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THE DIFFERENCE IN IMMEDIATE CHANGES IN DORSIFLEXION
RANGE OF MOTION USING AN ULTRASOUND HEAT
TREATMENT, FOLLOWED BY TWO DIFFERENT STRETCHING
TECHNIQUES

presented by

Gregory Dale Hawthorne JR., ATC.

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of the requirements for the

M.S. degree in Kinesiology



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**THE DIFFERENCE IN IMMEDIATE CHANGES IN DORSIFLEXION
RANGE OF MOTION USING AN ULTRASOUND HEAT TREATMENT,
FOLLOWED BY TWO DIFFERENT STRETCHING TECHNIQUES**

By

Gregory Dale Hawthorne Jr., ATC

A THESIS

**Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of**

MASTER OF SCIENCE

Kinesiology

2008

ABSTRACT

THE DIFFERENCE IN IMMEDIATE CHANGES IN DORSIFLEXION RANGE OF MOTION USING AN ULTRASOUND HEAT TREATMENT, FOLLOWED BY TWO DIFFERENT STRETCHING TECHNIQUES

By

Gregory Dale Hawthorne Jr., ATC

Purpose: The purpose of this was to investigate and compare the effects of a therapeutic ultrasound treatment followed by a hold-relax stretching technique or a static stretching technique on ankle dorsiflexion range of motion.

Methods: A total of 28 participants volunteered for this study. All participants were administered a therapeutic ultrasound treatment to their triceps surae muscle group and then either received a hold-relax stretch or a static stretch. Dorsiflexion range of motion was measured pre and post treatment using the VICON motion capture software.

Results: Participants in the hold-relax stretch group experienced statistically significantly larger increases in active dorsiflexion and the participants in the static stretch group.

Conclusion: The combination effect of a therapeutic ultrasound treatment and a hold-relax stretch will elicit a greater increase in active dorsiflexion and the combination of a therapeutic ultrasound treatment and a static stretch. The current findings offer support to the use of the hold-relax stretching protocol used in this study. The findings also offer more information about the use of the VICON system.

ACKNOWLEDGEMENTS

I am not a very wordy person thus this will be short. I would however like to thank all my friends and classmates. I appreciate all the help that you provided on my journey in completing my thesis, without you do not think I would have been able to do it, especially you Jeremy and Amanda.

I would like to thank my committee members Dr. Roger Haut, Dr. Sally Eaves Nogle, and Dr. John Powell. To Dr. Haut, I want to thank you for taking on my project even though you had no clue of who I was. To Dr. Sally Nogle if it was not for you I would still be performing PNF stretching techniques improperly. Thank you for your wisdom support and upbeat and no-nonsense attitude. To Dr. Powell thank you for walking me through the thesis process. I know I tested your patience at times and I thank you for seeing me through. To all my committee members thank you for being so patient, understanding and flexible.

I would like to thank John Mukavich for his assistance with my research and also for his friendship. John you helped me stay focused and put in the hours needed to collect the data in such a short time, thank you so very much.

Special thanks goes to Jerrod Braman without your knowledge and expertise I would not have been able to complete my project. Thank you for being a friend and taking so much time out of the little available that you have. You made the long nights more enjoyable, guy.

I would also like to thank all the participants for volunteering for the study.

TABLE OF CONTENTS

LIST OF TABLES.....	vi
 CHAPTER 1	
INTRODUCTION.....	1
Overview of the Problem.....	1
Significance of the Problem.....	2
Problem Statement.....	5
Hypothesis.....	5
Definition of Terms.....	5
 CHAPTER 2	
LITERATURE REVIEW.....	8
Review of Content Literature.....	8
Static Stretching.....	8
Static Stretching Effects on Muscle Flexibility.....	9
Proprioceptive Neuromuscular Facilitation Stretches.....	9
PNF Stretching: Hold Relax Mechanisms.....	11
PNF Stretching Techniques' Effect on Muscle Flexibility.....	12
Therapeutic Ultrasound Mechanics.....	13
Ultrasound as a Thermal Modality.....	14
Thermal Modality Effects on Muscle Extensibility.....	16
Review of Method Literature.....	16
Thermal Modality Coupled with Stretch.....	16
Ultrasound and Stretching.....	17
Vicon Motion Capture System.....	18
Summary.....	19
 CHAPTER 3	
METHODS.....	21
Participants and Sampling Methods.....	21
Selection Criteria.....	21
Sampling Methods.....	21
Informed Consent.....	21
Assignment of Groups.....	22
Instrumentation.....	22
Ultrasound Device.....	22
Ultrasound Template.....	22
Vicon Motion Capture System.....	22
Orthopedic Incline Board.....	23
Treatment Protocol.....	23
Testing Procedures.....	23
Range of Motion.....	23
Ultrasound Protocol.....	24

Static Stretching Protocol.....	24
PNF Stretching Protocol.....	25
Research Design.....	26
Threats to Internal Validity.....	26
Threats to External Validity.....	27
Data Collection.....	27
Data Management.....	27
Data Analysis.....	27
 CHAPTER 4	
RESULTS.....	30
Demographic Information.....	30
Groups Comparison.....	31
Static Stretch Data.....	34
Hold Relax Data.....	35
Treatment Comparisons.....	3
 CHAPTER 5	
DISCUSSION.....	38
Analysis of ROM Gains.....	38
Utilization and Clinical Interpretation of Results.....	42
Limitations.....	43
Future Research Considerations.....	44
Conclusion.....	44
 APPENDICES.....	
A. Informed Consent.....	46
B. Demographic Data.....	50
C. BMI Chart.....	52
 REFERENCES.....	54

LIST OF TABLES

Table	
3-1	Treatment Group Assignment..... 26
4-1	Normalized Descriptive Statistics for Tibia-Fibula Angle Loss by Group..... 31
4-2	Analysis of Variance for Tibia-Fibula Angle Loss between Groups..... 32
4-3	Normalized Descriptive Statistics for Tibia-Fibula Angle Loss by Leg Dominance..... 33
4-4	Analysis of Variance for Tibia-Fibula Angle Loss Leg Dominance.... 34
4-5	Descriptive Statistics for Tibia-Fibula Angles of Static Stretch Group. 34
4-6	Paired T-test for Tibia-Fibula Angle Change for Static Stretch Group..... 35
4-7	Normalized Descriptive Statistics for Tibia-Fibula Angles of Hold-Relax Group..... 35
4-8	Paired T-test for Tibia-Fibula Angle Change for the Hold-Relax Group..... 36
4-9	Paired Samples T-test with Bonferroni Correction for Passive Tibia-Fibula Angle Change between Hold-Relax and Static Stretch Groups..... 36
4-10	Paired Samples T-test with Bonferroni Correction for Active Tibia-Fibula Angle Change Between Hold-Relax and Static Stretch Groups..... 37

Chapter I Introduction and Purpose

Overview of problem

The primary purpose of injury rehabilitation is to restore the body to normal or optimal function. Many injuries require immobilization during the healing process. This immobilization or injury may cause the connective tissue to progressively shorten; causing joint contractures and adhesions in the muscle that can cause a decrease in range of motion (ROM) (Butler, Moyer, Quedenfeld, & Sapega, 1981; Eagan, Heatherington, Lentell, & Morgan, 1992; Kottke, Paulley, D.L., & Ptak, 1966; W. Prentice, 2003). When this occurs there is a need to increase the ROM of the affected joint. Research shows that passive stretch alone has been effective in increasing ROM in humans (Hallium, Madding, Medeiros, & Wong, 1987; McCullogh, Pfeiffer, & Worrell, 1994). Research also shows that flexibility can be even further increased if heat modalities are coupled with passive stretching (Brashear, Taylor, & Waring, 1995; Brucker, Draper, Knight, & Rubley, 2005; DeVane, Hylton, & Wessling, 1987; Kottke, et al., 1966). There are still very few studies on the affect of heat modalities coupled with stretching on their combined ability to increase flexibility. While there is an array of different stretching techniques that are utilized in today's rehabilitative medicine, most of the research still focuses on static/passive stretching techniques. Various Proprioceptive Neuromuscular Facilitation (PNF) stretching techniques have been proven to be more effective than static stretching on increases of ROM (W. Cornelius & Hands, 1992; Spernoga, Uhl, Arnold, & Gansneder, 2001). There is no research that shows

the effect of various types of Proprioceptive Neuromuscular Facilitation (PNF) stretching techniques coupled with ultrasound (US).

Significance of Problem

Athletic Trainers have the ethical obligation to give their patients the best possible treatment available. When an athlete is injured and immobilized, scar tissue, adhesions, shortening of connective tissue, or contractures may occur (Butler, et al., 1981; Eagan, et al., 1992; Kottke, et al., 1966; W. Prentice, 2003). It is at this point that it is essential for the athletic trainer to restore the ROM of the injured patient to normal. In order for the athletic trainer to restore ROM they may use various methods of stretching, massage, treatment modalities, either singularly or in combination.

Restoration of range of motion is a pivotal part of rehabilitation. When rehabilitation programs are being created the first goal of the clinician is to regain ROM. ROM is needed to decrease the risk of re-injury (Pope, Herbert, & Kirwan, 1998) , strength gains are severely limited when ROM is not restored to an injured area (Bennell, Khan, Matthews, & Singleton, 2001) and restoration of ROM is essential to return to daily function. Pope et al. examined lower leg injuries and ankle dorsiflexion in 1093 Australian army trainees as they went through the routine twelve-week army training, to assess if decreases in ankle range of motion can be a predictor of injury. The results of the study showed that with a decrease in ankle dorsiflexion ROM there is an increase of 250% chance of injury.

The muscle length-tension relationship is a common known law in physiology that states; the amount of peak force a muscle can produce is related to its length, where the peak force lies where there is the greatest amount of myosin cross-bridging with actin filaments (Gordon, Huxley, & Julian, 1966). A decrease in muscle length (decreased ROM) will decrease the force production of a given muscle; this concept can be seen in research performed by Bennell et. al. (2001). Bennell's team examined 53 female dancers (ages 8-11) hip and ankle ROM and hip strength over a period of 12 months. The results showed that with an increase in active hip internal rotation ROM there was a significant increase in the strength of the hip internal rotator muscles. This increase in strength gain can be attributed to the length-tension relationship.

There are many different stretching techniques, static, passive, ballistic, active, and PNF that can be used by clinicians during the rehabilitation of injured individuals, to increase joint ROM or flexibility of the muscle. Research already supports that PNF stretching techniques increase ROM significantly greater than static, passive, or ballistic stretching techniques (Ekblom, Grahn, Nordenborg, & Wallin, 1985; Etnyre & Abraham, 1986; Hansen, Osternig, Robertson, & Troxel, 1990; Sady, Wortman, & Blanke, 1982; Spornoga, et al., 2001; Tanigawa, 1972). Though studies have shown the effects of PNF stretching, many clinicians continue the use of other forms of stretching techniques during the rehabilitation of their patients. It is common for clinicians to couple various treatment modalities with stretching protocols that have been proven to increase the extensibility of tissue (Brashear, et al., 1995; Draper, Castel, & Castel, 1995;

Gersten, 1955; Kottke, et al., 1966; Reed & Ashikaga, 1997; Warren, Lehmann, & Koblanski, 1971). This combination therapy of a therapeutic heat treatment modality and static stretching has been shown to elicit a greater increase in ROM than stretching alone (Anderson, Draper, Ricard, & Schilthies, 1998; Bandy & Irion, 1994; Bandy, Irion, & Briggler, 1998). Many clinicians may continue the use of static stretching due to the research supporting the increase of ROM when coupled with a therapeutic heating treatment modality, such as diathermy and/or US. PNF has been proven to increase ROM greater than static stretching alone, however there has been no studies comparing the PNF vs. static stretching coupled with an US treatment. An investigation needs to be conducted in order to distinguish whether PNF stretching will have a greater increase in ROM when coupled with US compared to static stretching coupled with US. This will provide clinicians the knowledge to make better decisions on what the best possible treatment is for their patient.

A clinician needs to restore the patient's body to optimal restoration following injury and restoring ROM is a pivotal component in doing so. A decrease of ROM can lead to increased injury and decreased strength thus inhibiting the patient's ability to return to their previous quality of life. A combination of US and stretching should be used in order to increase ROM so that the restricted segment may be actively worked in a greater ROM. Due to the lack of research, clinicians may be inhibiting the speed of patient recovery time by not utilizing PNF stretching techniques coupled with an US treatment, but continue to use static stretch techniques.

Problem Statement

The purpose of this study is to compare the range of motion (ROM) in ankle dorsiflexion after an US treatment immediately followed by the hold-relax PNF stretching technique or an US treatment immediately followed by a static stretch. The ROM will be measured through the use of the VICON motion capture system, the VICON Nexus software, the VICON Body Builder Software, and Microsoft Excel (VICON, Oxford, UK).

Hypothesis

a. Ultrasound followed immediately by a hold-relax proprioceptive neuromuscular facilitation stretching technique will elicit a greater increase in active ankle dorsiflexion range of motion than an ultrasound treatment immediately followed by a static stretch routine.

b. Ultrasound followed immediately by a hold-relax proprioceptive neuromuscular facilitation stretching technique will elicit a greater increase in passive ankle dorsiflexion range of motion than an ultrasound treatment immediately followed by a static stretch routine.

Definition of Terms

1. Proprioceptive Neuromuscular Facilitation: Methods of promoting or hastening the response of the neuromuscular mechanism through stimulation of proprioceptors (M. a. V. Knott, D. E., 1968)
2. Proprioceptive: Receiving stimulation within the tissues of the body (M. a. V. Knott, D. E., 1968)

3. Neuromuscular: pertaining to the nerves and muscles (Dorland, 1965)
4. Facilitation: The promotion or hastening of any natural process; the reverse of inhibition (Buchwald, 1967)
5. Passive Range of Motion (PROM): Movement induced in an articulation by the operator. This includes the range of active motion as well as the movement between the physiologic and anatomic barriers permitted by soft-tissue resiliency that the patient cannot do voluntarily. (E. & Greenman, 2003).
6. Active Range of Motion (AROM): Movement of an articulation between the physiologic barriers limited to the range produced voluntarily by the patient (E. & Greenman, 2003).
7. Pathological: altered or caused by disease; being such to a degree that is extreme, excessive, or markedly abnormal ("Dictionary," 2008).
8. Agonist: The targeted muscle or muscle that is currently being acted upon.
9. Antagonist: The opposing muscle of the agonist muscle (i.e. agonist-Triceps Surae: Antagonist-Anterior Tibialis).
10. Reciprocal Inhibition: The contraction of muscles is accompanied with the simultaneous inhibition of their antagonist (Sherrington, 1947).
11. Autogenic Inhibition: Reduction in excitability of a contracted or stretched muscle (Laporte & Lloyd, 1952).
12. Golgi Tendon Organ (GTO): Joint receptors that are located in the body that sense tension, and respond by inhibiting the contractility of muscle.
13. Isometric Contraction: A muscle contraction in which no motion is gained.

- 14. Isotonic Contraction: A muscle contraction in which muscle is shortened.
- 15. Concentric Contraction: An isotonic contraction in which the muscle shortens.
- 16. Eccentric Contraction: An isotonic contraction in which the muscle lengthens.
- 17. Body Mass Index (BMI): Is a statistical measure of the weight of a person compared to their height, The World Health Organization's measure for obesity.

Chapter II

Review of Literature

Lack of flexibility has been commonly suggested as a predisposing factor in many muscle strains and other injuries (Agre, 1985; Bassett, Califf, & Garret, 1984; Perrin & Worrell, 1992). Clinicians have historically considered flexibility training to be a key component in the prevention and rehabilitation of injuries, and also a great method to improve athletic performance (Coole & Geick, 1987; W. L. Cornelius, 1989; W. E. Prentice, 1983; Sady, et al., 1982). Clinicians use a variety of different muscle stretching techniques to accomplish the goal of increased flexibility to improve performance or to restore the patient to normal ROM (Ekblom, et al., 1985; Hansen, et al., 1990; W. E. Prentice, 1983; Surburg & Schrader, 1997; Tanigawa, 1972). Clinicians have also begun to couple thermal modalities with stretching routines to increase the ROM gain after the stretch regimen.

Review of Content Literature

Static Stretching Muscles and tendons are known to have both viscous and elastic properties (Chalmers, 2004; Magnusson, 1998). The viscous properties of the muscle tendon unit are the physiological action known as stress relaxation. Stress relaxation is characterized by the fact that if a muscle is being stretched with a sustained force, then the force being created by the viscous material to resist elongation decreases over time (Magnusson, et al., 1997; Taylor, Dalton, Seaber, & Garrett, 1990). Due to the property of stress relaxation, the elastic properties of muscles and tendons can react, this is

explained by the creep property which states if a force attempting to stretch a muscle is sustained, the muscle will gradually elongate (Stromberg & Wiederhielm, 1969). These properties explain how a static stretch creates increases in ROM.

Static Stretching Effects on Muscle Flexibility. Static and passive stretching techniques are a common solution to increase the flexibility of patients and athletes (Corbin & Noble, 1980). Studies have shown that passive or static stretching has been proven to significantly increase ROM (Hallium, et al., 1987; McCullogh, et al., 1994). A study by (Depino, Webright, & Arnold, 2000) has shown that the effects of this static stretch last for 3 minutes. Depino et.al. researched 30 collegiate military cadets' (ages 19 ± 5.1) hamstring flexibility. All subjects lacked 20 degrees of active knee extension and full extension was considered 180 degrees with hip at 90. There were 15 subjects placed in an experimental group, which underwent a stretching protocol consisting of four 30-second static hamstring stretches with 15 seconds of rest between each stretch. The 15 other subjects did not undergo the stretching protocol. The results of the study showed that this static stretch protocol significantly increased knee extension (5.6 degrees) for 3 minutes. While static stretching techniques are probably the most commonly used technique of stretching, studies have shown that PNF stretching techniques, primarily hold-relax techniques, elicit better results (Holcomb, 2000; W. E. Prentice, 1983; Spornoga, et al., 2001).

Proprioceptive Neuromuscular Facilitation Stretches. Proprioceptive Neuromuscular Facilitation (PNF) development began with the defined meanings

of the concepts “neuromuscular facilitation” and “inhibition” in early 1900’s by Sir Charles Sherrington. These definitions led to the development of PNF stretching by Dr. Herman Kabat and Maggie Knott (H Kabat, 1947). These stretching techniques were originally used to treat patients with spasticity and paresis by either facilitating muscle elongation , through advanced inhibitory mechanisms and/or improving the strength of the affected muscle through increased excitatory mechanisms (H. Kabat & Knott, 1953; M. Knott, 1952). The use of PNF stretching techniques on patients without neurological pathology soon followed (M. Knott & Barufaldi, 1961; Voss, Knott, & Kabat, 1955).

PNF stretching techniques are commonly known as “hold-relax, “contract-relax” and “contract-relax-agonist-contrast” (Etnyre & Abraham, 1986; Surburg & Schrader, 1997; Wenos & Konin, 2004). These stretching techniques use the diagonal patterns used for all PNF techniques and stress the use of all three planes of motion (Adler, Beckers, & Buck, 1993). The techniques of “contract-relax” and “hold-relax” are generally considered to involve a procedure that passively places the agonist muscle in a stretched position and then followed by an isometric contraction. Once the contraction is released, the cycle is finished with a passive stretch to acquire a range of motion (ROM) position (Etnyre & Abraham, 1986; Ferber, Osternig, & Gravelle, 2002; Hanten & Chandler, 1994; Holcomb, 2000). The technique that is generally referred to as, “contract-relax-agonist-contrast” technique is very similar to what is known as the “contract-relax” and “hold-relax” methods except that after the isometric contraction of the agonist there is a concentric contraction of the antagonist into new position for

the ROM (Rowlands, Marginson, & Lee, 2003). These terms used to describe PNF stretching techniques, though popular are incorrect, yet, the procedures that are described and commonly used are correct. The procedures that are described as “hold-relax, “contract-relax” and “contract-relax-agonist-contract” are actually the PNF technique known as hold-relax (Adler, et al., 1993). A passive stretch, following an isometric contraction, should only be used if the patient has a pathological issue with their antagonist muscle. The actual contract-relax technique is similar to the hold-relax technique, where there is only an isometric contraction of the agonist. With hold-relax, there is actually an isotonic contraction of the rotators, followed by an isometric contraction of the agonist, and finally the patient isotonicly contracts the antagonist into the new ROM (Adler, et al., 1993). There is no PNF technique that is actually termed “contract-relax-agonist-contract”.

PNF Stretching: Hold Relax Mechanisms. There is no concrete explanation of how the PNF stretching techniques actually increase ROM, only theories. The commonly accepted explanations for the neurophysiological responses are the concepts of autogenic inhibition and reciprocal inhibition (Chalmers, 2004).

Autogenic inhibition refers to a reduction in excitability of a contracted or stretched muscle. This decrease in excitability is attributed to the increased inhibitory signal from the Golgi tendon organ (GTO) (Laporte & Lloyd, 1952). The reduced firing of the muscle caused by the autogenic inhibition allows the muscle resting length to be reset at an elongated state (Laporte & Lloyd, 1952).

The GTO's have a lower threshold in response to a contraction compared to that of a stretch. Autogenic inhibition creates a window after an isometric contraction in which the agonist can increase its length.

As defined earlier, the contraction of muscles accompanied with the simultaneous inhibition of their antagonist is reciprocal inhibition (Sherrington, 1947). This effect occurs because the descending commands that activate the motoneurons of the contracting muscle also innervate input to the *Ia*-inhibitory interneurons that synapses into the motoneurons of the antagonist muscle. This action can be even more affected by the increased innervation of the contracting muscles *Ia*-afferents converging on the same *Ia*-inhibitory interneurons (Katz, Penicaud, & Rossi, 1991; Laporte & Lloyd, 1952). During a hold-relax stretch when the antagonist muscle isotonically contracts the agonist muscle receives signals to decrease contractility, thus allowing for an increase in ROM.

PNF Stretching Techniques' Effect on Muscle Flexibility. Proprioceptive Neuromuscular Facilitation (PNF) stretching techniques are currently increasing in popularity amongst clinicians based on survey by (Surburg & Schrader, 1997). PNF stretching has been shown to cause a greater increase of ROM when compared to static, passive, or ballistic stretching routines (Etnyre & Abraham, 1986; Sharman, Cresswell, & Riek, 2006; Tanigawa, 1972). A study by (Spernoga, et al., 2001) researched 30 collegiate military cadets (ages 18.8±.63) hamstring flexibility. All subjects lacked 20 degrees of active knee extension; full extension was considered 180 degrees with hip at 90. There were 15 subjects placed in an experimental group, that underwent a modified-hold-

relax stretching protocol that consisted of an investigator applying a passive stretch to the hamstring for 7 seconds, the subject then maximally isometrically contracted the hamstring for 7 second followed by a 5 second rest, then the investigator passively stretched the hamstring for 7 seconds, this was repeated 5 times. The fifteen other subjects lay supine for 5 minutes. The results showed that hamstring flexibility was significantly increased (2.33 degrees) for 6 minutes following a modified hold-relax stretching protocol. This result proved to be twice as long as the static stretch duration that was found by the (Depino, et al., 2000)) study which was very similar in design. This could be why the use of the hold-relax technique is quickly becoming the most frequent PNF stretching technique used by clinicians (Surburg & Schrader, 1997). However, even with these results the static stretch is still used more frequently than hold-relax techniques. This could be for many different reasons, from clinicians not having knowledge of hold-relax techniques, from inadequate clinician to patient ratio, the ability of the patient to perform static stretch without assistance, or it could be due to the studies that have been published stating the effects of coupled heat therapy and static stretch regime.

Therapeutic Ultrasound Mechanics. Ultrasound is defined as inaudible, acoustic vibrations of high frequency that may produce either thermal or non-thermal physiologic effects. The sound waves created by ultrasound travel by use of longitudinal waves. The vibrations created by the sound waves enter into the tissue and cause compression and rarefactions of the molecules of the tissue. This vibration of the molecules increases the temperature of the tissue.

As the sound waves enter into denser tissue there is greater absorption of energy, increase vibration, which leads to increase in temperature (W. Prentice, 2003).

The ultrasound machines create acoustic energy through the conversion of electrical energy. Electrical energy is converted to acoustic energy in the transducer, also referred to as the applicator. Within the transducer lies a piezoelectric crystal. When alternating electrical current generated at the same frequency as the crystal resonance is passed through the piezoelectric crystal, the crystal will expand and compress creating a reverse piezoelectric effect. The crystal will expand and contract at the same frequency as the electrical current causing vibration and thus the acoustic energy that we consider ultrasound. The waves that are produced from the piezoelectric crystal have a frequency between .75 and 3.0 MHz. (W. Prentice, 2003).

The energy output of an ultrasound transducer comes from the effective radiating area (ERA) and is used when determining the intensity. The ERA is a measure of the rate at which energy is being delivered per unit area. This area is usually smaller than the actual transducer head (W. Prentice, 2003).

Ultrasound as a Thermal Modality. Therapeutic ultrasound has been used extensively to treat many conditions due to its thermal effects (Draper, 1998).

The thermal effects of ultrasound are generated through the use of the continuous treatment protocol opposed to the pulsed treatment. Ultrasound has been shown to increase tissue temperature up to 5 cm deep with very little increase in skin temperature (Draper, et al., 1995; Draper, et al., 1998; Lehmann,

DeLateur, & Silverman, 1966). Studies have shown that with various increases in tissue temperature different physiological characteristics change (Forrest & Rosen, 1989; Lehmann, Delateur, Stonebridge, & Warren, 1967; Lehmann, DeLateur, Warren, & Stonebridge, 1967). Studies have shown that the viscoelastic properties of collagen are altered when the tissue reaches temperatures above 39.6 degrees C.

When performing an ultrasound treatment in order to cause an increase in temperature to a specific tissue, specific settings must be used, with frequency being one of the most important. The frequency setting depends on the depth of penetration of the target tissue. The lower the frequency the deeper the penetration (W. Prentice, 2003). The depth of ultrasound penetration is usually described in half-values, or the depth at which 50% of the energy has been dissipated (Draper, et al., 1995). Ultrasound machines have been noted to produce thermal effects between 1 and 2 half-value depths. Where 1 MHz has a half-value of 2.5cm and 3 MHz has a value of 1.6. A study by (Hayes, Merrick, Sandrey, & Cordova, 2004) has shown that an ultrasound treatment, with the settings of 3 MHz, 1.5 w/cm², and treatment area of 2 times transducer creates vigorous heating, and increase of 4 degrees C, at 2.5 cm deep in 4 minutes.

A coupling medium must be used with an ultrasound treatment in order to effectively allow transmission of sound waves into the tissue (W. Prentice, 2003). Several studies have shown that the use of a room temperature ultrasound gel is the most effective medium (Bishop, Draper, Knight, Brent Feland, & Eggett, 2004; Oshikoya, et al., 2000).

Thermal Modality Effects on Muscle Extensibility. The use of heat modalities to improve stretching has become common practice to the clinician. Heat is said to lessen nerve sensitivity, increase blood flow, increase tissue metabolism, decrease muscle spindle sensitivity to stretch, cause muscle relaxation, and increase tissue flexibility (Eagan, et al., 1992). It has been shown that when coupled with static stretching the application of heat modalities has increased ROM, greater than static stretching alone (Anderson, et al., 1998; DeVane, et al., 1987; Draper, Knight, L., Peres, & Ricard, 2002).

Ultrasound treatment is a commonly used modality by clinicians for treating soft tissue injuries, (Draper, et al., 1995), joint dysfunctions (Draper, et al., 1995; Reed & Ashikaga, 1997), and other musculoskeletal injuries (DeLateur & Lehmann, 1990; J.C., 1993). Studies have shown that US increases the extensibility of non-human tissue (Gersten, 1955; Warren, et al., 1971). A study by (Anderson, et al., 1998) has shown that static stretching immediately following an US treatment significantly increased ankle dorsiflexion ROM greater than static stretching alone. There are no studies examining the effects of a hold-relax stretching protocol coupled with an US treatment.

Review of Method Literature

Thermal modality coupled with Stretch. As stated earlier there are several studies that address effects of thermal modalities and their effects on ROM when coupled with stretching. Some of these studies used a weight pulley system to cause a static stretch (Brucker, et al., 2005; DeVane, et al., 1987; Draper, et al., 2002), while others used the participants own body weight

(Anderson, et al., 1998). These studies also used different measuring devices either an inclinometer (Anderson, et al., 1998; Brucker, et al., 2005; Draper, et al., 2002) or a goniometer (DeVane, et al., 1987).

The coupling of a heat modality and the stretching regime also varied between studies. The studies either began the stretching routine during the treatment (Brucker, et al., 2005; DeVane, et al., 1987; Draper, et al., 2002) or the participants started the stretching routine immediately following the application of the heat modality (Anderson, et al., 1998). All the results concluded that ROM is immediately increased more when a static stretch is coupled with a thermal modality rather than alone.

Ultrasound and Stretching. Research shows that with proper application of therapeutic US the muscle tissue temperature can increase 3-6 degrees Celsius and the tendon 5-8 degrees Celsius (Chan, Draper, Measom, & Myrer, 1998). Research also shows that when stretch is applied to non-human tissue at this temperature permanent elongation is a result (Gersten, 1955; Warren, et al., 1971). These same studies also suggest that if stretch is applied at the peak temperature less tissue damage will occur. The temperature changes in human tissue that occur as a result of an US treatment only last a few minutes (Draper, Durrant, Rose, & Schulthies, 1996; Draper & Ricard, 1995), and because of this the stretch must be applied immediately following treatment

In order to achieve these temperature changes the US parameters should be set at 3mhz continuous wave, a 1.5 w/cm² intensity, duration of 7 minutes and with a treatment area 4 times the head of the transducer(Anderson, et al., 1998).

These parameters will cause a deep heating effect in the muscle, and will allow the tissue to be stretched to a greater degree. Anderson et. al. examined the effects of US followed by a static stretch protocol of the triceps surae muscle group on ankle dorsiflexion range of motion. Forty healthy college aged (20.4 ± 2.5) subjects were used (Male=18, Female=22). The investigators placed 20 subjects in an experimental group and 20 in a control group. The experimental group was given an US treatment, while lying prone on treatment table, with the parameters aforementioned. Immediately following the US treatment the subjects underwent a static stretching protocol. This protocol consisted of two stretches, the first having the subjects stand upright with their knee in full extension, then leaning forward keeping their leg straight until discomfort, not pain. This position is held for 20 seconds and then followed by a ten second rest. The subject then performed the same stretch with their knee bent to 15 degrees and followed by a ten second rest. The static stretching protocol was repeated three more times. The control group was instructed to lie prone on a treatment table for 7 minutes and then immediately perform the same static stretching protocol as the experimental group. Ankle dorsiflexion ROM was measured prior to all treatment and immediately following treatment. ROM information was gathered through the use of an inclinometer. The results of the study showed that a static stretch, preceded by an US treatment, elicited a significantly greater increase in ankle dorsiflexion (US=3 degrees) ROM than with static stretch alone (SS=2 degrees).

Vicon Motion Capture System. The VICON system uses six cameras with infrared strobes to illuminate reflective markers placed on specific anatomical landmarks. The system assesses marker position within the global laboratory coordination. The system is used to track three-dimensional motion of the body segment(s) that are targeted by the reflective markers. The VICON system has been proven to be an accurate measuring tool for ankle motion (Kidder, Abuzzahab, Harris, & Johnson, 1996). Research studies have incorporated the use of this system with accurate results in assessing ankle kinematics (Canseco, Long, Marks, Khazzam, & Harris, 2007; Khazzam, Long, Marks, & Harris, 2007). Research has shown that the use of the VICON system is a useful tool in measuring range of motion (Ehara, Fujimoto, Miyazaki, Mochimaru, & S, 1997; Henmi, Yonenobu, Masatomi, & Oda, 2006). Henmi et. al. (2006) compared goniometric measurements and VICON measurements of elbow, hinge joint, extension and flexion. The results of the study showed high correlation (0.91) between the VICON measurements and the goniometer measurements.

Summary

It is known that stretching is a common practice in the field of athletic training. It is also known that stretching will increase flexibility and ROM, and when coupled with a therapeutic heating modality the effect of a static stretch is enhanced. It has been shown that a PNF hold-relax stretch can cause larger ROM increases that last twice as long as a static stretch. There is no research that assesses the effect of a PNF stretch coupled with a therapeutic heat modality. This lack of information can deter clinicians from utilizing the PNF

stretching techniques, which may decrease the quality of care that patients receive. Further research needs to be done in order to fill this gap in knowledge.

Chapter III

Methods

The purpose of this study is to assess the difference between the effects of a hold-relax stretch protocol and a static stretch protocol, both being preceded by an US treatment, on dorsiflexion ROM. The treatment protocols were administered to the triceps surae muscle group

Participants and Sampling Methods:

Selection Criteria. In order for a participant to have been considered for the study, the individual had to be between the ages of 18-25 years old with a calculated BMI that was below 30 (APPENDIX C). Any perspective subject was eliminated from the pool of applicants if the individual had any form of ankle or lower leg musculoskeletal injury within the last 6 months, if they had ever had surgery on one of their ankles or lower leg, or if the test put the individual at any increased risk (allergy to ultrasound gel, connective tissue disorders, etc.) There were twenty-eight subjects included in the project.

Sampling Methods. Participants were recruited through the use of convenience sampling by verbally asking individuals to participate and by posting sign-up sheets in athletic training rooms across the university. All participants were students of a large mid-western university

Informed Consent. After participants were chosen for the study, the study procedures were explained to the participants verbally and by way of a document that accompanied the sign-up sheet. The subjects signed an informed consent

sheet upon their arrival to the testing site (Appendix A). All subjects had the ability to drop out of the study at any point in time.

Assignment of groups. The study used a counterbalanced experimental research design. The participants acted as their own control group and were randomly assigned to the four study groups based on their dominant leg and the two treatment protocols. (Table 3-1). Assignment of treatments was determined by time slot, with each successive person being in a different group, there were 4 groups. The groups contained the subjects of the same number, ex. Subject 2 was in group 2, and every 4 subjects there after, ex. group 1 contained subjects 1, 5, 9, 13, 17, 21, and 25.

Instrumentation

Ultrasound Device. The ultrasound device used was a Dynatron 150 ultrasound machine (Dynatronics, Salt Lake City, UT). The Dynatron 150 was used for the therapeutic ultrasound treatment protocols. The machine was used to increase the tissue temperature of the triceps surae muscle group.

Ultrasound Template. A template that measures 4 times the head of the US transducer was cut out of cast padding. This template was used to ensure that all subjects received an ultrasound treatment that covered the same area.

Vicon Motion Capture System (VICON, Oxford, UK): 6 Vicon Mx3 cameras were used to capture the motion of the ankle joint. The pictures are then processed in the VICON software, Vicon Nexus and Vicon Bodybuilder. This software is used to interpret the data captured by the VICON cameras and calculate the angle of the ankle

Orthopedic Incline Board (Incline Board Company, East Lansing, MI).

This incline board was used to perform the static stretch protocol. The incline board that was used is adjustable from the range of 15-30 degrees with 5-degree increments.

Treatment protocol

Testing Procedures. The testing began by measuring the subject's height and weight. The subjects' height and weight measurements were used to calculate their BMI using the following formula, $BMI = (\text{body weight in lbs.} \times 703) / (\text{height in inches})^2$. The participants completed a questionnaire of basic demographic information (APPENDIX B). The subjects were directed to lay prone on a treatment table. The motion analysis markers were placed on their right and left lower leg, ankle and foot. The markers were placed on the medial and lateral borders of the tibial plateau, on the calf musculature two inches below the joint line, the medial and lateral malleoli, the plantar and dorsal surfaces of the second metatarsal head, and on the lateral aspect of the head of the fifth metatarsal.

Range of Motion. Following the placement of the markers the subjects had their ankle dorsiflexion range of motion (ROM), both passive and active, measured with the patient lying prone using the VICON motion capture system. In order to achieve active ROM the subjects were asked to actively dorsiflex ankle as far as possible and hold that position for three seconds, all the time maintaining shin contact with the table. Passive ROM was achieved by having the investigator lie on his back, grasp the head of the second metatarsal between

the first and second phalange and the thumb of both hands, and applying a force that caused ankle dorsiflexion, using the foot as a lever arm. The ankle was passively dorsiflexed maximally and held for three seconds. The ROM measurements were taken only on the leg that was to receive treatment.

Ultrasound Protocol. After the markers were placed and ROM was measured the subject underwent the ultrasound protocol. First the US template was placed over the muscular tendinous junction of the triceps surae muscle group. This junction was found by having the subject actively plantarflex against a resistance provided by the investigator revealing the junction. The subjects then received an US treatment with the following parameters: 3 mhz, 1.5 Watts/cm², duration of 7 minutes, the transducer was moved with the approximate speed of 4 cm/sec. These parameters coupled with static stretch have been proven to significantly increase dorsiflexion ROM (Anderson, et al., 1998). This protocol first occurred on the leg that was randomly assigned as the first and then 30 seconds following the complete measurement of the first leg, testing was performed on the second leg.

The following stretching protocols were either performed on one leg or the other. The group that the subject was in decided the treatment technique that was used on the legs. This group assignment also determined which leg was treated first.

Static Stretching Protocol. Immediately following the US treatment the subject was instructed to stand upright and perform two different static stretches on an Orthopedic Incline Board (Incline Board Company, East Lansing, MI) that

was set with an angle of 30 degrees. The subject was instructed to place foot, of test leg, flat on slant board and to lean forward into stretch until discomfort is felt, but avoiding pain. The non-test foot was held above ground, having the subject bend their knee during stretch did this. The first stretch was performed for 20 seconds with knee in full extension, followed by a 10 second rest. The subject then performed another 20 second stretch this time with the knee bent at 15 degrees, followed by a 10 second rest. The subjects repeated this cycle three more times (4 minutes total). Ankle dorsiflexion PROM and AROM was then assessed immediately following stretch.

PNF Stretching Protocol. Immediately following the US treatment the subject was instructed to continue lying prone on the table. The investigator then put the subject through a hold-relax stretching regimen, as explained by (Adler, et al., 1993).

1. The investigator placed their hand on the ball of the subject's foot and had the subject actively the ankle into dorsiflexion.
2. When the ankle was maximally dorsiflexed the subject was instructed to isometrically plantarflex, invert, and internally rotate the ankle for 7 seconds, while the investigator allowed for no movement, contraction began light and became maximal to investigators force.
3. The participant and investigator then relaxed.
4. The participant was then immediately instructed to dorsiflex ankle into new range of motion and investigator followed with their hand, adding a passive stretch, which was held for 7 seconds.

5. Steps 2-4 were then repeated 6 more times (total time ~90 seconds).

Following hold-relax stretch regimen ankle dorsiflexion PROM and AROM was measured.

Research Design

The ultrasound treatment administered was an independent variable. Another independent variable was the stretch protocol that the subject underwent. The current study tests the effect of these independent variables on the dependent variable of ankle dorsiflexion range of motion. The design of this study is a quasi-experimental repeated-measures counterbalanced design (Table 3-1).

Table 3.1 Treatment Group Assignment

Treatment Group	Dominant Leg Hold-Relax	Non-Dominant Leg Hold-Relax	Dominant Leg Static	Non-Dominant Leg Static
Group 1	First	NA	NA	Second
Group 2	Second	NA	NA	First
Group 3	NA	First	Second	NA
Group 4	NA	Second	First	NA

Threats to Internal Validity

There are very few threats to internal validity due to the fact that the participants were completely tested in one session. History could have been a threat, however with a relatively short testing session and use of only one room for all subjects decreased this threat. Instrument decay was also a threat; the US

machine could have slowly lost uniformity over time. Due to the short testing period and proper care of the unit this threat was almost eliminated.

Threats to External Validity

Reactivity was a threat to external validity; because of the participant guideline criteria the results of this study may have a decreased scope of applicability. This threat was buffered by having a broad selection criterion for participants. The testing protocol was also designed in a method would could be reproducible in an actual clinical setting.

Data Collection

All demographic data were collected and stored in a binder that was only handled by primary investigator. There was no information collected that revealed participants identity. The relevant, data were entered into an EXCEL spreadsheet and combined with other study data.

Data Management

Test data were stored on the computer that was used during testing, located in Gait Analysis Lab, room A422 in Fee Hall Michigan State University, East Lansing Michigan. No computer data contained information pertaining the participants' identity. All demographic information was stored in a locked cabinet in locked office.

Data Analysis

The range of motion data were collected by the VICON motion capture system and stored in the VICON Nexus software. A model was created to input the date into the VICON Bodybuilder software. The software model created two

virtual points, one being the knee joint center represented by the midpoint between the markers on the lateral and medial aspects of the tibial plateau. The other virtual point that was created was the ankle joint center that represented the midpoint between the markers on the lateral and medial malleoli. After these points were created both lower leg (tibia) and foot body segments were created using the Bodybuilder software. The tibia segment endpoints were the knee joint center and the ankle joint center. The foot segment endpoints were the ankle joint center and the marker that was placed on the dorsal aspect of the second metatarsal head. This model created a virtual ankle with hinge joint properties. This model was then applied to each individual subjects' motion data that was collected by the VICON Nexus software. The model displayed the ankle dorsiflexion angle as if the tibia segment was the y-axis and the x-axis was perpendicular to it, in the direction of the foot segment. Dorsiflexion measurements were collected for all trials and 90 degrees was added to establish a visual zero point, this angle is called the tibia-foot angle (TFA). The TFA will be used to assess maximum dorsiflexion. A decrease in TFA from pre-test to post-test shows a gain in maximum dorsiflexion.

Demographic information was summarized using descriptive statistics. All data collected through testing was either ratio or interval levels of measurement. In order to determine the difference in the ROM of both static stretch and hold-relax stretch protocols, a paired t-test was used with acceptance of $p < .05$, Bonferroni's correction was used when performing multiple t-test with the same data set. An ANOVA was used to determine within groups and between groups,

within differences with acceptance of $p < .05$. All analyses were conducted using the Statistical Package for the Social Sciences version 15.1 (SPSS, 2005).

Chapter 4

RESULTS

The results section is divided into demographic data, group comparisons, static stretch data (SS), hold-relax (HR) data, and treatment comparisons. The HR and SS groups were compared to each other examining the differences in both passive and active ROM gains. Overall the (HR) group had a significantly greater change in tibial-foot angle (TFA) following treatment.

Demographic Information

A total of 28 college age students (16 females (21.25 years old) and 12 males (20.75 years old) from a Mid-Western university participated in the current study. All demographic information was collected via questionnaire that subject completed upon arrival to testing session. Fourteen subjects had a mild activity level (11 females and 3 males) while the other fourteen subjects had a vigorous activity level (5 females and 9 males). Twenty-seven subjects were right leg dominant while only one subject (male) was left leg dominant. The average BMI for all subjects was 24.589 (23.75 for females and 25.71 for males).

All subjects underwent both static stretch and hold relax stretch treatments. The subjects were placed into four different testing groups that decided which leg would receive the HR treatment and whether treatment would be first or second (Table 3-1). Three subjects were removed from data analysis, two (1 female and 1 male) because of investigator error during testing and 1 (female) for being an outlier, recorded measurements were over 4 standard deviations from mean.

Groups Comparison

An ANOVA was used to determine if there were any differences between treatment groups in post-treatment changes of TFA. The descriptive data of TFA changes for each group is presented in Table 4-1. The data in the table shows that all groups had a positive change in ankle dorsiflexion.

Table 4-1: Normalized Descriptive Statistics for Tibia-Fibula Angle Loss by Group

	Group	N	Mean	Std. Deviation	Std. Error	Min	Max
SS Active ROM	1	6	2.564	1.329	0.543	0.513	4.479
	2	5	0.289	4.232	1.893	-5.839	5.186
	3	7	2.163	1.473	0.557	-0.119	4.000
	4	7	1.619	3.643	1.377	-4.549	6.049
	Total	25	1.732	2.807	0.561	-5.839	6.049
SS Passive ROM	1	6	2.875	3.438	1.404	-0.784	7.300
	2	5	2.276	1.961	0.877	0.263	4.866
	3	7	0.425	2.944	1.113	-3.226	4.433
	4	7	3.509	2.016	0.762	0.853	6.967
	Total	25	2.247	2.796	0.559	-3.226	7.300
HR Active ROM	1	6	4.548	3.138	1.281	-0.172	8.654
	2	5	4.822	4.660	2.084	0.057	10.261
	3	7	4.965	3.146	1.189	0.844	8.985
	4	7	2.130	1.937	0.732	-0.261	5.631
	Total	25	4.043	3.254	0.651	-0.261	10.261
HR Passive ROM	1	6	1.404	4.273	1.744	-5.105	5.496
	2	5	3.984	5.463	2.443	-4.767	9.158
	3	7	4.118	1.689	0.638	2.098	7.038
	4	7	2.800	2.343	0.886	0.002	6.590
	Total	25	3.071	3.475	0.695	-5.105	9.158

Note: Mean= average of TFA changes, Min=smallest TFA change, Max=largest TFA change

The ANOVA results for TFA changes in each group are presented in Table 4-2. A comparison of the post-treatment TFA changes and group indicated that there were no significant differences between groups for each dependent variable, $p=.05$, as seen in Table 4-2. The data suggest that the order of treatment did not effect the TFA changes that occurred between pre and post-

treatment. Hence, any changes that occurred to the TFA may be attributed to the treatment protocol administered to leg.

Table 4-2: Analysis of Variance for Tibia-Fibula Angle Loss between Groups

		Sum of Squares	df	Mean Square	F	<i>P</i> *
SS Active ROM	Between Groups	15.948	3.000	5.316	0.645	0.595
	Within Groups	173.142	21.000	8.245		
	Total	189.091	24.000			
SS Passive ROM	Between Groups	36.772	3.000	12.257	1.706	0.196
	Within Groups	150.883	21.000	7.185		
	Total	187.655	24.000			
HR Active ROM	Between Groups	36.138	3.000	12.046	1.161	0.348
	Within Groups	217.977	21.000	10.380		
	Total	254.115	24.000			
HR Passive ROM	Between Groups	29.031	3.000	9.677	0.779	0.519
	Within Groups	260.720	21.000	12.415		
	Total	289.751	24.000			

*(significant at the $p \geq .05$ level)

An ANOVA was used to determine if leg dominance had an effect on TFA changes. The descriptive data for TFA changes based on leg dominance can be seen in Table 4-3. The data in the table shows that both dominant and non-dominant legs experience a gain in ankle ROM with both stretching protocols. Both stretching protocols also show an increase in both active and passive ROM in both dominant and non-dominant legs.

Table 4-3: Normalized Descriptive Statistics for Tibia-Fibula Angle Loss by Leg Dominance

	Leg	N	Mean	Std. Deviation	Std. Error	Min	Max
HR Active ROM	Dominant	11	4.673	3.692	1.113	-0.172	10.261
	Non-Dominant	14	3.548	2.909	0.777	-0.261	8.985
	Total	25	4.043	3.254	0.651	-0.261	10.261
HR Passive ROM	Dominant	11	2.577	4.784	1.442	-5.105	9.158
	Non-Dominant	14	3.459	2.078	0.555	0.002	7.038
	Total	25	3.071	3.475	0.695	-5.105	9.158
SS Active ROM	Dominant	11	1.530	3.076	0.927	-5.839	5.186
	Non-Dominant	14	1.891	2.685	0.718	-4.549	6.049
	Total	25	1.732	2.807	0.561	-5.839	6.049
SS Passive ROM	Dominant	11	2.603	2.747	0.828	-0.784	7.300
	Non-Dominant	14	1.967	2.905	0.776	-3.226	6.967
	Total	25	2.247	2.796	0.559	-3.226	7.300

Note: Mean= average of TFA changes, Min=smallest TFA change, Max=largest TFA change

The ANOVA results comparing TFA changes and leg dominance are presented in Table 4-4. A comparison of post-treatment TFA changes and leg dominance indicated that there were no significant difference in leg dominance, for each dependent variable, $p=.05$, as seen in Table 4-4. The data suggest that leg dominance did not cause a difference in treatment effect. Hence, all legs that received the same treatment can be combined into one group, either HR or SS. These results warranted that further analysis could be performed using the treatment administered, HR or SS, as two groups to be compared.

Table 4-4: Analysis of Variance for Tibia-Fibula Angle Loss Leg Dominance

		Sum of Squares	df	Mean Square	F	p
HR Active ROM	Between Groups	7.796	1.000	7.796	0.728	0.402
	Within Groups	246.319	23.000	10.710		
	Total	254.115	24.000			
SS Passive ROM	Between Groups	4.793	1.000	4.793	0.387	0.540
	Within Groups	284.958	23.000	12.389		
	Total	289.751	24.000			
SS Active ROM	Between Groups	0.803	1.000	0.803	0.098	0.757
	Within Groups	188.288	23.000	8.186		
	Total	189.091	24.000			
SS Passive ROM	Between Groups	2.490	1.000	2.490	0.309	0.583
	Within Groups	185.165	23.000	8.051		
	Total	187.655	24.000			

*(significant at the $p \geq .05$ level)

Static Stretch Data

A paired t-test was used to determine the effect of the SS treatment protocol on TFA. The t-test compared the pre-treatment, active and passive ROM, for each TFA to their corresponding post-treatment TFA. The descriptive statistics of the TFA data for the SS group are presented in Table 4-5.

Table 4-5: Descriptive Statistics for Tibia-Fibula Angles of the Static Stretch Group

	Mean	N	Std. Deviation	Std. Error Mean
Active Pretest	95.161	25	5.942	1.189
Active Posttest	93.429	25	5.786	1.157
Passive Pretest	94.674	25	7.105	1.421
Passive Posttest	92.427	25	6.979	1.396

Note: Mean= average TFA

The paired t-tests showed that there was a significant difference between pre-treatment TFA and post-treatment TFA, for both passive and active measures (active $t_{(24)}=3.085$, $p=0.005$, passive $t_{(24)}=4.017$, $p=0.000$). TFA The t-test data for the SS group is presented in Table 4-6.

Table 4-6: Paired T-test for Tibia-Fibula Angle Change for the Static Stretch Group

	Mean	Std. Deviation	Std. Error Mean	t	df	p
Active TFA	1.732	2.807	0.561	3.085	24	0.005
Passive TFA	2.247	2.796	0.559	4.017	24	0.000

*(significant at the $p \geq .05$ level) / Note: Values based on normalized data
Mean=difference between pre and post treatment TFA

Hold-Relax Data

A paired t-test was used to determine the effect of the HR treatment protocol on TFA. The t-test compared the pre-treatment, active and passive ROM, TFA to their corresponding post-treatment TFA. The descriptive statistics of the TFA data for the HR group are presented in Table 4-7.

Table 4-7: Normalized Descriptive Statistics for Tibia-Fibula Angles of the Hold-Relax Group

	Mean	N	Std. Deviation	Std. Error Mean
Active Pretest	95.324	25	5.838	1.168
Active Posttest	91.281	25	5.0789	1.0158
Passive Pretest	94.892	25	4.975	0.995
Passive Posttest	91.821	25	5.186	1.0372

Note: Mean= average TFA

The paired t-test showed that there was a significant difference between pre-treatment TFA and post-treatment TFA, for both passive and active ROM measures (active $t_{(24)}=6.212$, $p=0.000$, passive $t_{(24)}=4.419$, $p=0.000$). The t-test data for the HR group is presented in Table 4-8.

Table 4-8: Paired T-test for Tibia-Fibula Angle Change for the Hold-Relax Group

	Mean	Std. Deviation	Std. Error Mean	t	df	p
Active TFA	4.043	3.254	0.651	6.212	24	0.000
Passive TFA	3.071	3.475	0.695	4.419	24	0.000

*(significant at the $p \geq .05$ level) /Note: Values based on normalized data
Mean=difference between pre and post treatment TFA

Treatment Comparisons

A paired t-test was used to compare the difference between passive TFA change of the HR group and the SS group. The paired t-test showed that there was no difference in passive TFA change between the HR and SS groups ($t_{(24)}=0.920$, $p=.367$). The t-test data is presented in Table 4-9.

Table 4-9: Paired Samples T-test with Bonferroni Correction for Passive Tibia-Fibula Angle Change between Hold-Relax and Static Stretch Groups

	Mean	Std. Deviation	Std. Error Mean	t	df	p
HR-SS	0.824	4.478	0.896	0.920	24	0.367

*(significant at the $p \geq .025$) / Note: Values based on normalized data. Mean = difference of passive TFA average of HR group and SS group

A paired t-test was used to compare the difference between the active TFA change of the HR group and the SS group. This paired t-test result showed

that there was a significant difference in active TFA change between the HR and SS groups ($t_{(24)} = 2.655$, $p = 0.014$). The t-test data is presented in Table 4-10.

Table 4-10: Paired Samples T-test with Bonferroni Correction for Active Tibia-Fibula Angle Change between Hold-Relax and Static Stretch Groups

	Mean	Std. Deviation	Std. Error Mean	t	df	p
HR – SS	2.311	4.352	0.87	2.655	24	0.014

*(significant at the $p \geq .025$) / Note: Values based on normalized data. Mean = difference of active TFA average of HR group and SS group

This data supports the hypothesis that, ultrasound followed immediately by a hold-relax proprioceptive neuromuscular facilitation stretching technique will elicit a greater increase in active ankle dorsiflexion range of motion than an ultrasound treatment immediately followed by a static stretch routine. The data does not support the hypothesis that, ultrasound followed immediately by a hold-relax proprioceptive neuromuscular facilitation stretching technique will elicit a greater increase in passive ankle dorsiflexion range of motion than an ultrasound treatment immediately followed by a static stretch routine.

CHAPTER 5

DISCUSSION

The purpose of this study was to compare the dorsiflexion range of motion, both active and passive, of a static stretch and hold-relax stretch following the application of a therapeutic dosage of ultrasound... Based on a review of literature this was the first study to compare a Hold Relax muscle stretch protocol to a Static Stretch protocol with both treatments being coupled with a therapeutic heating modality.

Static and PNF forms of stretching and their effects on ROM and muscle extensibility have been debated in previous studies (Depino, et al., 2000; McCullogh, et al., 1994; Spemoga, et al., 2001), with most results showing that a PNF stretching protocol increases ROM greater than a SS protocol (Sharman, et al., 2006; Spemoga, et al., 2001; Tanigawa, 1972). Furthermore, the effects of stretching coupled with various tissue warming mechanisms have been previously researched (Anderson, et al., 1998; DeVane, et al., 1987; Draper, et al., 2002; Wenos & Konin, 2004), however a literature review yielded no research that demonstrates the effects of a coupled treatment of ultrasound and a PNF Hold-Relax stretch. The current study adds to the nature of the current literature that supports the use of HR stretching protocols over SS.

Analysis of ROM Gains

Maximum ankle dorsiflexion was recorded as the tibia-foot angle (TFA), the smaller the TFA the greater dorsiflexion the subject possesses. The study measured TFA changes for both active and passive ROM, for each group. The

results of the study show that the active TFA change for the HR group had significantly decreased more so than the active TFA change for the SS group, thus the HR group (mean=4.043) had a significantly greater increase in active dorsiflexion, post-treatment, than the SS group (1.732). This increase in dorsiflexion ROM may be attributed to the PNF principles of autogenic inhibition and reciprocal inhibition. Autogenic inhibition, the decrease of muscle excitability in a contracted or stretched muscle, is utilized by both static stretch techniques and the hold-relax technique. Reciprocal inhibition is one of the primary principles behind the effects of the hold-relax PNF techniques, and is defined by the concept that when an agonist muscle contracts the antagonist must relax. Static stretching techniques do not utilize this principle, because there is no muscle contraction preceding the stretch. Though both static and hold-relax stretches both experience autogenic inhibition, the hold-relax techniques elicits a quicker reaction from the GTO, 7-8 seconds, compared to static stretch, 30 seconds (Sharman, et al., 2006). The combining effect of both autogenic inhibition and reciprocal inhibition created gains in ROM during the hold-relax technique (Laporte & Lloyd, 1952). The isometric contraction, of the triceps surae, in the hold-relax technique causes autogenic inhibition, which creates a window of time to in which the triceps surae can increase its length. The following concentric contraction of the ankle dorsiflexors elongates the triceps surae, not only because of the inhibition created by autogenic inhibition but also because of the reciprocal inhibition that occurs within the triceps surae muscle group(Sharman, et al., 2006).

Research also suggests that the assisted force that was applied during the contraction of the dorsiflexors also contributed to the increase in maximum dorsiflexion (Mitchell, et al., 2007). Research shows that during a hold-relax stretch a greater stretching force can be applied to the stretched muscle without causing increased discomfort to the patient (Mitchell, et al., 2007). Mitchell, et al. (2007) also concluded that with repetitions of a “contract-relax” stretch, the stretch was actually a modified-hold-relax stretch, to the hamstrings the subjects stretch tolerance had significantly increased between trials one and four. The current study did not follow the same guidelines as Mitchell, et al. (2007) however, his findings should still be considered applicable, for their findings hint to the muscle contraction being the reason for the increased stretch tolerance.

The therapeutic US treatment and the static stretch protocol that was performed in the current study were very similar to the parameters used by (Anderson, et al., 1998). The results of the study were that US and static stretch caused an immediate increased dorsiflexion ROM (mean=3deg) significantly more than static stretch alone (mean=2deg). The researchers of study only tested the right leg of each subject, the dominant leg, which could limit the scope of application of their study. The use of only one leg limits the scope of application to the leg being tested, the dominant leg, the protocols of the study cannot be assumed to affect the non-dominant leg in the same degree as the leg examined in the study. In the current study we had the subjects act as their own control groups, which allowed for testing of both legs, so that all findings will have a broader scope of practice, allowing research results to be applied to both

dominant and non-dominant legs. The results showed that the treatment protocols did not have different effects based on order of application.

Though there were no other statistically significant results, the gains in maximal dorsiflexion were higher for the HR group (PROM mean=3.071, AROM mean=4.043) than the SS group (PROM mean=2.247, AROM mean=1.732). These results support the trend in research supporting the use of the hold-relax PNF stretching technique.

Anderson et al (1998) conducted a study that was similar to the current study. His results yielded an increase of 3 degrees in passive dorsiflexion following the same SS protocol, preceded by an US treatment with the same parameters as the current study. The current study showed the SS group had a mean passive increase in maximum ankle dorsiflexion of 2.247 degrees. The difference in ROM gains is most likely attributed to the force used to obtain passive ROM. Anderson et al (1998) measured passive dorsiflexion in the weight bearing position, while the current study used a force applied by the investigator. The use of the subject's body weight applies a larger force than is producible by the investigator and this could be the reason why the current study had a lesser PROM gain in dorsiflexion. Weight bearing ROM was not used in current study because active dorsiflexion was also being measured in the study. The increased time of positioning the patient for a weight bearing PROM measurement would cause had the potential to decrease the effects of the treatment. Research has shown in the past that the effect of static stretching becomes statistically insignificant after only 3 minutes (Depino, et al., 2000). The

time that it would have taken in order to measure both the AROM and PROM of dorsiflexion may have had significant impact.

Utilization and Clinical Interpretation of Results

Research has demonstrated the effects that the two stretching techniques have on joint ROM and tissue extensibility. Some of these projects have examined the coupled effects of therapeutic thermal modalities and stretching techniques on the same characteristics. The use of static stretching protocols, with and without US, is still the most popular stretching technique among athletic trainers (Surburg & Schrader, 1997), despite research that supports the fact that PNF stretching techniques, more specifically the hold-relax (HR) technique, increase joint ROM greater than any other form of stretching. Based on a review of literature, until now the effect of a treatment that couples a hold-relax stretch preceded by therapeutic US, on joint ROM and tissue extensibility, has never been compared to a treatment that couples a hold-relax and static stretch preceded by therapeutic US. This study provides a basis for the use of the coupled treatment of a Hold Relax stretch and therapeutic ultrasound to increase ankle joint range of motion and triceps surae tissue extensibility, more specifically active dorsiflexion, instead of the standard static stretch and US treatment. Although the majority of treatment for decreased tissue extensibility and joint ROM will also consist of various other forms of tissue and joint mobilization, the results of this study provide an efficacy for the hold-relax stretch technique that has been coupled with an ultrasound treatment.

The use of the hold-relax stretch coupled with an ultrasound provides a good treatment for individuals who have a decrease ankle dorsiflexion range of motion, specifically AROM, due to triceps surae tissue restrictions. The efficacy for use of a hold-relax stretch protocol instead of a static stretch procedure, becomes apparent when there is limited time for treatment. The, static stretch protocol took over twice as long (240 seconds) as the HR protocol, compared to the HR time of (~90 seconds). The HR treatment should be followed by manual resistance slow-reversal PNF exercises, or some form of resistance, in order to increase the strength and endurance of the muscle fibers that have had decreased activation, and thus increasing joint function.

Limitations

One limitation to the study was the sample population. Only individuals between the ages of 18-25 participated in the study. Recruiting participants from a larger age range would provide greater diversity to the research.

Another limitation to this study was the method of measuring passive dorsiflexion. The data collected showed that some individuals had a decrease in maximal passive ankle dorsiflexion following stretch. This is most likely due to investigator error and the inability of the investigator to apply a consistent force when creating passive dorsiflexion. This could be remedied by the use of a force plate, force gauge, or even a pulley system with weights. The use of the VICON system limits the use of certain instruments because they may block the reflective markers from the cameras. A pulley system, that is connected to the foot, in which a set amount of weight is used, would be ideal.

Future Research Considerations

Future research should consider repeating test while using a different method of producing passive dorsiflexion. Other research should consider the duration of the effects of coupled treatments, heating modalities and stretching. All stretching techniques should be compared with itself, with heating modalities vs. no modality and compared against other stretching techniques.

Other directions of research should include the complete assessment of ankle motion, pre and post treatment. All motions should be measured including, inversion, eversion, internal rotation, external rotation, plantarflexion, and dorsiflexion. This could be done through the use of a motion capture system, such as VICON. This knowledge should provide more information on the effects stretching of ankle kinematics. Thus allowing for better assessment on which stretching protocol is most efficient and efficacious.

Conclusion

This study examined the effects of a hold-relax stretching protocol compared to a static stretch protocol, both preceded by a therapeutic ultrasound treatment, on triceps surae muscle extensibility as measured through ankle dorsiflexion. More specifically this study compared the effects on both active and passive dorsiflexion. Stretching is a common practice in rehabilitation and due to the many different methods it can be confusing which technique should be utilized. This was the first study to observe the effects of a HR stretching protocol coupled with a therapeutic ultrasound treatment.

At the present time a hold-relax stretching protocol, preceded by a therapeutic US treatment, yields greater increases in both passive range of motion and active range of motion when compared to a static stretch, with the active range of motion being larger. Further studies should go deeper into the effects of hold-relax and other stretching protocols, such as full ankle kinematics, the duration of treatment effect, and the effects in various populations.

APPENDIX A
INFORMED CONSENT

The Comparison in Changes in Dorsiflexion Range of Motion Using an Ultrasound Heat Treatment and Triceps Suræ Stretching.

Participants Informed Consent Form

For questions regarding the research study, please contact:

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Phone: 517-432-5018
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For questions regarding your rights as a research participant, please contact:

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Dear Subject

Thank you for considering participation in the research project "The Comparison in Dorsiflexion Range of Motion Using an Ultrasound Heat Treatment Followed by Two Techniques of Triceps Suræ Stretching". The purpose of this study is to examine the effects of a hold-relax (HR) and static stretch (SS) technique on the extensibility of the triceps suræ muscle group following a therapeutic ultrasound treatment.

You will need to spend approximately 1 hour participating in this study. All work will be conducted under the supervision of an individual who is an expert in the current experimental techniques and who works regularly in the Orthopedic Biomechanics Laboratories (OBL). This research study will involve gathering data from a demographic questionnaire and a Vicon Motion Capture System (Vicon, Oxford, UK).

Upon arrival to the study, A422 East Fee Hall Michigan State University East Lansing, MI 48824, your height, weight, age, gender, dominant kicking leg, and fitness activity will be documented. **In order to participate in this study you must be at least 18 years old.** You will then be asked to lie on your stomach on a table with your lower legs hanging off the edge of that table. You will then have retro-reflective markers placed on the skin over specific anatomical landmarks of the

lower leg, ankle and foot. The retro-reflective markers are used to record motion data through the Vicon motion capture system and the markers will be attached to the skin using hypoallergenic tape. Following the placement of the markers the investigator will passively dorsiflex one of your ankles by using the foot as a level arm. The final position of the ankle will be recorded by the Vicon. This technique measures the resting extensibility of the triceps surae tissue. You will then be instructed to actively dorsiflex your ankle by moving your toes as far as you can towards your shin and that position will be recorded.

Next, a therapeutic ultrasound treatment will be applied to the triceps surae muscle of your leg. The ultrasound settings are 3 mhz, 1.5 Watts/cm², with duration of 7 minutes, the transducer will be moved with the approximate speed of 4 cm/sec. Ultrasound will immediately be followed by either a static stretch protocol or a hold-relax protocol, the specific technique depends on your group assignment. The stretching techniques are as follows:

- The static stretch (SS) protocol will consist of you standing on a slanted board that has a twenty-degree angle and leaning forward until a stretch is felt in the calf musculature. This stretch will occur with knee straight and with the knee bent at 15 degrees and will be performed 5-7 times.
- The hold-relax stretch protocol will be performed by the investigator and consists of you lying in your original position and performing a series of active isometric (no-movement) and isotonic (movement) contractions of the ankle musculature against the resistance applied by the investigator.

Following the therapeutic ultrasound treatment and the designated stretching protocol, the dorsiflexion range of motion, passive and active, will again be measured.

At this point the opposite leg will be undergo the same regimen as stated above, except the stretching technique will be the procedure not used on the first leg. Dorsiflexion range of motion will be measured in the same sequence and manner as the first leg.

The acoustic energy that ultrasound machines produce has the potential to cause a burning sensation in the tissue. The risk of this occurring is minimized as the ultrasound application will be conducted by a trained clinician and the intensity level and duration are customary therapeutic dosages. The stretching protocols cause minimal to no risk because they are self-administered. You will be asked to contract the lower leg musculature to varying degrees and asked to terminate the contraction at the point of pain. There is no increased risk of injury from the markers being placed on your body.

You may refuse to answer any question, and you may withdraw from the experiment at anytime for any reason without penalty. If you are injured as a result of your participation in this research study, Michigan State University will assist you in obtaining emergency medical care, if necessary, for your research related injuries. If you have insurance for medical care, your insurance carrier will be billed in the ordinary manner. As with any medical insurance, any cost that are not covered or in excess of what is paid for by your insurance, including deductibles, will be your responsibility. The University's policy is not to provide financial compensation for lost wages, disability, pain or discomfort, unless required by law to do so. This does not mean you are giving up any legal rights you may have.

Your privacy will be protected to the maximum extent allowable by law. Data analysis will be based on aggregate data and no participant will be identified. The de-identified data will be stored in the Gait Laboratory (A422 East Fee Hall) for an indefinite time period.

You may potentially benefit directly from your participation in this research study through the temporary increase of triceps surae extensibility following treatment. Your participation in this study will contribute to the better understanding of different treatment techniques and their physiological effects on the triceps surae tissue.

If you have any concerns or questions about this research study, such as scientific issues, how to do any part of it, or to report an injury, please contact Dr. John Powell at Department of Kinesiology Michigan State University 105 IM Circle East Lansing, MI 48824,

email: powellj4@ath.msu.edu, phone: 517-432-5018, or fax: 517-353-2944.

If you have any questions or concerns about your role and rights as a research participant, or would like to register a complaint about this research study, you may contact, anonymously if you wish, the Director of MSU's Human Research Protection Programs, Dr. Peter Vasilenko, at 517-355-2180, FAX 517-432-4503, or e-mail irb@msu.edu, or regular mail at: 202 Olds Hall, MSU, East Lansing, MI 48824. Your signature below indicates your willingness to participate and that you are at least 18 years old.

Thank you for your time and cooperation

I have read the above description of this study. I understand my rights as a participant and agree to voluntarily participate in this study.

Please Print:

First Name

Middle Initial

Last Name

Signature

Date

APPENDIX B
DEMOGRAPHIC DATA

Subject #:

Date:

Time:

Height:

Weight:

Age:

Gender:

BMI:

Group:

Dominant Leg:

Activity Level:

Appendix C

BMI Chart

20 21 22 23 24 25 26 27 28 29 30 31 32																	
Height (inches)	Body Weight (Pounds)																
58	91	96	100	105	110	115	119	124	129	134	138	143	148	153	158	162	167
59	94	99	104	109	114	119	124	128	129	134	143	148	153	158	163	168	173
60	97	102	107	112	118	123	128	133	137	143	148	153	158	163	168	174	179
61	100	106	111	116	122	127	132	137	143	148	153	158	164	169	175	180	185
62	104	109	115	120	126	131	136	142	147	153	158	164	169	175	180	186	191
63	107	113	118	124	130	135	141	146	152	158	163	169	175	180	186	181	197
64	110	116	122	128	134	140	145	151	157	163	169	174	180	186	192	197	204
65	114	120	126	132	138	144	150	156	162	168	174	180	186	192	198	204	210
66	118	124	130	136	142	148	155	161	167	173	179	186	195	198	204	210	216
67	121	127	134	140	146	153	159	166	172	178	185	191	198	204	211	217	223
68	125	131	138	144	151	158	164	171	177	184	190	197	203	210	216	223	230
69	128	135	142	149	155	162	169	176	182	189	196	203	209	216	223	230	236
70	132	139	146	153	160	167	174	181	188	195	202	209	216	222	229	236	243
71	136	143	150	157	165	182	179	186	193	200	208	215	222	229	236	243	250
72	140	147	154	162	169	188	184	191	199	206	213	221	229	234	242	250	258
73	144	151	159	166	175	182	189	197	204	212	219	227	235	242	250	257	265
74	148	155	163	171	179	186	194	202	210	218	225	233	240	249	256	264	272
75	152	160	168	179	184	192	200	208	216	224	232	240	248	256	264	272	279
76	156	150	172	180	189	197	205	213	221	230	238	246	254	263	271	279	287

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