EXAMINING ANKLE JOINT LAXITY USING TWO DIFFERENT KNEE POSITIONS AND WITH SIMULATED MUSCLE GUARDING

by

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pursue. I am irrevocably grateful for the drive and motivation they give me to push for excellence. I could not have accomplished this without the support of my family.

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ABSTRACT

Context: Anterior drawer and talar tilt tests are commonly used to manually assess lateral ankle sprains. Several factors affect the reliability of these tests including the individual clinician's experience and skill, knee positioning, and muscle guarding. ***Objectives:*** To compare involuntary activity of the gastrocnemius during laxity testing at different knee positions. Secondarily to compare these laxity measurements during a simulated situation of muscle guarding. ***Design:*** A repeated-measures design with knee position as the independent variable. ***Setting:*** University research laboratory. ***Participants:*** 33 healthy volunteer subjects (16 male, 17 female) between ages 18-25 were tested. ***Interventions:*** The ankle was loaded under 2 test conditions (relaxed, simulated muscle guarding) at two knee positions (0°, 90° flexion) while recording gastrocnemius EMG activity. ***Main Outcome Measures:*** Anterior displacement (mm), IE motion (degrees of motion), peak EMG values of the gastrocnemius (mV). ***Results:*** Anterior displacement was significantly different at 90° knee flexion compared to 0° ($P = .007$). IE motion was significantly greater at 0° knee flexion compared to 90° knee flexion ($P < .001$). Peak EMG activity of the gastrocnemius was significantly different at 90° knee flexion during anterior displacement ($P < .001$). Simulated muscle guarding significantly reduced anterior displacement compared to the relaxed condition (90° knee flexion, $P = .016$; 0° knee flexion, $P = .008$) and reduced IE motion (90° knee flexion $P < .001$; 0° knee flexion, $P = .03$). ***Conclusions:*** Involuntary muscle activity of the gastrocnemius does not appear to affect ankle laxity at different knee positioning. Additionally, knee position did not affect laxity measurements during simulated anterior drawer testing. However Talar tilt testing may be best performed with the knee in the 0° knee flexion position. Lastly, simulated muscle guarding significantly reduced ankle laxity and should be a consideration when performing theses clinical examination techniques. ***Key words:*** ankle arthrometer, anterior drawer, talar tilt, electromyography, manual examination.

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Chapter 1

INTRODUCTION

Lateral ankle sprains are among the most commonly incurred injuries in the physically active population.[1-3,5,6,8,12,13,18] In the United States alone, it is estimated that more than 23,000 ankle sprains occur every day.[12] Following acute ankle injury, recognition of mechanical laxity and accurate diagnosis are crucial to further guide the treatment and prevention strategies of re-injury.[13] In the event of a lateral ankle sprain the degree of laxity must be assessed to recognize mechanical instability of the ankle joint and therefore the severity of injury. The anterior drawer and talar tilt tests are manual stress tests used by clinicians to assess the ligamentous structures in the ankle joint.[14] These manual stress tests are routinely used to determine the ligamentous integrity of the talocrural joint and subtalar joint by arbitrary measurement of translation or rotation of the foot compared to the uninvolved limb. The anterior drawer test is performed by applying an anterior load to the foot on a fixed lower leg and stresses the anterior talofibular ligament (ATFL).[1,5,14] The talar tilt test is performed by applying an inversion-eversion torque or rotation to the foot and stresses the calcaneofibular ligament (CFL).[12,14] Manual examination of ankle joint laxity is deficient in sensitivity and is heavily reliant on the individual clinician's experience to interpret ligament stress end-feels.[1,3,7]

Instrumented measurement of the ankle joint allows for a more valid and reliable measure of ankle ligament laxity compared to manual examination.[1-3,7] Instrumented measurement of ankle joint laxity has been used extensively since the first publication of ankle arthrometry in 1999.[3] An ankle arthrometer is an instrument that allows for quantitative measurement of the ankle joint, measuring both rotation (inversion-eversion [IE] motion) and anteroposterior (AP) displacement of the foot relative to the tibia, similar to the manual stress tests previously mentioned.[2,3,7,18] Previous research has demonstrated that the positioning of the knee joint can cause a significant difference in ankle joint laxity.[1] While Kovaleski and colleagues have speculated that the differences in ankle joint laxity are related to involuntary activity of the gastrocnemius-achilles complex, there is no contemporary evidence to support this notion.[1] Electromyography (EMG) is an instrumented technique used to record and analyze electrical activity produced when a muscle contracts and provides a convenient way to quantify involuntary muscle activity. EMG has been used in previous research by Arampatzis et al. as a method to detect the change in muscle activation of the gastrocnemius at different knee and ankle positions.[21] Reduced EMG activity of the gastrocnemius at knee joint angles greater than 80° has been justified by the active insufficiency of the muscle. At pronounced knee joint angles, the gastrocnemius reaches a critical shortened length at which force cannot be generated.[22]

Muscle guarding refers to muscle spasm and joint stiffening associated with pain and swelling in response to ligamentous injury in order to prevent active motion and protect the damaged tissue.[13,14] Muscle guarding and spasm inhibits joint movement making both manual and instrumented examination extremely difficult to assess ankle laxity. Following acute ankle sprains, guarding occurs when the foot is held in a neutral position to prevent active and passive motion. The ankle dorsiflexors, including the tibialis anterior, are primarily active in muscle guarding of the ankle joint to prevent stressing the ATFL in plantar flexion. From a clinical perspective, muscle guarding can make manual examination difficult and result in false-negative manual stress tests or altered end-feel presentation. According to Lynch et al. acute muscle guarding associated with pain and swelling can mask true laxity 4 to 7 days after the injury.[22] A vicious cycle of muscle guarding and time lost from competition/activity can result in inaccurate injury diagnosis.

The prevalence of ankle sprains in the active population stresses the need for prompt and accurate diagnosis by the athletic trainer. The anterior drawer and talar tilt tests are two of the most common clinical examination techniques used in the evaluation of acute ankle sprains. Therefore, the primary purpose of this study was to determine which position of the knee joint (0° and 90° flexion) had the greatest influence on peak EMG activity of the gastrocnemius muscle during loaded ankle arthrometry. Additionally, to better understand the influence of muscle guarding during the execution of these two clinical examination techniques we compared ankle arthrometry measurements between a relaxed and simulated muscle guarding condition. We hypothesized that 90° knee flexion position would elicit greater peak EMG activity; and that voluntary muscle contraction during the loaded arthrometric measurements would result in decreased laxity.

Chapter 2

METHODS

2.1 Participants

Thirty-three volunteers (16 males, 17 females, age 20.2 ± 1.7 years, height 172 ± 9.7 cm, mass 68.4 ± 15.6 kg) were recruited from a large university campus community to participate in this study. An *a priori* power analysis determined that 33 subjects were needed to find statistical significance and power the study. Upon reporting for testing, subjects were asked to complete an approved inform consent document (HSIRB # 440092-1), demographic information, injury history documentation, and complete the Foot and Ankle Outcome Score (FAOS). In order to be included in this investigation subjects had to score between 90 and 100 on the FAOS, be injury-free at the time of study and not have had any previous knee or ankle surgeries. These criteria were based on a previous study investigating ankle arthrometry by Kovaleski et al.[1]

2.2 Instrumentation

2.2.1 Foot and Ankle Outcome Score (FAOS)

The FAOS is a subjective assessment of ankle function in daily activities and recreation.[9] The FAOS consists of 5 subscales: Pain, Other Symptoms, Function in daily living (ADL), Function in sport and recreation (Sport/Rec), and foot and ankle-related Quality of Life (QOL). The previous week is taken into consideration when answering the questionnaire. Standardized answer options are given (5 Likert boxes) and each question gets a score from 0 to 4. A normalized score (100 indicating no symptoms and 0 indicating extreme symptoms) is calculated for each subscale. (Additional information on the FAOS can be found at www.koos.nu)

2.2.2 Ankle Arthrometry

The portable ankle arthrometer (Blue Bay Research Inc., Navarre, FL) was used to measure displacement (anterior drawer) and rotation (talar tilt) of the foot in relation to the leg (Figure 1). The ankle arthrometer consists of an adjustable plate fixed to the foot, a load-measuring handle attached to the footplate through which the load is applied, a tibial pad attached to the tibia and a spatial kinematic linkage.[1,-4, 7,14,17] A spatial kinematic linkage is a 6 degrees-of-motion electrogoniometer that measures applied forces, translations, and rotations to the foot. The spatial linkage connects the tibial pad to the footplate, which allows for measurement of motion from the footplate relative to the tibial pad. The foot is secured to the footplate by a heel cup that grips the calcaneus below the malleoli and a dorsal foot clamp that secures the midfoot to the footplate. A strap placed just above the malleoli on the anterior surface of the leg prevents the tibia from lifting off the table during anterior loading. A fixed load is applied to the handle and the position of the footplate relative to the position of the tibial pad is calculated and recorded.[1-4]

2.2.3 Electromyography

Electromyography (EMG) allows for instrumented recording and measurement of electrical activity within a muscle at rest and during contraction. This study used a portable Delsys (Delsys DE 2.1, Delsys Inc., Boston, MA- USA) EMG dry surface electrode unit. The areas for dry surface electrode placement were shaved and then cleansed with isopropyl alcohol to reduce skin impedance during testing. EMG signals were amplified to correct for gain (x 1000), filtered (6-400 Hz bandwidth), and digitized at a sampling rate of 1kHz.

2.3 Procedures

Prior to carrying out the arthrometry measurements, subjects were asked which foot they would use to kick a ball with. This leg was then used for all subsequent measurements. The test leg was then prepared for EMG electrode placement; for the gastrocnemius, the electrode was placed over the belly of the medial head, while another was placed over the tibialis anterior (Figure 2). Both placements were recommended by the SENIAM project (http://www.seniam.org/). A grounding electrode was placed on the patella. Special consideration was given to the electrode placement of the tibialis anterior because the tibial pad from the arthrometer was in a position to compress the electrode. Therefore, the electrode was positioned after the tibial pad from the arthrometer was secured (Figure 2).

Following EMG electrode placement, the first knee position condition was selected randomly. For the 0° flexion (complete extension position) subjects were asked to lie supine on the portable treatment table (Figure 3). For the 90° flexion position, a wooden bolster was placed on the portable treatment table and adjusted to maintain 90° of knee flexion during the arthrometric measurements (Figure 4). We realize that this testing position is not clinically viable, however it was necessary to accommodate the arthrometric laboratory setup, and enable us to recreate the bent knee test position. The ankle arthrometer was positioned in a manner previously described by Hubbard et al.[2] Subjects remained in 10° of plantar flexion to isolate the anterior talofibular ligament throughout the testing procedure. This ankle position was monitored by watching the built-in inclinometer on the custom LabVIEW program (National Instruments, Austin, TX) running the ankle arthrometer.

A total of three test trials were performed to simulate the anterior drawer and talar tilt tests using the ankle arthrometer. The anterior displacement occurred during loading to 130 N of force while IE motion was loaded to 4 Nm of force. Digital output for both parameters were carefully monitored using the arthrometer laptop computer. For each knee position condition (0° and 90° of flexion) two different sets of EMG activity were recorded. The order in which the data sets were collected was randomly assigned. The first set of data were collected while the subjects were asked to refrain from voluntary muscle contraction (relaxed). During this relaxed condition, only EMG data from the gastrocnemius were collected. The second set of EMG data were collected during a simulated muscle guarding condition. In order to determine the reference contraction to simulate muscle guarding, subjects were asked to maximally contract and pull their foot upward (dorsiflexion) and hold for a period of 4 seconds. The maximum value derived from this contraction served as the MVC and enabled us to determine the 30% value necessary for each simulated guarding trial. The 30% of MVC then served as our reference target for subjects to maintain during the simulated muscle guarding test trials. During each test trial, a line was displayed on the computer screen for the subjects to see and maintain the 30% MVC during the ankle arthrometry loading.

The average of three trials for anterior displacement and IE motion was taken at each knee position and this laxity measurement was used for subsequent data analysis. During each trial that included monitoring gastrocnemius activity (relaxed condition), EMG was recorded using an Analog-Digital converter and custom LabVIEW program. Peak EMG activity of the gastrocnemius from each trial was recorded and processed using the LabVIEW program. Raw data were processed by correcting for DC bias, correcting for gain (dividing by 1000) and then taking the Root Mean Square (RMS) over 100ms. The values were converted from volts to millivolts (mV). EMG activity during the simulated muscle guarding condition was used only to display the 30% target line and was not used in data analysis.

2.4 Statistical Analysis

We used SPSS software (version 20.0; SPSS Inc., Chicago, IL) for the statistical analysis. The dependent variables included anterior displacement (millimeters), IE motion (degrees), and peak EMG activity (millivolts). The independent variables included knee position (0° and 90° flexion), and testing condition (relaxed vs. simulated muscle guarding). Separate dependent samples t-tests were used to compare each of the dependent variables during the two different knee positions. An additional set of dependent samples t-tests were analyzed comparing the anterior displacement and IE motion measurements between the relaxed and simulated muscle guarding conditions at each knee position.

Chapter 3

RESULTS

Although anterior displacement was found to be significantly different at 90° knee flexion (Figure 5) (10.63 ± 2.30 mm) compared to 0° knee flexion (9.84 ± 2.23 mm) (t = -1.93, *P* = .007) with a small effect size (*d* = .33); we questioned the clinical significance of a difference less that 1.00 mm. Conversely, IE motion was significantly greater at 0° knee flexion (62.99 ± 11.89°) compared to at 90° knee flexion (53.78 ± 10.36°) (t = 6.58, *P* < .001) with a large effect size (*d* = 1.1) (Figure 6). Resultant peak EMG activity of the gastrocnemius during the anterior displacement trials was statistically different at 90° knee flexion (0.00901 ± 0.009 mV) versus 0° knee flexion (0.00687 ± 0.00487 mV) (t = -1.69, *P* < .001) with a small effect size (*d* = .29); however we again question the clinical significance of such a small difference (Figure 7). No significant difference was found for gastrocnemius peak EMG activity between IE motion trials at 90° knee flexion (0.00729 ± 0.00436 mV) versus 0° knee flexion (0.0073 ± 0.00669 mV) (t= .008, *P* = .689) (Figure 8).

As expected, simulated muscle guarding of the tibialis anterior significantly reduced (between 36-57% reduction) laxity reinforced by large effect sizes in all test conditions. Anterior displacement at 90° knee flexion reduced to 5.31 ± 1.73 mm (t = 11.58, *P* = .016, *d* = 2.4) and at 0° knee flexion reduced to 5.61 ± 1.51 mm (t = 14.23, *P* = .008, *d* = 2.1) (Figure 9). IE motion at 0° knee flexion reduced to 23.23 ± 7.72° (t = 20.12, *P* = .030, *d* = 3.4) and at 90° knee flexion to 21.04 ± 7.00° (t = 21.60, *P* = .001, *d* = 3.7) (Figure 10).

Chapter 4

DISCUSSION

The cornerstone of ankle sprain injury assessment relies heavily on proper execution of both the anterior drawer and talar tilt tests to gauge laxity and determine injury severity. Previous research demonstrated that knee position can alter laxity derived from these two tests.[1] Using similar methodology, we set out to determine whether or not these differences in laxity were the result of involuntary contraction of the gastrocnemius muscle.[1] Additionally we were interested in the effect of simulated muscle guarding on these clinical measures. Although our results determined a significant difference in anterior displacement between the two knee positions (0° and 90° flexion) we are not convinced that the small difference (.79 mm) is of any clinical significance, especially when the SD's for both means were in excess of 2.00 mm. Additionally, although peak EMG activity of the gastrocnemius during these trials was statistically significant, on close examination the difference between the means was extremely small (0.000414 mV) supported by a small effect size (*d*=.29). We contend that the peak gastrocnemius activity during these two different positions of knee flexion is negligible. This leads us to conclude that while performing the anterior drawer test in a clinical setting, the position of the knee may be of negligible influence as well. Conversely, the 9.21° difference in IE motion between 0° and 90° flexion may suggest that the talar tilt test is best performed while the knee is in the extended position. Additional evidence to support this was reinforced by the lack of differences in peak EMG activity of the gastrocnemius during this test condition.

Examination of the lateral ankle ligaments is critical following inversion ankle sprains. In manual examination clinicians use the anterior drawer and talar tilt tests to assess laxity of the lateral ankle ligaments.[7,13] These manual stress tests are heavily dependent on subjective measurement and can be hindered in reliability due to individual (clinician) error. The skill and experience of the clinician, patient-positioning deviations, and difficulty interpreting ligamentous end-feel reduce the reliability of manual examination.[1,3,7] The ankle arthrometer was invented to improve diagnostic reliability of ankle laxity testing. Ankle arthrometry provides instrumented measurement of ankle joint laxity and has been reported to have high validity and reliability for measurement of ankle joint laxity (ICC = .80-.99).[1,2,13] The limb positioning for manual stress tests varies in the literature between flexion and extension of the knee.[1,3,7,17] In addition to the previously mentioned challenges of manual examination of lateral ankle sprains, the effect of muscle guarding can reduce the reliability of laxity testing or altogether make manual examination extremely difficult. Muscle guarding occurs following acute ankle sprains and causes the injured athlete to submaximally contract the extrinsic muscles of the ankle resulting in increased joint stiffness.[13,18] No previous research has reported quantitative measurement of ankle laxity using an ankle arthrometer during submaximal contraction of the ankle musculature. Our intent was to measure ankle joint laxity during simulated muscle guarding to quantify how much ankle stiffness can reduce joint laxity compared to measures when the subject is relaxed.

We hypothesized that knee positioning would alter anterior displacement because of involuntary contraction of the gastrocnemius. Our results strongly support the findings of Kovaleski et al., who were the first to investigate differences in ankle laxity with varying knee and ankle positions using an ankle arthrometer identical to the one used in this study.[1] In fact, the difference in laxity between the 90° flexion and 0° flexion was very close to the difference reported in our study (1.61 vs 0.79 mm). Additionally their laxity values at 0° flexion (8.12 ± 2.1 mm) and 90° flexion (9.73 ± 2.3 mm) were nearly identical to those we report. Schwarz et al. reported normative values for anterior displacement ranging from 8.59-9.95 mm using 125N of anterior loading force (with the knee in full extension).[17] The values we report (Figure 5) at 0° flexion fall within this normative range reported by Schwartz et al.[17] These comparative findings point to the importance of standardizing loading forces as well as knee and ankle positioning; especially when comparing research trials.

Although our findings indicated that anterior displacement was different at 90° knee flexion, contrary to what we hypothesized peak EMG activity was slightly higher at 90° knee flexion (Figure 7). While values for peak EMG recording were calculated to be statistically different, the clinical significance of these values is questioned because the difference is almost negligible. This suggests that the influence of the gastrocnemius muscle as a counterforce to the anterior drawer motion is trivial. This is counter to the traditional biomechanical perspective whereas the gastrocnemius muscle is thought to be in a slackened position at 90° knee flexion and 10° plantar flexion. A 1999 report by Davis et al. examining Achilles tendon tension suggested that ankle positioning more so than knee positioning was the primary determinant for tension across the Achilles tendon. Based on their findings, ankle positioning greater than 20° of plantar flexion negates the effect of knee positioning on Achilles tendon tension.[16] Subjects in our study were positioned in 10° plantar flexion, therefore our different knee positions should have affected the EMG activity of the gastrocnemius, but no difference was observed. Our method of EMG recording involved surface EMG electrodes; considered to be an acceptable method in recording muscle activity. One might argue that indwelling EMG analysis may have provided a more accurate means of recording activity in the medial head of the gastrocnemius. However using such a technique in conjunction with the ankle arthrometer would have been very difficult from a methodological standpoint.

An unexpected finding was that IE motion was significantly higher at 0° knee flexion (62.99°) compared to 90° knee flexion (53.78) (Figure 6). This finding has the potential to impact traditional clinical practice with regard to the execution of the talar tilt test. We speculate that at the 90° knee flexion position involvement of monoarticular muscles (i.e. peroneals) along with increased stiffness from capsuloligamentous structures surrounding the ankle may have an effect on IE motion. We believe that this is the first study to report such a finding, and suggest additional study is warranted to determine a reasonable explanation. Again, referencing the normative values reported by Schwarz et al. (39.9-42.1°) our values compare favorably with those reported for IE motion using 4Nm for IE loading however, testing was performed with the knee in 10° to 20° of flexion.[17] When we compare our 0° knee flexion value (62.99°) to that reported by Hubbard et al.[4] taken in full knee extension (59.6 ± 7.5°) our IE motion is quite similar. When compared to our 90° knee flexion IE motion value (53.78°) it becomes apparent that as the knee joint moves from a position of full knee extension to a position of flexion, these IE motion values are changing.

Following acute lateral ankle sprain, muscle guarding produces a protective joint stiffness that attempts to resist deviation from the neutral joint position. The effect this joint stiffening has on ankle joint laxity has yet to be measured. Our test methodology enabled us to conveniently add this simulated muscle guarding component to our investigation. We selected 30% MVC of the tibialis anterior for our simulated muscle guarding condition for several reasons. First, the weight of the arthrometer and pressure from the foot clamps and tibial pad caused the subjects to activate the dorsiflexors in some capacity (<15% MVC). Additionally, pilot testing demonstrated that testing with % MVC greater than 40% made laxity testing unreliable or impossible. The active stiffness created by the subject past 40% MVC was greater than or equal to the forces applied by the examiner to appropriately move the arthrometer through the necessary testing motions. Hunter et al. described 30% MVC as an accurate representation of active stiffness allowing normal reflex contraction of the lower leg muscles when an external force is applied to the ankle joint.[11] Therefore we settled on 30% MVC as our simulated muscle guarding condition. Our results determined that maintaining 30% MVC of the tibialis anterior muscle greatly reduced ankle laxity (both anterior displacement and IE motion). This finding suggests that muscle guarding can significantly reduce ankle joint laxity. From a clinical perspective, this has implications when performing the anterior drawer and talar tilt tests during ankle injury evaluation. This further stresses the importance to the clinician to perform these two tests very early in the acute stages following ankle injury before muscle guarding takes hold. Furthermore, our study demonstrates that the ankle arthrometer can be used for acute assessment of laxity when the joint is guarded and follow-up comparison days after the injury is possible to determine the extent of injury or to assess treatment outcomes.

We acknowledge the following limitations of our study. Our anterior loading force of 130N is different from other studies that loaded between 100N and 125N.[4,17] Additionally during the simulated muscle guarding condition, we did not monitor gastrocnemius EMG activity and acknowledged the fact the cocontraction of the antagonist muscle could have affected the laxity measurements. Furthermore due to the inability to simultaneously sync the EMG and arthrometer signals together, we instead relied on verbal "start" and "stop" cueing from the examiner to an assistant who controlled the LabVIEW program for EMG recording. This may have resulted in minor timing error between the two signals. Baseline MVC of the gastrocnemius was not recorded for comparison to the findings of peak EMG values during the relaxed condition. Although we speculate that the low peak EMG values for the involuntary gastrocnemius muscle are extremely small, without gastrocnemius MVC values we cannot say with a level of certainty that this is true.

The prevalence at which ankle sprains occur in the athletic population stresses the importance for accurate clinical diagnosis. The anterior drawer and talar tilt tests are used often by athletic trainers to initiate early ankle sprain treatment. The results of this research effort suggests that the anterior drawer test can be performed with the knee in either a bent or straight position. However talar tilt testing should be performed with the knee extended. Further investigation is needed to explain the differences found in IE motion at each knee position. Research focused on muscle guarding and its effects on ankle laxity is needed to better understand the findings of our study.

Chapter 5

FIGURES

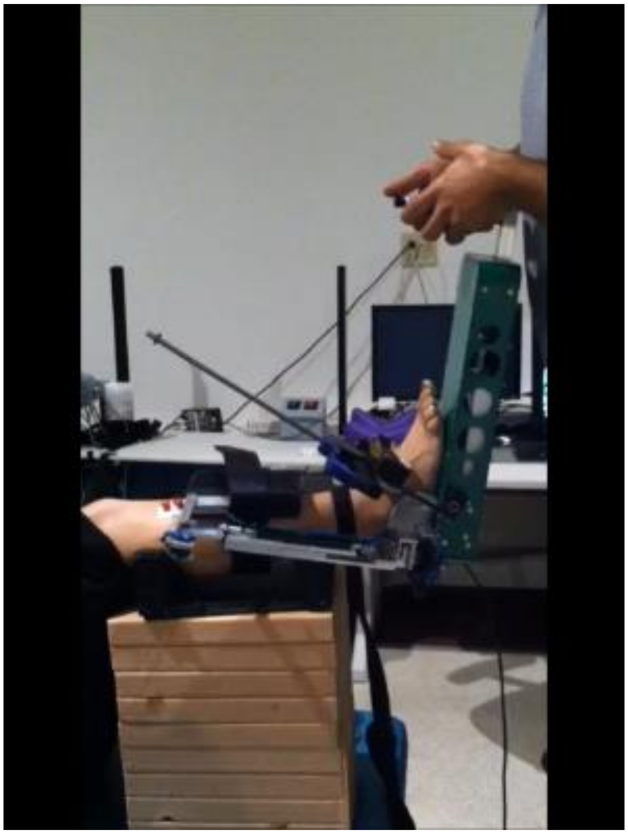

Figure 1: Ankle Arthrometer.

Figure 2: Electrode placement for the tibialis anterior muscle (left). Electrode placement for the gastrocnemius muscle (right).

Figure 3: 0° knee flexion testing position.

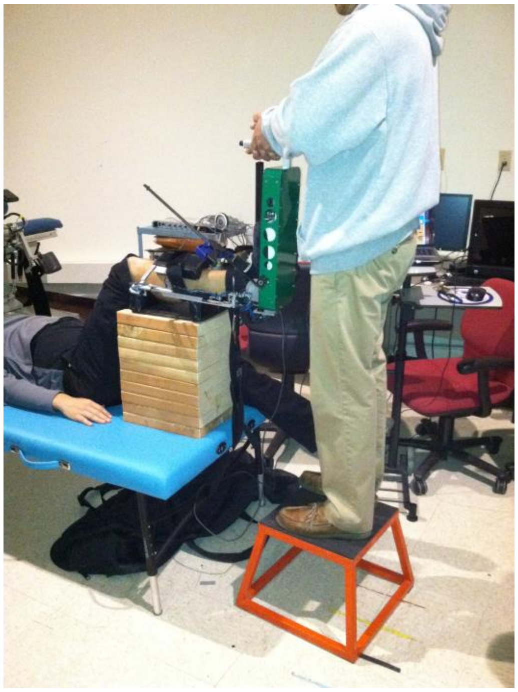

Figure 4: 90° knee flexion testing position.

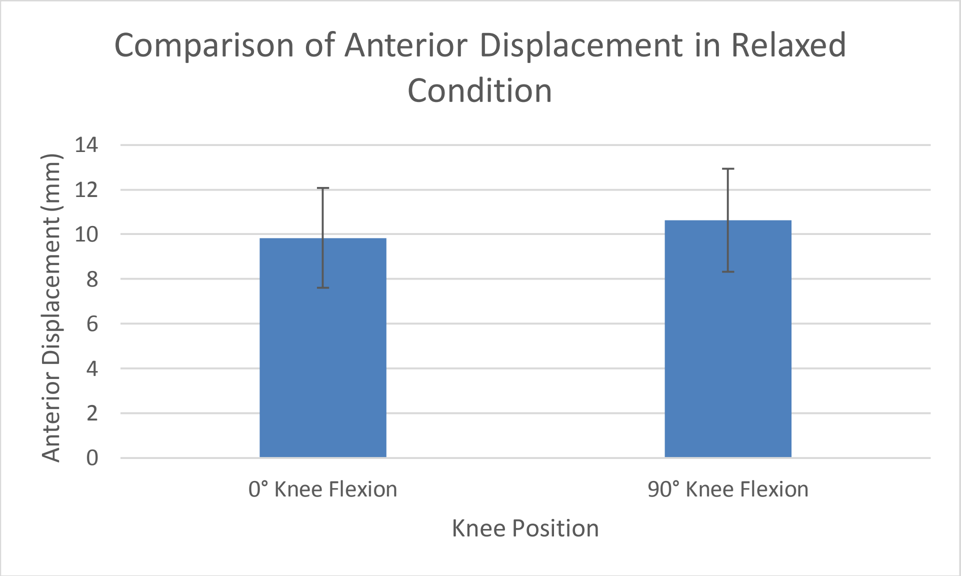

Figure 5: Anterior displacement was significantly different at 90° knee flexion (10.63 ± 2.3 mm) compared to 0° knee flexion (9.84 ± 2.23 mm).

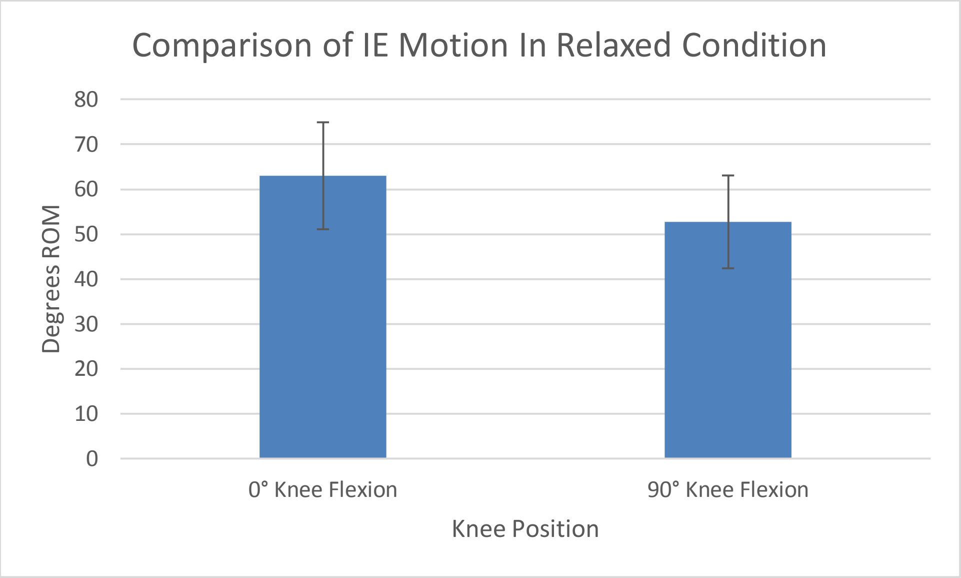

Figure 6: IE Motion was significantly greater at 0° knee flexion (62.99 ± 11.89°) compared to 90° knee flexion (53.78 ± 10.36°).

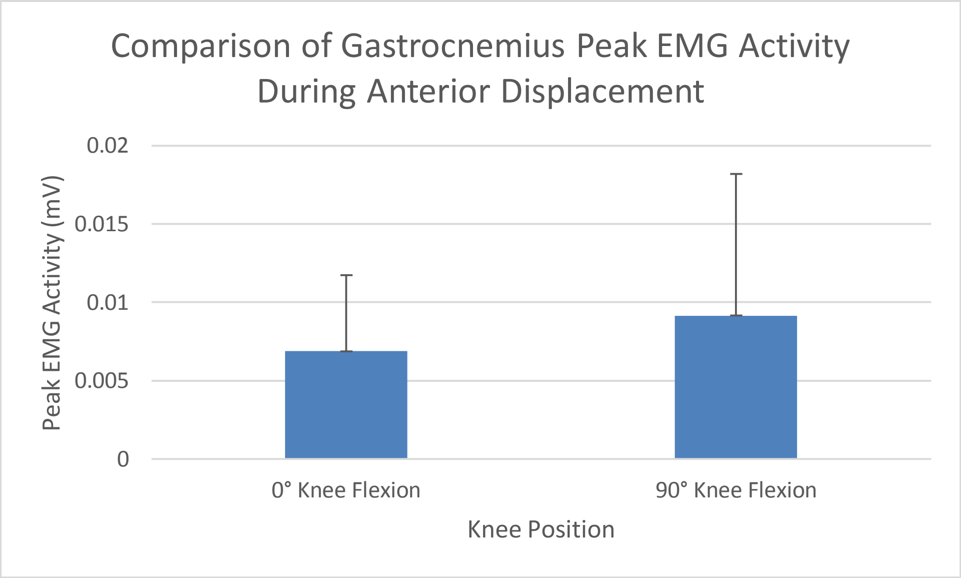

Figure 7: Peak EMG activity of the gastrocnemius (during anterior displacement) was significantly lower at 0° knee flexion (0.00687 ± 0.00487 mV) compared to 90° knee flexion (0.00902 ± 0.00903 mV).

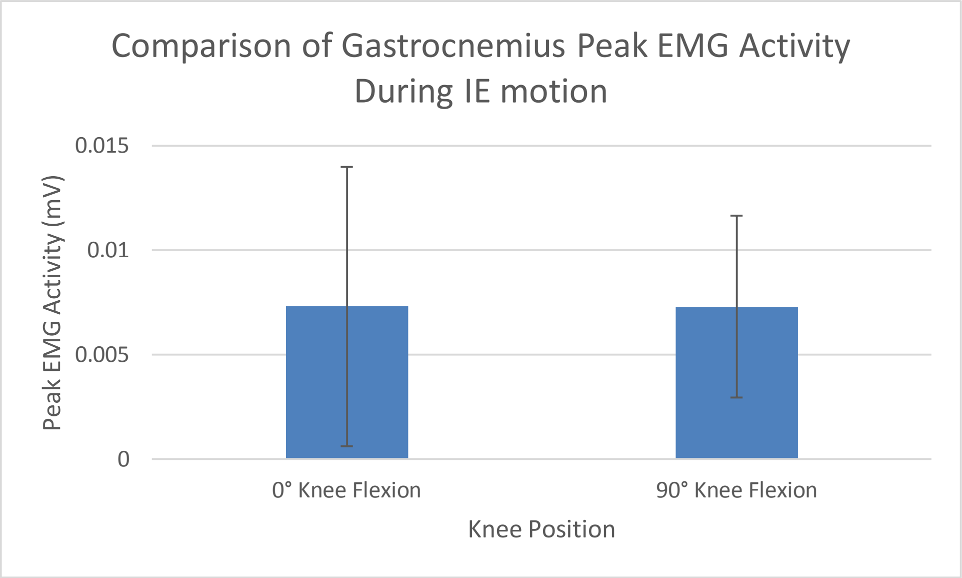

Figure 8: No significant difference was found gastrocnemius peak EMG activity (during IE motion) at 0° knee flexion (0.00729 ± 0.00436 mV) compared to 90° knee flexion (0.0073 ± 0.00669 mV).

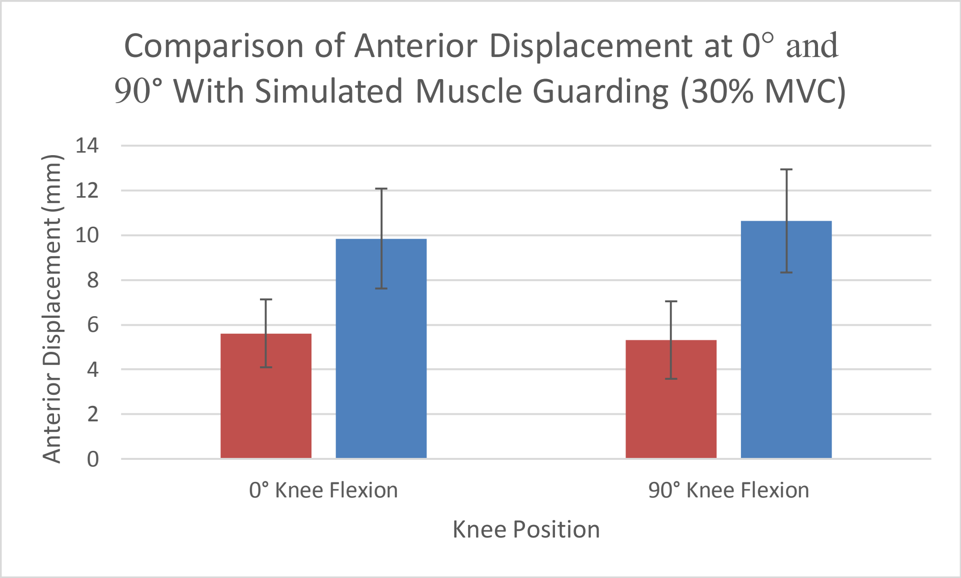

Figure 9: Anterior displacement was significantly decreased in the simulated muscle guarding condition compared to the relaxed condition for 0° knee flexion (5.61 ± 1.73 mm) and also for 90° knee flexion (5.31 ± 1.51 mm).

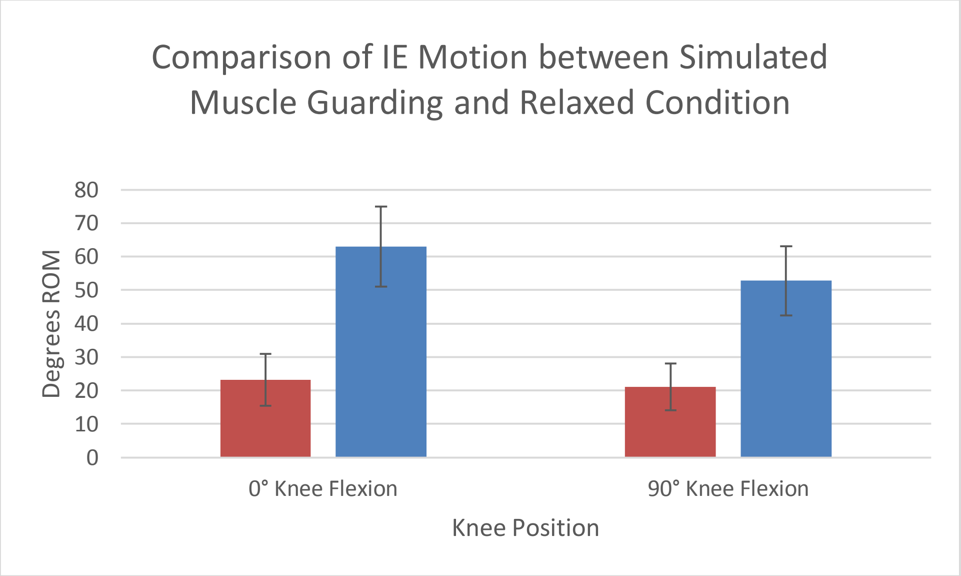

Figure 10: IE motion was significantly decreased in the simulated muscle guarding condition compared to the relaxed condition for 0° knee flexion (23.23 ± 7.71°) and also for 90° knee flexion (21.04 ± 7.00°).

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Appendix A

INFORMED CONSENT FORM

RESEARCH STUDY: Examining Ankle Joint Laxity using Two Different Knee Positions and With Simulated Muscle Guarding (HSIRB # 440092-1)

INVESTIGATORS: Shawn Hanlon (graduate student), Jaclyn Caccese (doctoral student), and Thomas Kaminski, Ph.D (professor) in the Department of Kinesiology and Applied Physiology.

WHAT IS THE PURPOSE OF THIS STUDY?
The purpose of this study is to compare the looseness of the ankle joint at different knee positions with foot relaxed and while contracting your ankle muscles using a device that is able to measure this looseness.

WHAT WILL YOU BE ASKED TO DO?
You are being asked to take part in this study because you have not sustained an injury to your ankles in the past 6 months. You will be one of thirty-four (17 male, 17 female) participants between the ages of 18-25, from the University of Delaware. In addition, you will be asked to fill out a foot and ankle survey, which asks you to rate your pain (if any) during daily activities. You must score at least 95 out of 100 to be included in this study. You will be excluded from the study if you have a history of any knee or ankle injury or surgery in the past 6 months.
This study is voluntary and requires you to participate in a single 30 minute session. After signing this consent form, you will be asked to fill out a foot and ankle pain survey which asks about pain you may experience during daily activities. All testing will be performed in the Human Performance Laboratory at the University of Delaware. Your leg hair will need to be shaved and the skin will need to be cleaned with an alcohol pad in five locations on your dominant lower leg. This is necessary to ensure good contact of the muscle sensors to the skin. The pads will monitor the electrical activity when a muscle is being used. Your foot will be placed on the footpad of the ankle arthrometer and will be secured to your foot by an adjustable heel cup and a soft adjustable clamp over the top of your foot. A third pad will be wrapped to your shin with an elastic strap. Your leg will be strapped to the table to using an adjustable strap to secure your leg from lifting off of the table during testing. We will be measuring the looseness of your ankle in two directions, shifting forward and backward and rotating side to side. Measurements will be taken with you in two positions: First seated with your knee straight and your ankle off the edge (Figure A),

and second lying on your back with your leg bent and resting on a stand (Figure B). In each testing position, measurements will be taken in two conditions: with you contracting your ankle muscle to meet a low level of effort (target line will be displayed on a computer screen), and again with you being asked not to flex any muscles.

WHAT ARE THE POSSIBLE RISKS AND DISCOMFORTS?

You may experience some stretch discomfort at the end range of motion of the measurements. However there is no risk of injury and any discomfort you might experience will be momentary. There are limits in place for the amount of force applied to your ankle that eliminate the risk of injury as a result of testing.

WHAT ARE THE POTENTIAL BENEFITS?

You will not benefit directly from taking part in this research. Your participation in this study will benefit future research in recognizing ankle ligament sprains using the ankle arthrometer.

HOW WILL CONFIDENTIALITY BE MAINTAINED?

Data will be kept confidential and your information will be assigned a code number. The list connecting your name to this number will be kept in a locked file. When the study is completed and the data have been analyzed, the list will be destroyed. Data will be kept securely in electronic storage formats and saved indefinitely. Your name will not be used in any report. We will make every effort to keep all research records that identify you confidential to the extent permitted by law. In the event of any publication or presentation resulting from the research, no personally identifiable information will be shared. Your research records may be viewed by the University of Delaware Institutional Review Board, but the confidentiality of your records will be protected to the extent permitted by law.

WILL THERE BE ANY COSTS RELATED TO THE RESEARCH?
There are NO costs associated with your participation.

WILL THERE BE ANY COMPENSATION FOR PARTICIPATION?
You will receive no payment for participating in the study.

WHAT IF YOU ARE INJURED BECAUSE OF THE STUDY?
If you are injured during research procedures, you will be offered first aid at no cost. If you require additional medical treatment, you will be responsible for the cost.

DO YOU HAVE TO TAKE PART IN THIS STUDY?
Taking part in this research study is entirely voluntary. You do not have to participate in this research. If you choose to take part, you have the right to stop at any time. If you decide not to participate or if you decide to stop taking part in the research at a later date, there will be no penalty or loss of benefits to which you are otherwise entitled. Your refusal will not influence current or future relationships with the University of Delaware. As a student, if you decide not to take part in this research, your choice will have no effect on your academic status or your grade in the class.

WHO SHOULD YOU CALL IF YOU HAVE QUESTIONS OR CONCERNS?
If you have any questions about this study, please contact the Principal Investigator, Shawn Hanlon at 856-404-1322, hanlon@udel.edu or the Advisor, Dr. Thomas W. Kaminski at 302-831-6402 or kaminski@udel.edu.
If you have any questions or concerns about your rights as a research participant, you may contact the University of Delaware Institutional Review Board at 302-831-2137. Your signature below indicates that you are agreeing to take part in this research study. You have been informed about the study's purpose, procedures, possible risks and benefits. You have been given the opportunity to ask questions about the research and those questions have been answered. You will be given a copy of this consent form to keep.
By signing this consent form, you indicate that you voluntarily agree to participate in this study.

________________________________	______________
Signature of Participant	Date

____
Printed Name of Participant

Appendix B

FAOS QUESTIONNAIRE

Foot and Ankle Outcome Score (FAOS), English version LK1.0 1
FAOS FOOT & ANKLE SURVEY
Todays date: _____/______/______ Date of birth: _____/______/______
Name: ____

INSTRUCTIONS: This survey asks for your view about your foot/ankle. This information will help us keep track of how you feel about your foot/ankle and how well you are able to do your usual activities. Answer every question by ticking the appropriate box, only one box for each question. If you are unsure about how to answer a question, please give the best answer you can.

Symptoms

These questions should be answered thinking of your foot/ankle symptoms during the **last week**.

S1. Do you have swelling in your foot/ankle?
Never Rarely Sometimes Often Always

_ _ _ _ _
S2. Do you feel grinding, hear clicking or any other type of noise when your foot/ankle
moves?
Never Rarely Sometimes Often Always

_ _ _ _ _
S3. Does your foot/ankle catch or hang up when moving?
Never Rarely Sometimes Often Always

_ _ _ _ _
S4. Can you straighten your foot/ankle fully?
Always Often Sometimes Rarely Never

_ _ _ _ _
S5. Can you bend your foot/ankle fully?
Always Often Sometimes Rarely Never

_ _ _ _ _

Stiffness

The following questions concern the amount of joint stiffness you have experienced during the **last week** in your foot/ankle. Stiffness is a sensation of restriction or slowness in the ease with which you move your joints.

S6. How severe is your foot/ankle stiffness after first wakening in the morning?
None Mild Moderate Severe Extreme

_ _ _ _ _
S7. How severe is your foot/ankle stiffness after sitting, lying or resting **later in the day**?
None Mild Moderate Severe Extreme

_ _ _ _ _
Foot and Ankle Outcome Score (FAOS), English version LK1.0 2

Pain
P1. How often do you experience foot/ankle pain?
Never Monthly Weekly Daily Always

_ _ _ _ _
What amount of foot/ankle pain have you experienced the **last week** during the following activities?
P2. Twisting/pivoting on your foot/ankle
None Mild Moderate Severe Extreme

_ _ _ _ _
P3. Straightening foot/ankle fully
None Mild Moderate Severe Extreme

_ _ _ _ _
P4. Bending foot/ankle fully
None Mild Moderate Severe Extreme

_ _ _ _ _
P5. Walking on flat surface
None Mild Moderate Severe Extreme

_ _ _ _ _
P6. Going up or down stairs
None Mild Moderate Severe Extreme

_ _ _ _ _
P7. At night while in bed
None Mild Moderate Severe Extreme

_ _ _ _ _
P8. Sitting or lying
None Mild Moderate Severe Extreme

_ _ _ _ _
P9. Standing upright
None Mild Moderate Severe Extreme

_ _ _ _ _

Function, daily living
The following questions concern your physical function. By this we mean your ability to move around and to look after yourself. For each of the following

activities please indicate the degree of difficulty you have experienced in the **last week** due to your foot/ankle.
A1. Descending stairs
None Mild Moderate Severe Extreme

_ _ _ _ _
A2. Ascending stairs
None Mild Moderate Severe Extreme

_ _ _ _ _
Foot and Ankle Outcome Score (FAOS), English version LK1.0 3
For each of the following activities please indicate the degree of difficulty you have experienced in the **last week** due to your foot/ankle.
A3. Rising from sitting
None Mild Moderate Severe Extreme

_ _ _ _ _
A4. Standing
None Mild Moderate Severe Extreme

_ _ _ _ _
A5. Bending to floor/pick up an object
None Mild Moderate Severe Extreme

_ _ _ _ _
A6. Walking on flat surface
None Mild Moderate Severe Extreme

_ _ _ _ _
A7. Getting in/out of car
None Mild Moderate Severe Extreme

_ _ _ _ _
A8. Going shopping
None Mild Moderate Severe Extreme

_ _ _ _ _
A9. Putting on socks/stockings
None Mild Moderate Severe Extreme

_ _ _ _ _
A10. Rising from bed
None Mild Moderate Severe Extreme

_ _ _ _ _
A11. Taking off socks/stockings
None Mild Moderate Severe Extreme

_ _ _ _ _
A12. Lying in bed (turning over, maintaining foot/ankle position)
None Mild Moderate Severe Extreme

_ _ _ _ _
A13. Getting in/out of bath
None Mild Moderate Severe Extreme

_ _ _ _ _

A14. Sitting
None Mild Moderate Severe Extreme

_ _ _ _ _

A15. Getting on/off toilet
None Mild Moderate Severe Extreme

_ _ _ _ _

Foot and Ankle Outcome Score (FAOS), English version LK1.0 4
For each of the following activities please indicate the degree of difficulty you have experienced in the **last week** due to your foot/ankle.

A16. Heavy domestic duties (moving heavy boxes, scrubbing floors, etc)
None Mild Moderate Severe Extreme

_ _ _ _ _

A17. Light domestic duties (cooking, dusting, etc)
None Mild Moderate Severe Extreme

_ _ _ _ _

Function, sports and recreational activities

The following questions concern your physical function when being active on a higher level. The questions should be answered thinking of what degree of difficulty you have experienced during the **last week** due to your foot/ankle.

SP1. Squatting
None Mild Moderate Severe Extreme

_ _ _ _ _

SP2. Running
None Mild Moderate Severe Extreme

_ _ _ _ _

SP3. Jumping
None Mild Moderate Severe Extreme

_ _ _ _ _

SP4. Twisting/pivoting on your injured foot/ankle
None Mild Moderate Severe Extreme

_ _ _ _ _

SP5. Kneeling
None Mild Moderate Severe Extreme

_ _ _ _ _

Quality of Life

Q1. How often are you aware of your foot/ankle problem?
Never Monthly Weekly Daily Constantly

_ _ _ _ _

Q2. Have you modified your life style to avoid potentially damaging activities

to your foot/ankle?
Not at all Mildly Moderately Severely Totally

_ _ _ _ _
Q3. How much are you troubled with lack of confidence in your foot/ankle?
Not at all Mildly Moderately Severely Extremely

_ _ _ _ _
Q4. In general, how much difficulty do you have with your foot/ankle?
None Mild Moderate Severe Extreme

_ _ _ _ _
Thank you very much for completing all the questions in this questionnaire. Questionnaire and User's Guide can be downloaded from: www.koos.nu

Appendix C

SPECIFIC AIMS

Lateral ankle sprains are one of the most frequent acute injuries in the physically active population due to the structure of the ankle joint.[1,2,5,6,8,12,13,18] Manual examination is utilized to assess the extent of injury to that ankle following injury. The presence and amount of joint laxity dictates the degree of injury to the lateral ankle ligaments. Clinicians use the anterior drawer and talar tilt tests to recognize mechanical ligament laxity. These manual stress tests are clinically useful when combined with a full manual examination, however the tests are highly subjective and vary in reliability based on the individual clinician's skills and experience with ligamentous end-feels. Furthermore, these stress tests are performed with variations in patient-positioning and are debated in literature.[1,5,14] Another encumber of manual examination is the presence of muscle guarding. Muscle guarding is a protective stiffening of the ankle to resist motion following injury. No previous research has investigated the effects of muscle guarding on ankle joint laxity. Previous research has demonstrated that the positioning of the knee joint can cause a significant difference in ankle joint laxity.[1] There is no reported evidence to explain why knee flexion positioning has an effect on the measurement of ankle joint laxity. Original research has indicated that involuntary muscle activity of the gastrocnemius muscle. With the use of electromyography (EMG), muscle activity of the gastrocnemius will be recorded while measuring anterior displacement (in millimeters), total inversion-eversion (in degrees of motion) on healthy subjects with a portable ankle arthrometer in two knee positions. Additionally, ankle laxity will be measured in a simulated muscle guarding condition and compared in each knee position to the relaxed condition laxity values.

The aim of this study is to determine if there is a difference in EMG activity of the gastrocnemius when testing lateral ankle ligament laxity (anterior displacement and total inversion-eversion) at 90° and 0° of knee flexion and to compare ankle laxity measurements when relaxed to laxity during simulated muscle guarding.

The study will be conducted using 16 male and 17 female volunteer healthy subjects from the University of Delaware. Participants will be deemed healthy if they report no record of previous ankle pathology in the past 6 months and score a 95 +/- 5 on a subjective Foot and Ankle Outcomes Score (FAOS).[9] Using an ankle arthometer, measurement of anterior displacement and total inversion-eversion of the foot will be compared at 0° and 90° knee flexion while simultaneously recording EMG activity of the gastrocnemius muscle for comparison. Additionally using EMG biofeedback, measures of anterior displacement and IE motion will be compared to the values recorded when the subject is asked to dorsiflex their ankle at 30% of their Maximal Voluntary Contraction (MVC).

Specific Aim 1: To determine if there is a difference in ankle laxity and peak gastrocnemius activity at 0° and 90° knee flexion during instrumented ankle arthrometry measurement

Hypothesis 1: The ankle complex will present the most laxity at 90° knee flexion and lower peak EMG activity compared to 0° knee flexion.

Specific Aim 2: To quantify the difference in ankle laxity measurement during 30% MVC of the tibialis anterior compared to no contraction.

Hypothesis 2: Voluntary muscle contraction of the tibialis anterior will reduce anterior displacement and IE motion compared to measurements taken when the subject is relaxed.

Appendix D

BACKGROUND AND SIGNIFICANCE

Ankle sprains are one of the most common acute injuries in the physically active population.[1,2,5,6,8,13,14] Following ligamentous injury to the ankle, it is essential that ankle laxity be assessed to determine the extent of damage incurred. Clinicians rely on manual examination to assess the integrity of the lateral ankle ligaments. Two of the most common manual stress tests are the anterior drawer and talar tilt tests, which are quantified by bilateral comparison.[14] These stress tests are performed with the application of an anterior load or an inversion-eversion rotation to the foot, respectively. The anterior drawer test is used to assess the integrity of the anterior talofibular ligament (ATFL) and the talar tilt (inversion) test assesses the calcaneofibular ligament (CFL). The reliability of these tests varies between clinicians due to differences in technique, clinical experience, presence of muscle guarding.[13,15] The anterior drawer test has been reported to range in sensitivity from 32% to 80%.[12,13] The talar tilt test has been reported to have a sensitivity of 52%.[12,13] Both tests when combined with patient history are clinically useful, however they remain arbitrary and subjective in measurement based on clinician sensitivity and experience. The ankle arthrometer was developed to improve the diagnostic reliability of ankle laxity testing and to study the effect of ligament sectioning on the load-displacement characteristics of the ankle joint complex both in vitro and in vivo.[12] The reliability of the ankle arthrometer has been reported to have ICCs of .80-.98 (good to excellent) for intertester and intratester reliability.[2]

Mechanical ankle instability has been found to be facilitated by pathologic laxity, arthrokinematic restrictions, degenerative changes, and synovial changes to the joint.[13] The interests of this study focused on the causes of ligamentous laxity or joint hypermobility in healthy ankles and therefore it is important to identify the structures that dictate ankle laxity and stability. Mobility in the ankle joint is allowed by accessory motions of the subtalar and talocrural joints.[13] The subtalar joint allows the triplanar motions of pronation and supination (Figure 1).[12,13] The talocrural joint allows voluntary plantar flexion and dorsiflexion (Figure 2).[12,13] Hertel et al. identifies the components of ankle stability: When loaded, the subtalar and talocrural joints both convert torque between the lower leg (internal and external rotation) and the foot (pronation and supination).[12] When fully loaded, the articular surfaces are the primary stabilizers against talar rotation and translation. The talocrural joint receives ligamentous support from the ATFL, CFL, PTFL (posterior talofibular ligament), and joint capsule. The subtalar joint receives ligamentous support from three groups of ligaments: deep ligaments, peripheral ligaments, and retinacula. The deep ligaments act as cruciate ligaments resisting supination. The peripheral ligaments prevent inversion and internal rotation. The fibers of the inferior extensor retinacula have also been shown to help in subtalar stabilization. The musculotendinous units surrounding the ankle are of interest in this study in their role of dynamic protection of the ankle joint.[10] The eccentric functions of the peroneals and muscles of the anterior compartment are integral in the control of forced rearfoot supination.[13] Additionally, the motor nerve supply to the muscles (tibial, deep peroneal, and superficial peroneal) and sensory nerve supply (mix of three motor nerves, sural, and saphenous) play a role in joint stability.[12,13] The subtalar and talocrural joints have been shown to be richly innervated by ligamentous and musculotendinous mechanoreceptors which contribute to proprioception input in the foot and ankle which alter reflexive response of the muscles acting on the ankle.[12,13]

It has been determined by Kovaleski et al. through arthrometric measurement that when assessing ankle laxity, varied knee and ankle positions can produce significant differences in measurement of total anterior displacement and total IE range of motion (ROM).[1] These two laxity measurements are identical mechanics to the anterior drawer and talar tilt stress tests. Respectively, Kovaleski et al. compared ankle laxity measurements at 90° knee flexion and 0° knee flexion and 0° and 10° ankle plantar flexion.[1] It was found that the ankle yielded the largest range of anterior displacement when subjects were placed in 90° of knee flexion and 10° ankle plantar flexion. No previous research has investigated differences in IE motion at different knee positions. No definitive explanation was provided as to why this knee and ankle positioning produces greater laxity than the other variables. A proposed explanation to accredit the differences found in ankle laxity is involuntary activity of the gastrocnemius muscle which is slackened in knee flexion.[1,17,20] Flexing the knee likely relaxes the gastrocnemius-Achilles tendon and reduce tightness at the ankle, while placing the muscle on stretch (knee extended versus knee flexed) will strain the parallel elastic component of the tissue itself and the surrounding fascia.[1,14]

Electromyographic (EMG) recording of the gastrocnemius will be used to monitor electrical activity produced from the muscle when it contracts and relaxes while measuring anterior displacement and IE motion at both knee positions to determine differences in muscle activation. Research on ankle laxity using EMG primarily focuses on the eccentric activation of the peroneal muscles in the prevention of injury.[16] No previous study has investigated muscle activity of the gastrocnemius during instrumented laxity testing.

As previously stated, measurement of ankle laxity can be difficult if muscle guarding occurs. Muscle guarding as explained by Hubbard et al. is thought to be caused by altered proprioceptive input from the musculotendinous and ligamentous mechanoreceptors around the ankle.[14] The increase in stiffness to the joint capsule is relayed to γ-motorneurons of the muscles and tendons that cross the ankle joint, which reduce the threshold of muscle spindle activation facilitating contraction from stabilizing muscles. Muscle guarding creates increased global joint stiffness and apprehension to joint motion, making physical examination difficult. It is common for an athlete or patient to be apprehensive to ligamentous stress testing by contracting the tibialis anterior and assisting ankle dorsiflexors to increase joint stiffness. This investigation attempted to quantify how much ankle laxity is reduced by muscle guarding. To measure the difference in ankle laxity (anterior displacement and IE motion), subjects were tested once while contracting their ankle dorsiflexors at 30% of voluntary contraction (MVC) and again no muscle contraction of the dorsiflexors.

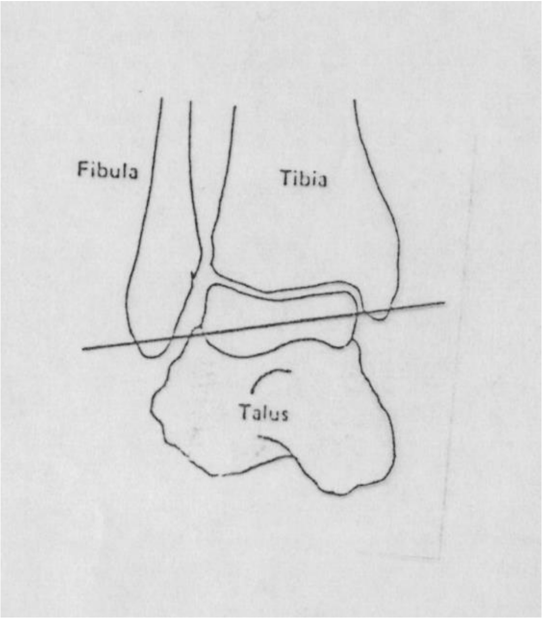


Figure D.1: Talocrural joint axis of rotation. [12,13]

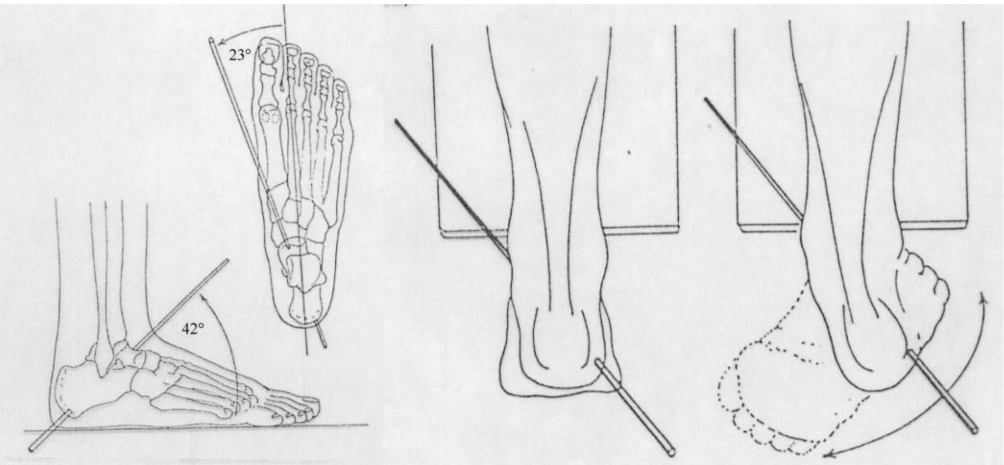
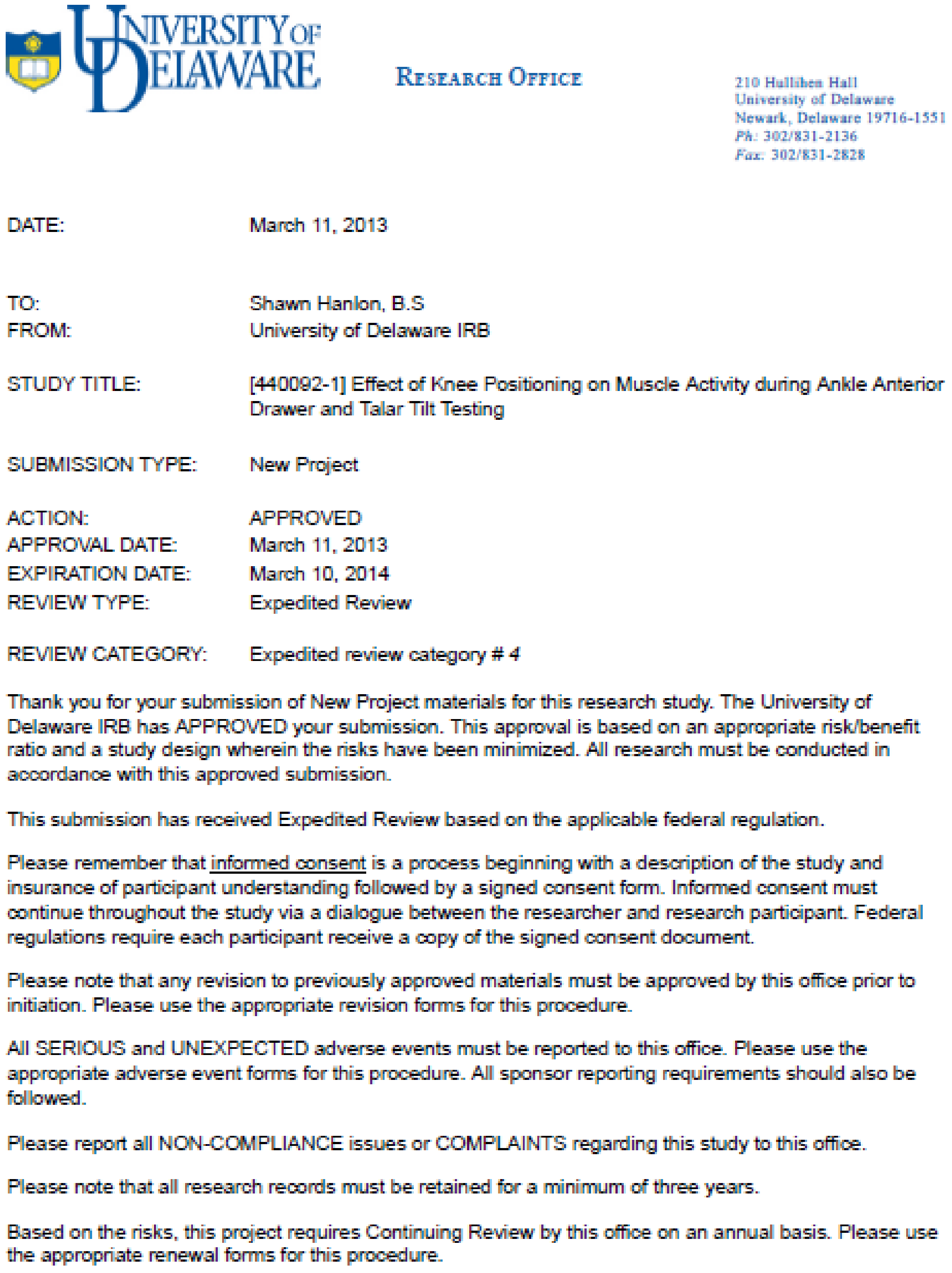


Figure D.2: Subtalar joint axis of rotation.[12,13]

Appendix E

IRB LETTER



UNIVERSITY OF DELAWARE

RESEARCH OFFICE

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DATE:	March 11, 2013
TO:	Shawn Hanlon, B.S
FROM:	University of Delaware IRB
STUDY TITLE:	[440092-1] Effect of Knee Positioning on Muscle Activity during Ankle Anterior Drawer and Talar Tilt Testing
SUBMISSION TYPE:	New Project
ACTION:	APPROVED
APPROVAL DATE:	March 11, 2013
EXPIRATION DATE:	March 10, 2014
REVIEW TYPE:	Expedited Review
REVIEW CATEGORY:	Expedited review category # 4

Thank you for your submission of New Project materials for this research study. The University of Delaware IRB has APPROVED your submission. This approval is based on an appropriate risk/benefit ratio and a study design wherein the risks have been minimized. All research must be conducted in accordance with this approved submission.

This submission has received Expedited Review based on the applicable federal regulation.

Please remember that informed consent is a process beginning with a description of the study and insurance of participant understanding followed by a signed consent form. Informed consent must continue throughout the study via a dialogue between the researcher and research participant. Federal regulations require each participant receive a copy of the signed consent document.

Please note that any revision to previously approved materials must be approved by this office prior to initiation. Please use the appropriate revision forms for this procedure.

All SERIOUS and UNEXPECTED adverse events must be reported to this office. Please use the appropriate adverse event forms for this procedure. All sponsor reporting requirements should also be followed.

Please report all NON-COMPLIANCE issues or COMPLAINTS regarding this study to this office.

Please note that all research records must be retained for a minimum of three years.

Based on the risks, this project requires Continuing Review by this office on an annual basis. Please use the appropriate renewal forms for this procedure.

If you have any questions, please contact Jody-Lynn Berg at (302) 831-1119 or jlberg@udel.edu. Please include your study title and reference number in all correspondence with this office.