filled out a Health History Questionnaire and a Par-Q. They brought these forms to the study to be reviewed and analyzed by the researchers prior to commencement of the study. All data collection occurred during one visit from each participant. If any of the exclusionary criteria were met, the individual was turned away. Once they were approved, the participant went into Bentson Bunker Room 14 with three clinicians and the researcher for examinations involving the Modified Thomas and Ely's Test. The three clinicians performed the Modified Thomas Test and the Ely's Test in a randomized order, and the order in which each clinician was selected to perform the special tests was randomized. Additionally, after each special test was performed, the participant was required to stand for one minute to minimize the effects of muscle stretching from previous special tests. The three clinicians will be given a script a week in advance to study and will read from the same script to consistently deliver instructions to the participants for the special tests. In addition, the positive indications for each special test were listed on the script to aid the clinicians. Markers to obtain hip flexion were placed similar to those in Schache et al.⁵ and Norris et al.⁴² at the lateral femoral condyle of the

femur and greater trochanter of the femur as in and the posterior aspect of the humeral head. An additional marker was placed at the lateral malleolus to aid the measurement of knee flexion.⁴² Marker location for pelvic tilt measures was used at the anterior superior iliac spine (ASIS), posterior superior iliac spine (PSIS).²⁴ Also, a marker was placed at the midpoint to determine an adequate axis for the intersecting line at 90° (Figure 4). Pelvic angles were measured at a later date using Dartfish Motion Analysis Software while the participant was standing in normal posture and again post-exercise. Once the images were collected, they were analyzed and compared with the findings of the three clinicians to validate each special test at a later date. Also, the height of the participants was recorded for demographic purposes during this time. Only one clinician was in the room with the participant at one time, therefore eliminating bias in the evaluation of the Modified Thomas and Ely's Tests. Bias could occur if one clinician performed the tests in front of others, therefore, the other clinicians may be persuaded to agree with their findings without employing their own clinical acknowledgement. Therefore, when one clinician was giving the assessment, the other two waited outside of the room in order to avoid bias. Once in the room, the clinicians determined the presence of hip flexor contracture with the guidelines for the Modified Thomas and Ely's Tests that they received two weeks prior to examination.



Figure 4. Placement of Markers for Two-Dimensional Motion Analysis

The clinicians performed the tests with the following procedures according to Starkey et al.⁸. They performed the Modified Thomas test (See Figure 5), which is performed on the edge of the examination table when the patient grabs the uninvolved leg and brings the knee to their chest. They lay back onto the table and let the other leg rest in a relaxed state.⁸ If the opposite knee flexes or hip flexes, then that is a positive implication for hip flexor contracture.⁸ For the Ely's Test (See Figure 6), the patient was placed in the prone position with the clinician standing at their side.⁸ The clinician then passively flexed the knee towards the buttocks.⁸ If the hip raised from the table on the side tested, then a positive sign for rectus femoris tightness was elicited.⁸ Each clinician declared a "pass" or a "fail" for both of the Special Tests. The order of the clinicians evaluating participants was randomized. The results were documented in a chart and the clinician was dismissed. Two more clinicians took turns performing the same tests on the participant, blinded to each other's findings. Pass or fail of the tests did not exclude the participant from the remainder of the study.



Figure 5. The Modified Thomas Test as described by Starkey et al.⁸



Figure 6. The Ely's Test as described by Starkey et al.⁸

The participant progressed to the Biomechanics Lab. Initially, the individual was standing on the force plate while filmed by the camera in order to obtain their weight for demographic purposes and images were captured to later determine the participant's current pelvic tilt after the data collection was complete. The participant was asked to perform a five-minute warm-up on an exercise bike at their self-determined pace, followed by eight squats with their own body weight and finally eight squats with the empty bar on their back. Once warmed-up, they went into a squat rack above the force plate. The squat rack had a substantial load that could not be lifted from the rack. Warm-up isometric contractions of 25%, 50%, 75% and 90% effort were performed before the final two 100% perceived effort. The isometric squats were each be performed at 90° of knee flexion, as validated by Bazyler et al.¹³ to be the closest equivalent of a traditional 1RM. In between each warm-up set, the participant rested one minute.

Once the 1RM were established, the participant was given a five minute break in order to regenerate adenosine triphosphate (ATP).⁴⁰ This prescription of rest is usually administered when the participant is lifting to achieve maximal strength.⁴⁰ Then, they performed a second isometric squat at maximum force. A third was prescribed in the instance that there was greater than ten pounds of difference between the first two values. The two closest values were evaluated and the greater of those two values was selected as the 1RM. During the rest period following the isometric squats, the examiners determined the participant's squat load for the next phase. The participant was required to perform eight repetitions of a back squat with a load that was 80% of their 1RM.⁴⁰ Images were captured during the exercise to later be analyzed by Dartfish Motion Analysis. Then, a post-exercise image was taken of the individual to determine if there were any increases in anterior pelvic tilt or hip flexion during the squat for each repetition. Measurements of the back squat were taken to assess pelvic tilt and hip flexion at angles approximately at 90° of knee flexion to determine if there was a difference in posture or mechanics when fatigue became a factor.¹³ Pelvic tilt was calculated as the angle measured by the PSIS in relation to the vertical intersecting line and the midpoint between the PSIS and ASIS. Then that angle was subtracted from 180° to determine the angle of anterior pelvic tilt. This method was used since the marker for the ASIS disappears during the squat at 90°.

Statistical Analysis

Inter-rater reliability of the special tests were calculated using chance-corrected Fleiss Kappa (K) values. An alpha level of <.05 was used to test statistical significance between clinicians. Pelvic tilt was measured during the back squat exercise using a repeated measures ANOVA for the knee angles of 90 degrees with every repetition.¹³ The measurements showed whether pelvic tilt changed from fatigue during the exercise. If the ANOVA was found to be

significant, Bonferroni adjusted pair-wise comparisons were used to assess significant differences between the repetitions.

CHAPTER 4. MANUSCRIPT

Abstract

Athletic trainers require efficiency to diagnose hip flexor contracture, a postural defect adversely affecting performance. The study's purpose investigated the Modified Thomas (MTT) and Ely's Tests' inter-rater reliability and determined a relationship of hip flexor contracture with a back squat. The MTT exhibited inter-rater reliability for iliopsoas contracture. Neither exhibited inter-rater reliability for rectus femoris contracture. During the back squat, anterior pelvic tilt increased from repetitions one to eight and hip flexion angles between repetitions one and five were statistically significant. Findings suggest the MTT possesses inter-rater reliability diagnosing iliopsoas contracture and a relationship amid the pathology and performance.

Introduction

Sports injury prevention is a primary goal of certified athletic trainers. In order to screen for potential injuries or re-injuries, Athletic Trainers evaluate participants with a history, physical examination, strength and cardiovascular endurance training, stretching protocols and special tests¹⁻⁵. The use of special tests in orthopedic evaluations allow the clinician to differentiate between abnormalities and injuries. If a clinician relies on the outcomes of special tests that have low reliability and validity, the chance of successful diagnosis and treatment may be unlikely. Certain special tests are used to assess the range of motion and flexibility of anatomical appendages that may impact the posture of the patient. Additionally, patient posture and prevalence to injury is impacted by changes in flexibility and strength in the muscles surrounding the body's joints.^{1,2,6-12} The restrictions in range of motion surrounding these joints subject the body to altered biomechanical movements, which increases the amount of expended energy and predisposition to injury.^{4,13,14} Analysis of this phenomenon in the pelvis by the way of

orthopedic special tests can reveal critical information on the importance of the pelvis for posture.^{6,14,15}

The chief purpose of this study was to determine the utility of the Modified Thomas Test and Ely's Test orthopedic special tests by evaluating the reliability of these special tests to determine hip flexor contracture. An additional purpose of this study evaluated how hip flexor contracture affects dynamic performance. We took a multifactorial approach to analyze these commonly used special tests to: 1) determine inter-rater reliability between three certified athletic trainers, and 2) analyze the relationship between a static special tests and dynamic activity. The process of evaluating hip flexor contracture, an indicating factor to the presence of anterior pelvic tilt, encompasses each of these purposes. Anterior pelvic tilt is diagnosed when the distance between the midpoint of both anterior-superior iliac spines and the coronal plane is greater than the distance from the symphysis pubis and the coronal plane.⁹ Among the dominant anterior hip musculature is the rectus femoris, which becomes tight during anterior pelvic tilt. Additionally, the iliacus, psoas major and psoas minor accompany the rectus femoris in its contracted state, therefore coined 'hip flexor contracture'. Weakness of the hamstrings or inadequate lengthening also contribute to anterior pelvic tilt, as the anterior hip musculature dominates.¹⁶

A contracture of the hip flexors directly impacts the anterior tilt of the pelvis, thereby requiring an assessment tool to determine the existence of hip flexor contracture and another to evaluate athletic performance. For this study, a dynamic back squat was used as the assessment tool for athletic performance. Therefore, we hypothesized the following: 1) the Modified Thomas Test and Ely's Tests will have low inter-rater reliability; 2) there will be significant increase in the amount of pelvic tilt present after the back squat exercises in relation to the

measures prior to the back squat measures; 3) the participants' hip flexion angles will increase from repetition one to repetition eight. With the chosen methodology, the researchers hoped to contribute to the fields of athletic training and exercise science by exploring the role of hip flexor tightness affecting position of the pelvis and dynamic performance.

Methods

Design

A causal-comparative trial involving the comparison of hip flexor contracture and its effect on a dynamic movement in 20 active individuals with a history of resistance training experience were recruited. Three examiners performed two orthopedic special tests (Modified Thomas Test and Ely's Test) known to diagnose hip flexor contracture on each participant. Motion analysis measured hip flexion and knee flexion angles during these special tests to determine the presence of hip flexor contracture. Since anterior pelvic tilt is linked with hip flexor contracture, we assessed pelvic tilt angles and hip flexion angles during the dynamic back squat. Hip flexion angles were assessed to potentially link hip flexion contracture to changes in back squat form. All assessments and interventions were approved by the North Dakota State University Institutional Review Board.

Participants

Twenty recreationally active participants (10 M age=22.3 ± 2.06 years, 10 F age=21.7 ± 2.36 years) met the inclusion criteria as they performed back squat exercises in their workouts at least once per week for the past six months, which was vital to ensuring proper technique and conditioning for the task performed in the study. To validate the individuals' experience, they were instructed to perform a body weight squat during which their form was assessed ; this eliminated any participants that did not use correct squat form. In addition, if the participant

presented lower body injury or a cardiovascular pathology (such as asthma), they were excluded from the study. Further exclusions were included with a Health History Questionnaire (Premier Performance Inc., Decatur, Georgia) and a Physical Activity Readiness Questionnaire (Par-Q) (American College of Sports Medicine, Indianapolis, Indiana). If they marked yes in either questionnaire, the participant was disqualified from the study. Zero participants were disqualified from the study due to exclusionary criteria. Each participant completed an informed consent form prior to participating in the intervention.

Procedures

Once approved for the study, reflective markers based from the Norris et al.¹² study were placed on the posterior aspect of the humeral head, anterior superior iliac spine (ASIS), posterior superior iliac spine (PSIS), the midline between the ASIS and PSIS, approximately 6 inches above the midline marker that intersects the midline at 90°, greater trochanter, lateral femoral condyle, and the lateral malleolus. The Modified Thomas Test and Ely's Tests were conducted by three examiners with 42 total years of experience as Board Certified Athletic Trainers, who were provided with scripts a week prior to the study. This script described the orthopedic special tests they were to perform and the positive indications for each. The Modified Thomas Test and Ely's Test were performed as directed by Starkey et al.¹⁷. The determining factors of which hip flexion and knee flexion angles were indicative of hip flexor contracture were used as stated in Magee et al.¹⁸ In order to minimize outcome bias by participant stretching, the order of the tests and order of the examiners were randomized throughout the examinations. After each special test, the participant was required to stand up by the table for one minute before the next special test could be performed.

The Modified Thomas Test was performed with the participant standing at the edge of the table, where they grasped their left knee and brought it back to their chest while simultaneously laying onto their back. The right leg was examined by the clinician, who noted indicators for a ‘positive’ test as the right leg rose from the table or the knee moved into extension. The leg rising from the table indicated iliopsoas contracture, while the knee moved into extension, indicated rectus femoris tightness.

The Ely’s Test was performed with the participant in the prone position and the clinician standing outside of the camera’s view of the markers on the ipsilateral side being assessed. The clinician passively flexed the heel to the buttocks or until they met resistance. The test was indicated positive by the clinician if the ipsilateral hip rose from the table during passive knee flexion.

The participants were taken to the Biomechanics Lab where an American Medical Technologies Incorporated (AMTI) AccuPower (Watertown, Massachusetts) force plate was placed within a standard squat rack. The force plate was zeroed and the participants stood to have their body weight measured. During this time, the camera placed to the side of the squat rack recorded the participants’ right sagittal plane while they stood in a relaxed position. Once the weight was collected, the participants were instructed to perform a five-minute warm-up on an exercise bike at self-determined pace. To provide additional functional warm-up, the participants moved into the squat rack where they performed eight body weight squats and eight back squats with a standard barbell (45 lbs). During this period, the researchers monitored the point of the squat where the knee angle was at approximately 90° and the thighs were ‘parallel’ to the floor. After the warm-up period, researchers lowered the safety racks to the participants’ shoulder height during the ‘parallel’ squat position. The bar was placed on the racks, then loaded

with more weight than could be lifted by the participant. Each participant performed isometric squats for one set of 25%, 50%, 75% and 90% of their perceived maximal effort as an acclimation progression. The duration of each repetition was three seconds. This progression allowed the participants to become familiar with the isometric squat. Then, two sets of maximal perceived effort were performed for three seconds each. Participants could rest as long as they wanted in-between trials. The greatest force output value of the maximal perceived effort was recorded. However, if the difference between maximal perceived effort trials was greater than 10 pounds, the participant performed one additional maximal effort trial. The greater value of the two-closest values was taken as the maximal voluntary contraction (MVC) that represented their one-repetition maximum. While the participant had a five-minute rest break, the exercise load was determined through calculation of 80% of the MVC. The participant performed eight repetitions of their 80% MVC while recorded with a camera. After the participant racked the bar, they stood back and allowed the camera to record them again in a relaxed stance. Once the recording was finished, the participant was released from the study.

Finally, after the testing was completed, all videos were uploaded onto a laptop computer. Joint angles were measured using Dartfish Motion Analysis Software version 8.0 (Fribourg, Switzerland). While analyzing the Modified Thomas Test and Ely's Test, hip flexion and knee flexion angles were measured. Hip flexion was measured as the angle created by the markers drawn from the posterior humeral head to the greater trochanter of the femur and the lateral femoral condyle. Additionally, knee flexion was measured as the angle created by the greater trochanter of the femur, the lateral femoral condyle and the lateral malleolus. In order to compare with the results of Peeler et al.^{8,19}, our researchers were required to adjust the reported angle. When Dartfish Motion Analysis measures angles, it reports the angle within the 180°

mark and not the reverse angle as reported in Peeler et al.^{8,19} Therefore, in order to have comparable results, our researchers subtracted the value reported by Dartfish Motion Analysis from 180° (Reported Angle= 180 – degree measured by Dartfish). The angles were calculated and reported in this way during each special test performed by the examiners on the participants. Then, angles collected from the squat session were measured. The actual angle evaluated by Dartfish Motion Analysis was reported for comparisons with the literature. During the pre- and post-squat standing posture assessments, pelvic tilt was calculated. The pelvic tilt angle was drawn from two axes created from the iliac spines and the center of the body. The connecting markers included the anterior superior iliac spine to the midpoint of the iliac spines, creating the horizontal axis and intersected by a line drawn from the trunk marker to the midpoint of the iliac spines. The following equation determined the amount of pelvic tilt present: Angle of the pelvis – 90°= Amount of Pelvic Tilt. Unfortunately, this same technique could not be performed during the dynamic squat repetitions, due to concealment of the ASIS marker by the trunk and thigh during the down phase. Therefore, the following process was used to calculate the amount of pelvic tilt: an angle was drawn from the trunk marker to the midpoint of the iliac spines to create the vertical axis, intersected by a line drawn from the posterior superior iliac spine (PSIS) to the midpoint of the iliac spines to determine the posterior angle of the pelvis. Thus, the following equation was utilized to determine pelvic tilt (180°- Posterior Angle of the Pelvis) – 90° to determine the amount of tilt present in the anterior plane of the pelvis. For all pelvic tilt measures, positive values were associated with anterior pelvic tilt while negative values were considered posterior pelvic tilt. The values were placed into Microsoft Excel spreadsheets and then were transferred over to SPSS version 24 for statistical analysis.

Statistical Analysis

SPSS version 24 was used to analyze the data. Each test was analyzed against an alpha level of $<.05$ to establish statistical significance. Clinician scoring for the Modified Thomas Test and Ely's Test was based on percentages that represented the number of positive results elicited by the clinicians for every participant. To determine inter-rater reliability for the Modified Thomas Test and Ely's Test, Fleiss' Kappa values were used. The study incorporated paired t-tests to measure pre- and post-squat pelvic tilt angles. Two, one-way ANOVAs were run, one for differences between repetitions with anterior pelvic tilt and another for differences with hip flexion during the dynamic squat set. The ANOVA for hip flexion was found to be significant so Bonferroni corrected paired samples t-tests were used to test for statistical significance between repetitions.

Results

Demographic information is presented in Table 2. The targeted sample included active individuals who routinely perform resistance training exercises on a regular basis and had implemented the back squat exercise into their workout routine at least once per week for a minimum of the past 6 months. The participants included 10 males (age= 22.3 ± 2.06 years) and 10 females (age= 21.7 ± 2.36 years).

Table 2. Participant Demographics (Mean and SD)

	Age	Height (inches)	Weight (lbs)	1RM value (lbs)
Male	22.3 ± 2.06	72.1 ± 3.07	219 ± 37.89	304.25 ± 66.16
Female	21.7 ± 2.36	65.8 ± 3.16	155.4 ± 26.92	178.4 ± 33.2
Total	22 ± 2.18	68.95 ± 4.43	187.2 ± 45.69	241.33 ± 82.24

Measurement of hip angle and knee angle for the Modified Thomas and Ely's Tests are presented in Table 3. The angles were measured via Dartfish Motion Analysis software version

8.0. The values in Table 3 are overall means of all measured angles for the three examiners and the twenty participants.

Table 3. Hip and Knee Angle Measures for Modified Thomas Test (MTT) and Ely’s Test (Mean and SD)

	MTT Hip ∠	MTT Knee ∠	Ely Hip ∠	Ely Knee ∠
Male	174.3 ± 12.79	127.2 ± 21.82	175.0 ± 7.58	45.1 ± 9.65
Female	179.2 ± 12.03	136.0 ± 13.58	175.9 ± 4.29	39.5 ± 8.05
Total	176.8 ± 12.56	131.6 ± 18.56	175.4 ± 6.12	42.3 ± 9.25

Table 4 exhibits the raw data for the three examiners for the special test being rated as positive or negative for each subject. In each column a “+” represents a positive indication by the examiner and a “-” represents a negative indication acknowledged by the examiner. Because of the variance in the subjectivity of the measurements each clinician recorded, there are differences in the overall findings in the special test diagnoses. In Table 5, the percentages were collected from each examiner per special test. The percentage shows how many times examiners elicited a ‘positive’ result when performing the Modified Thomas Test and Ely’s Test individually.

Table 4. Indications for Modified Thomas Test (MTT) and Ely’s Test to Determine Presence of Hip Flexor Contracture (+) or Non-existence (-)

Participant	Sex	MTT (ILIO)	MTT (RF)	Ely
1	M	-,-,+	-,+,-	+,-,-
2	M	+,-,+	+,-,+	-,-,-
3	M	-,-,-	+,-,-	+,-,-
4	M	+,-,+	+,-,+	-,-,+
5	M	+,-,+	+,-,-	+,-,-
6	F	-,-,-	+,-,-	-,-,-
7	M	-,-,-	+,-,-	+,-,-
8	M	-,-,+	+,-,-	+,-,-
9	F	-,-,+	-,-,-	-,-,-
10	F	+,-,+	+,-,+	-,-,-
11	F	-,-,-	+,-,-	-,-,-
12	F	-,-,-	+,-,-	-,-,-
13	F	-,-,-	+,-,-	-,-,-
14	M	+,-,+	+,-,-	+,-,-
15	M	+,-,-	+,-,-	-,-,-
16	F	+,-,+	+,-,-	-,-,-
17	F	-,-,-	-,-,-	-,-,-
18	M	+,-,+	+,-,+	-,-,+
19	F	+,-,+	+,-,-	-,-,-
20	F	+,-,-	-,-,-	-,-,-

Table 5. Ratio/Percentage for Modified Thomas Test (MTT) and Ely’s Test Per Examiner

Examiner	+ MTT Ratio	Percentage	+ Ely Ratio	Percentage
1	17/20	85%	6/20	30%
2	14/20	70%	4/20	20%
3	10/20	50%	3/20	15%

Statistics for inter-rater reliability of the Modified Thomas and Ely’s Tests are displayed in Table 6 using Fleiss’ Kappa (K) values ($p < .05$). The Modified Thomas Test was split into two reliability tests, one for rectus femoris tightness and the other for iliopsoas tightness. Reliability was determined through the following degrees of agreement for Kappa coefficients: ≤ 0 poor, 0-0.2 slight, 0.2-0.4 fair, 0.4-0.6 moderate, 0.6-0.8 substantial, and 0.8-1.0 almost perfect. Table 6 represents Ely’s Test’s Kappa coefficients and the Modified Thomas Test’s Kappa coefficients for iliopsoas (hip) and rectus femoris (knee) tightness. Due to a Kappa coefficient of -0.010

($p=.53$) for the Modified Thomas Test, there were no statistically significant differences determine rectus femoris tightness. The results of our study indicate there is poor inter-rater reliability for the Modified Thomas Test when testing for rectus femoris tightness. However, when testing for iliopsoas tightness, the Kappa coefficient was 0.224 ($p=.04$). As interpreted by degrees of agreement, the Modified Thomas Test has slight to fair agreement between raters to determine iliopsoas tightness. Since there was a small sample size in this study, we acknowledge that the inter-rater reliability may improve with an increase in sample size. We justify this with our p-value ($p=.04$). Since there is statistical significance between raters, then we may hypothesize that the inter-rater reliability may increase for iliopsoas assessment. Finally, Ely's Test elicited a Kappa coefficient of -0.080 ($p=.73$). This level of agreement shows no difference from zero and has poor reliability to determine rectus femoris tightness consistently between raters.

Table 6. Fleiss' Kappa Coefficients to Determine Inter-rater Reliability of Modified Thomas Test (MTT) and Ely's Test (Ely)

Special Test	Kappa Coefficient	P-Value	Degree of Agreement
MTT Hip	0.224	.04	Slight-Fair
MTT Knee	-0.010	0.53	Poor
Ely	-0.080	0.73	Poor

Analysis of pelvic tilt angles in the static standing posture pre- and post-exercise were conducted through a paired samples t-test. No significant differences were found between pre-test and post-test in anterior pelvic tilt ($t=1.368$, $df=17$, $p=.190$).

Dynamic back squat exercises were analyzed over the course of eight repetitions. Assessment of pelvic tilt between these eight repetitions were conducted through a one-way ANOVA (1x8). Mauchly's Test of Sphericity was not found to be significant ($p=.109$). Therefore, a sphericity assumed test of the ANOVA was used, which revealed no statistically

significant differences when comparing pelvic tilt between repetitions of the back squat exercise ($F(7, 133)=1.415, p=.204$). However, as shown in Figure 7, there appears to be a general increase in anterior pelvic during the exercise set from repetition one to repetition eight.

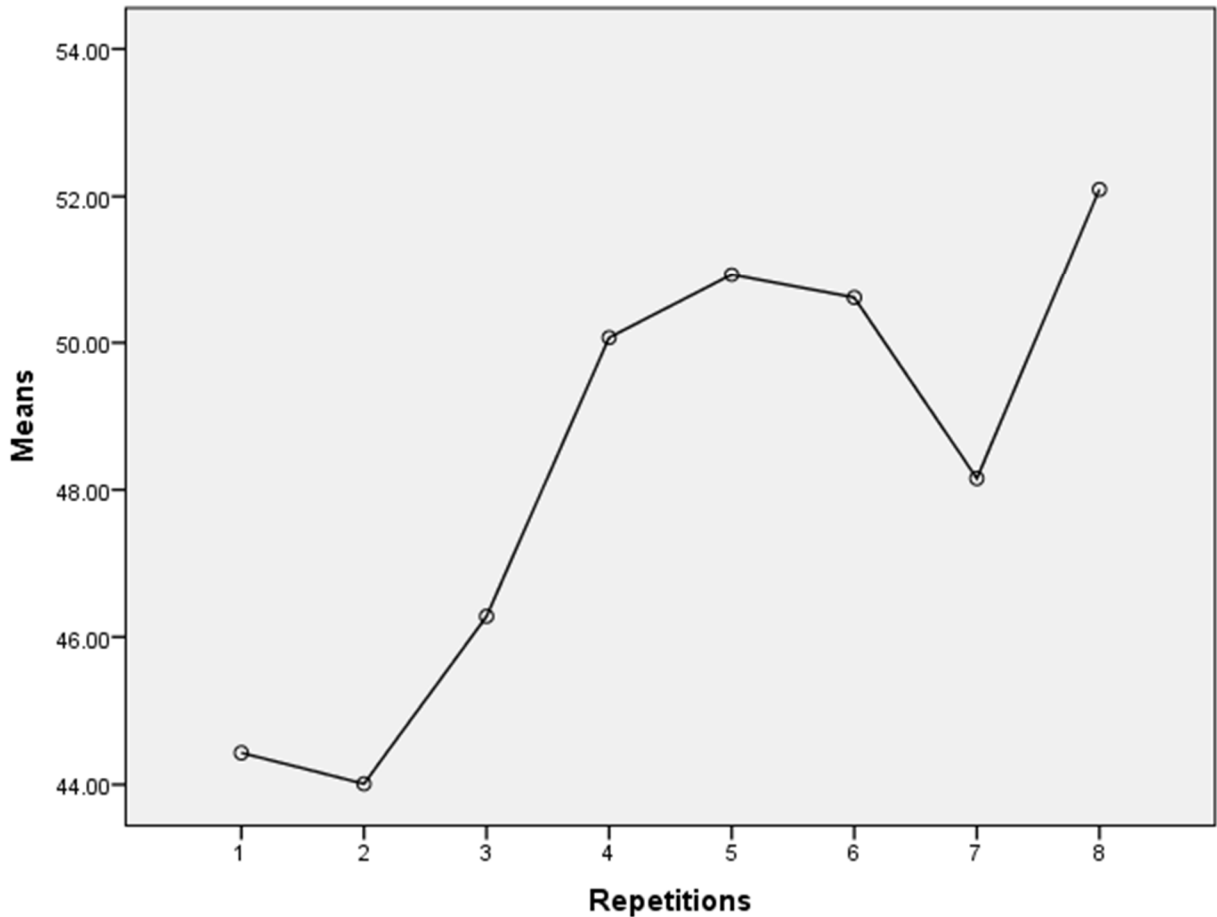


Figure 7. Estimated Anterior Pelvic Tilt Means for Every Squat Repetition

Additionally, hip flexion was measured during every repetition using a one-way ANOVA (1x8). Table 7 describes the mean and standard deviation for both hip flexion and pelvic tilt data for each repetition of the dynamic back squat. The Mauchly's Test of Sphericity was found to be statistically significant ($p=.016$). Therefore, the Greenhouse-Geisser results were used as the test for statistical significance ($F[4.204, 79.870] = 3.010, p=.021$). The significant results establish that at some point within the eight repetitions of the back squat exercise, there were differences

in hip flexion. As shown in Figure 8, the means show a sudden decrease in hip flexion during the fifth repetition and increases again as the set is completed. Since the ANOVA was found to be significant, paired samples t-tests were conducted to determine specific differences between repetitions. Bonferroni corrections were used to determine statistical significance of the data set $p=.05/28=.0018$. The first repetition and fifth repetition were found to be significantly different ($t=3.800$, $p=.001$). Other pairings were close to being statistically significant and are indeed worth mentioning; (repetition two versus repetition five; $t=3.167$, $p=.005$), (repetition four versus repetition five; $t=3.461$, $p=.003$), and (repetition five versus repetition eight; $t=-3.291$, $p=.004$).

Table 7. Mean Values Collected During Pelvic and Hip Analysis for Each Repetition of Dynamic Back Squat (Mean and SD)

Repetition	Pelvic Tilt	Hip Flexion
1	44.4 ± 17.4	89.8 ± 7.5
2	44.0 ± 16.4	89.9 ± 7.4
3	46.3 ± 16.9	89.2 ± 8.0
4	50.1 ± 17.4	89.0 ± 7.5
5	50.9 ± 19.8	86.8 ± 7.0
6	50.6 ± 16.2	88.5 ± 7.5
7	48.2 ± 18.7	88.3 ± 8.6
8	52.1 ± 29.1	89.9 ± 8.0

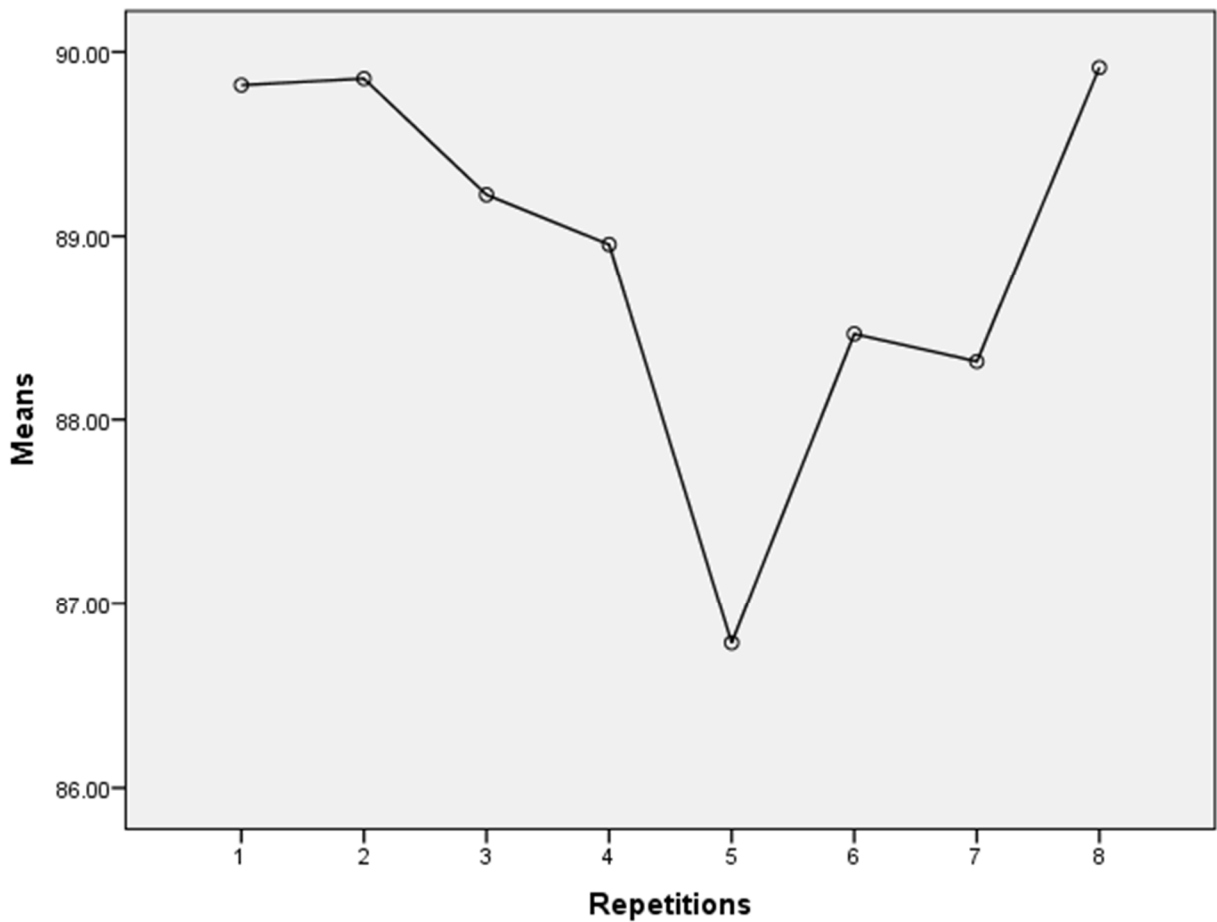


Figure 8. Estimated Hip Flexion Means for Every Squat Repetition

Discussion

Inter-rater Reliability

One purpose of this study was to determine the inter-rater reliability of the Modified Thomas and Ely's Tests. Our hypothesis was there would be a low inter-rater reliability for these tests. As depicted in Table 5, there was variation between the clinicians and the number of positive tests they declared for the Modified Thomas Test and Ely's Test. Iversen et al.³ performed the Ely's Test to measure muscle length to determine how physical examination and performance are affected in adults with knee osteoarthritis. The special tests were performed on 87 limbs in which 79 were positive, yielding a 91% positive outcome. This statistic by Iversen et

al.³ was larger than those obtained by our examiners. Iversen et al.³'s statistics for the Ely's Test were 61% higher than examiner one's results (30%), 71% higher than examiner two's results (20%) and 76% higher than examiner three's results (15%) for our study. Since Iversen et al.³ used a larger sample size and measured participants who were already experiencing a lower limb pathology, one could speculate the results would be higher due to the contributing role knee osteoarthritis may have with hip flexor contracture. In contrast to Iversen et al.³, Peeler et al.¹⁹ measured the inter- and intra-rater reliability of the Ely's Test, but the researchers did not provide positive outcome data. They determined pass/fail indicators and compared them with goniometric measures to determine the presence of rectus femoris contracture.¹⁹ Therefore, we could not compare our results to Peeler's¹⁹ study, who determined inter-rater reliability between three examiners for the Ely's Test.

The data above provides evidence there may be differences between clinician interpretation of the Ely's Test, which may skew overall inter-rater reliability. Although Iversen et al.³ provided data that seemed consistent, they did not specify individual positive special test percentages for each of the three physical therapists who performed the examinations. Instead, they consolidated the data into one large pool. Therefore, no comparison could be made between our individualized positive outcome data between examiners with Iversen's³ three examiners. When determining inter-rater reliability, the Modified Thomas Test (.22) was drastically different than the numbers listed by Starkey et al.¹⁷ (.58). However, Peeler et al.¹⁹ (.46), and Lee et al.²⁰ (.507/.207) had similar numbers for healthy individuals. Starkey¹⁷ reports an inter-rater reliability of .58, Peeler et al.¹⁹ reported .46 and Lee et al.²⁰ reported .501 in individuals with cerebral palsy and .207 without pathology. The Kappa statistics in our study determined a .22 inter-rater reliability when testing for iliopsoas contracture, which is consistent with the inter-

rater reliability described by Lee et al.²⁰ However, our inter-rater reliability value was less than the value described by Peeler et al.¹⁹ The greatest differential value was described by Starkey et al.'s¹⁷ result as it is drastically higher than all of the other values described in the literature and our study. This supports our hypothesis that a low inter-rater reliability would be associated with the Modified Thomas Test and Ely's Test during this study.

For the Modified Thomas Test, the inter-rater reliability was lower than Starkey et al.¹⁷, Peeler et al.¹⁹, and Lee et al.²⁰; however, the sample size of our study may have hindered reliability. Since we used a sample size of twenty individuals, we may not have evaluated enough participants to show a higher agreement between raters. The Modified Thomas Test had statistical significance to determine iliopsoas contracture ($p=.04$); therefore, there is statistical agreement between raters. However, based on the results of the current study, the Modified Thomas Test is not reliable to assess rectus femoris contracture due to poor agreement between raters.

Since the Ely's Test was considered inconclusive for reliability and validity in the literature by Starkey et al.¹⁷ we sought to determine a potential inter-rater reliability. The results from our study showed near zero consistency within raters, which contrasts Peeler et al.¹⁹ significantly (chance-corrected Kappa value of .46). This could be attributed to different body mechanics utilized as the Peeler et al.¹⁹ study had the participant perform knee flexion in an active movement, instead of passive as the test is intended.

Range of Motion for Modified Thomas and Ely's Tests

Table 2 listed the hip and knee flexion angles for the Modified Thomas and Ely's Tests. For the Modified Thomas Test, we obtained a mean hip flexion angle of $176.9 \pm 12.6^\circ$, which contrasted other published works. Previous authors published research that measured hip

extension were in reference to 180° of hip flexion. They described this same position as 0° of hip extension. Therefore, if a previous author described a measure in excess of 180°, then it would also be considered a negative measure for our study, since 180° and 0° were described in the same position. If the obtained mean hip flexion angle in our study was adjusted to meet these criteria, then our value would equal $-3.1 \pm 12.6^\circ$. Harvey et al.² reported a hip angle of -11.9° , which was described as hip extension. Researchers using two-dimensional motion analysis techniques similar to ours obtained hip extension values of $2.8 \pm 10.1^\circ$ (Vigotsky et al.⁷) and $12.0 \pm 7.8^\circ$ (Young et al.²²). Finally, a study by Schache et al.²³ noted a mean hip extension of 17.4° when three-dimensional motion analysis was conducted. None of the previously highlighted studies determined a hip flexion value with their mean measures. Their samples each determined a measure of hip extension for these measures. Therefore, when compared to our study, the hip angle measures in the previous studies would be similar since we also achieved hip extension during our mean hip angle measures.

Only two studies measured knee flexion angles with the Modified Thomas Test. Peeler et al.⁸ found knee flexion angle to be $50 \pm 12^\circ$. Specifically, men alone exhibited $47 \pm 12^\circ$ and women $51 \pm 12^\circ$. The angles were determined via goniometer and at first glance differ significantly from our results. We determined a mean knee flexion angle of 131.6 ± 18.56 , where men exhibit $127.2 \pm 21.82^\circ$ and women exhibit $136 \pm 13.58^\circ$ with the two-dimensional motion analysis software. The differences in these angles may result from the angle that Peeler et al.⁸ measured. We used almost identical markers for knee flexion, with the exception of the knee marker. However, the angle that Peeler appeared to report was not the angle created by the greater trochanter, fibular head and the lateral malleolus, but the opposite angle. If one was to re-calculate our angles to coordinate with their measures, our results would be different (Total:

48.4 ± 12°, Men: 52.8 ± 21.8°, Women: 44 ± 13.6°). To make this correction, one would simply subtract the inner knee angle from 180° to achieve the outer angle. With these corrections, the measures that we obtained are consistent with those in the literature. Young et al.²² also measured the outer angle of the knee when determining knee angle measures. They reported 51.7 ± 7.6° in male Australian Rules (AR) football players. The reported values by Peeler and Young are consistent with the values obtained in this study, when the consistent angle was measured.

When compared to Peeler et al.¹⁹, there is a major difference in knee angle measures for the Ely's Test. Peeler et al.¹⁹ reported mean knee angles that reflected the angle opposite of what they described. Their markers were at the greater trochanter, fibular head and the lateral malleolus. We measured the inner angle that establishes knee flexion created by the greater trochanter, lateral femoral condyle, and the lateral malleolus. The average knee flexion angle for the Peeler study was 124 ± 7°, which was significantly different than the values obtained during our research (137.7 ± 9.25°). Again, we had to correct our data to measure the outer angle of the knee. We simply subtracted our value from 180° to mimic Peeler's angles, just as before with the Modified Thomas Test results. Besides the difference in measurement technique, we speculate a difference in measure with the technique of the Ely's Test affected the results. Peeler et al.¹⁹ used goniometry and an 'active' Ely's Test while we used motion analysis software to measure the hip flexion angle through the original 'passive' Ely's Test. With passive range of motion, the examiners may have gained extra degrees of range of motion since the muscle is stretched past a participant's active motion. Additionally, there were no hip flexion measurements in the Peeler study to compare with our results.

Anterior Pelvic Tilt

Based on evidence provided from other studies, we hypothesized anterior pelvic tilt would be greater post-back squat exercise when compared to the pre-back squat measures. There were no significant results to support this hypothesis, therefore we must refute our hypothesis. However, the mean for pelvic tilt within the sample was $2.82 \pm 8.76^\circ$. If one was to add the standard deviation into our mean, then the overall total of anterior pelvic tilt would fit into all values gathered by Zhu et al.⁹, Loppini et al.¹⁰, and text by Shultz et al.¹¹ Zhu et al.⁹ noted that pelvic tilt in the lateral decubitus (side-lying) position may vary from -25° posterior to 20° anterior. Loppini et al.¹⁰ reported a mean value of $11 \pm 8.3^\circ$ in total hip arthroplasty patients in the standing position. In a text by Shultz et al.¹¹, anterior pelvic tilt ranges differ between men and women (Male: $5-13^\circ$, Female: $7-17^\circ$). Our value falls into the range provided by Zhu et al.⁹; however, the difference is patient position. Loppini's participants were standing versus Zhu's lateral decubitus position. Also, Loppini's measurements were determined in a three-dimensional model with patients that were undergoing total hip arthroplasty. This differs from our participants because our participants were healthy with no evidence of recent orthopedic injury. In addition, the mean value obtained in this study was less than both male and female ranges from Shultz¹¹ This could be error from marker placement or a sample of individuals who were not experiencing excessive anterior pelvic tilt. The lack of significance from our pre- and post-squat results may be attributed to lack of extensive exercises involving activation of the rectus femoris and iliopsoas groups. Perhaps, one could make the argument that with the use of a complete lower body workout versus the single set of back squat exercises, there could be significant changes in pelvic tilt. Our mean of pelvic tilt angles was $48.32 \pm 3.59^\circ$ through the

dynamic back squat set. Unfortunately, these results cannot be compared to literature containing dynamic pelvic tilt measures during lower body exercise because none could be found.

Hip Flexion

We hypothesized the participants would have the greatest amount of hip flexion at the end of their back squat set as compared with the initial repetition. Our reasoning for this hypothesis stems from a finding from Hooper et al.²⁴, which assumes that individuals fatigue during exercise causing a detriment in lifting form. Our hypothesis was not supported as the values were greater between repetitions one and eight. There was a sizable decrease in hip flexion angle between repetition one and five. We attribute this phenomenon to fatigue, and the increase in hip flexion angle from repetition five to eight may be attributed to our verbal encouragement during repetitions six and eight. Additionally, in comparison to Norris et al.'s¹² hip flexion norms during a box lift, which is performed similar to a deadlift, the reported mean was $113.1 \pm 8.3^\circ$. Overall, our results showed a mean of $88.9 \pm 1.6^\circ$, which is significantly different than the mean hip flexion angles reported by Norris¹² at the bottom of the lift. A study by Hooper et al.²⁴ noted differences of biomechanics during fatigue with a back squat exercise. They measured hip flexion angles in twelve men (achieved hip flexion angles of 87° without fatigue, 100° fatigued) and thirteen women (achieved hip flexion angles of 88° without fatigue, 102° fatigued). Our results are equivalent to their measures when the individual is not fatigued, but Hooper et al.²⁴'s data exhibits greater hip flexion angle than ours when comparing their fatigued participants to our participants who were placed through sessions of isometric squats before performing one set of dynamic squats.

Lorenzetti et al.²⁵ reported hip flexion angles using three-dimensional motion analysis during squats that were restricted and unrestricted. The restrictions prevented the knee from

moving beyond the foot during the squat. With the maximum amount of weight (1/2 participant's body weight), the researchers reported hip flexion angles of $56.7 \pm 9.0^\circ$ (restricted) and $96 \pm 9.0^\circ$ (unrestricted). This data does not match the hip flexion angles that we determined, possibly due to differences in marker placement and type of motion analysis used. They performed three-dimensional motion analysis while our equipment measured two-dimensional motion analysis. Additionally, a study by Sheppard et al.²⁶ noted hip flexion angles at the beginning of a freestyle (unrestricted in lifting technique or session) wooden-handled box lift from 50% of the individual's height. These hip flexion angles were measured during three mechanical loads (10%, 20%, 30% of an isometric back strength assessment). The angle measures were $93.6 \pm 23.5^\circ$ (10%), $94.5 \pm 24.4^\circ$ (20%), and $98.1 \pm 21.6^\circ$ (30%). These numbers are difficult to compare to our data set as the participants in Sheppard et al.²⁶'s study were measured during the initial lift phase, while our study measured hip flexion angles at the 90° approximation of knee flexion. Therefore, it is difficult to determine these numbers are comparable due to differences in lifting technique and the situation in which the lifts are performed.

Some of the previous studies used different lifting techniques that may have produced results differently from our own study. In our study we performed a back squat, which involves hip flexion with the weight resting on the shoulders, whereas the lift performed by Norris et al.¹² and Sheppard et al.²⁶ was performed similar to a deadlifting exercise. Additionally, Sheppard et al.'s²⁶ lift began from a resting point at 50% of the individual's maximal height. This difference in lifting technique and potentially the point in which the angles were measured during a lift could require the participant to use less trunk flexion when lifting. The flexion and extension of the trunk could influence hip and pelvic angles. Our study, in comparison with previously

described studies, involved two different exercises that incorporated similar mechanics, but may yield different results due to the position of the weight that was lifted.

Pelvic Tilt

The amount of change in anterior pelvic tilt during the back squat was not significant in our study, however, was comparable to one piece of literature. Lamontagne et al.²⁷ compared femoroacetabular impingement participants and non-pathological participants and noted an effect that occurred on the pelvis from femoroacetabular impingement. The pelvic tilt measures for femoroacetabular impingement participants averaged $14.7 \pm 8.1^\circ$, while the control group averaged $24.2 \pm 6.8^\circ$. These values are much lower than those determined by our study ($48.3 \pm 3.6^\circ$). This may be due to the type of motion analysis used, as Lamontagne et al.²⁷ performed three-dimensional motion analysis and we performed two-dimensional motion analysis. Another difference may stem from marker placement and measures. Lamontagne et al.²⁷ did not specify which markers were used specifically for pelvic tilt and our marker placements may have been influenced by trunk movement. Therefore, we achieved much higher measurements of anterior pelvic tilt than the literature.

Conclusion

In the present study, we sought to determine the reliability of two orthopedic special tests, Modified Thomas Test and Ely's Test, in order to test the consistency between examiners with the special tests. A multifactorial approach was used to analyze these commonly used special tests to: 1) determine inter-rater reliability between three certified Athletic Trainers and 2) analyze the relationship between a static special test and dynamic activity.

Based on the results of this study and the literature, there cannot be a definitive claim that hip flexor contracture affects dynamic movements. Inter-rater reliability for the Modified

Thomas Test yielded slight to fair reliability to diagnose iliopsoas tightness. However, the study challenges the inter-rater reliability of the Modified Thomas Test and the Ely's Test for hip flexor contracture and how hip flexor contracture may affect dynamic movement. Although there were limitations in this study, there was a general trend towards an increase in anterior pelvic tilt during the duration of the dynamic back squat. Additionally, there is belief verbal cues after repetitions five and seven caused decreases in hip flexion angle, possibly overcoming fatigue. Dynamic movements may be affected by fatigue, leading to improper form or technique, which creates a possible incidence for injury.

Athletic Trainers should acknowledge the limitations associated with these two special tests and how deviations in biomechanical stature may adversely affect dynamic performance. Athletic Trainers should be able to diagnose improper techniques, teach and implement strategies to overcome differences in anatomical structure. With the knowledge obtained from this study, athletic trainers may reduce the prevalence of injury in the athletic population and increase the athlete's overall performance.

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