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1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE <i>9 Dec 96</i>	3. REPORT TYPE AND DATES COVERED
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4. TITLE AND SUBTITLE <i>A Study of H-Reflexes In Subjects With Acute Ankle Inversion Injuries</i>	5. FUNDING NUMBERS
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6. AUTHOR(S) <i>Robert C. Hall</i>

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <i>University of Kentucky</i>	8. PERFORMING ORGANIZATION REPORT NUMBER <i>96-077</i>
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9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) DEPARTMENT OF THE AIR FORCE AFIT/CI 2950 P STEET, BLDG 125 WRIGHT-PATTERSON AFB OH 45433-7765	10. SPONSORING / MONITORING AGENCY REPORT NUMBER 19961212 056
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11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT <i>Unlimited</i>	12b. DISTRIBUTION CODE
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13. ABSTRACT (Maximum 200 words)

14. SUBJECT TERMS	15. NUMBER OF PAGES <i>183</i>
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
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ABSTRACT OF THESIS

A STUDY OF H-REFLEXES IN SUBJECTS WITH ACUTE ANKLE INVERSION INJURIES

This study examined the H-reflex responses of the ankle invertor and evertor muscles in healthy individuals (N=20) and in individuals with an acute (< 10 days) ankle inversion injury (N=20). The purposes of this study were: 1) to determine whether or not a relationship exists between the H-reflex response and the amount of ankle swelling, and 2) to determine whether or not a relationship exists between the H-reflex response and the functional level of individuals with an acute ankle inversion injury. All subjects underwent identical testing procedures. Subjects were evaluated for their level of function, and assigned a rating (0-10). The ankle girth of both ankles were then measured using the figure-of-eight method. The H-reflex responses of the flexor digitorum longus and the peroneus longus muscles were elicited by electrical stimulation of either the tibial or common peroneal nerve just above the popliteal fossa and recorded from each limb. Based on the findings, the following conclusions were drawn: 1) acute ankle swelling is related to the reflex inhibition of the ipsilateral flexor digitorum longus muscle, 2) a relationship between the H-reflex response and the functional level of individuals with an acute ankle inversion injury was not established, 3) individuals with either a grade I or grade II acute ankle inversion injury may also have a bilateral injury to the peroneal nerve, and 4) The figure-of-eight girth measurement technique is clinically useful in quantifying side-to-side differences in ankle girth.

Robert C. Hall

Date

A STUDY OF H-REFLEXES IN SUBJECTS WITH ACUTE ANKLE INVERSION
INJURIES

By

Robert C. Hall

(Director of Thesis)

(Director of Graduate Studies)

(Date)

THESIS

Robert C. Hall

The Graduate School
University of Kentucky
1996

A STUDY OF H-REFLEXES IN SUBJECTS WITH ACUTE ANKLE INVERSION
INJURIES

THESIS

A thesis submitted in partial fulfillment
of the requirements for the degree of
Masters of Science in Physical Therapy
at the University of Kentucky

By

Robert C. Hall

Lexington, Kentucky

Director: Dr. Arthur J. Nitz

Associate Professor of Physical Therapy

Lexington, Kentucky

1996

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ACKNOWLEDGMENTS

I would like to thank God for granting my prayers for strength during the work on this project. I thank my wife, Kelly, who has lovingly sacrificed her time with me for the sake of my studies over the past two years. I also thank Dr. Arthur J. Nitz, P.T., and Dr. Terry M. Malone, P.T., A.T.C., for their encouragement and guidance, which has kept me on track during the course of my studies. I would like to thank Dr. John Nyland, P.T., A.T.C., and Darren Johnson, M.D., for their support and input. I thank Dr. Gary Wilkerson, A.T.C., and Jase Pinerola P.T., for their help on this project and their encouragement to pursue this study. A special thanks to Dr. Mary Kay Raynes, Ph.D., and Sam Gardner for help with the statistical analysis of the data. I thank my friends and colleagues, at the University of Kentucky Sports Medicine Clinic and at the University of Kentucky Athletic Training Room for their willingness to allow me to participate in the care of the athletes that they see. Finally, I would thank the U.S. Air Force for giving me the opportunity to better myself professionally.

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CHAPTER 1

INTRODUCTION

The relationship between joint effusion and reflex muscle inhibition has been studied most frequently in the human knee. DeAndrade et al. demonstrated significant quadriceps femoris weakness in 14 subjects with a human plasma induced knee joint effusion. They proposed that a reflexive inhibitory afferent pathway to be present that accounted for quadriceps inhibition arising from type I joint mechanoreceptors. They urged caution when rehabilitating patients with joint effusion.(15) Fahrer et al. demonstrated a decrease in quadriceps EMG activity and isometric strength in the presence of knee joint effusion, and suggested that reflexive muscle inhibition may be responsible for muscle weakness.(23) More recently, Kennedy et al. and Spencer et al., both measured electrically evoked Hoffmann reflexes (H-reflexes) in the quadriceps muscles of human knees that had been infused with saline.(53, 98) Both studies demonstrated decreased levels of motoneuron pool excitability via a reduction in quadriceps H-reflex amplitudes. Spencer et al. found that as little as 20-30 ml of joint effusion produced a significant reduction in the vastus medialis H-reflex amplitude.

Only recently have investigators reported on the effects of a saline induced ankle effusion upon the H-reflex of the gastroc-soleus muscles. A significant increase in the H-reflex amplitude was reported with a 10cc ankle effusion.(84) The relationship between a traumatic ankle joint effusion and the H-reflex of the muscles that assist with stabilizing the ankle has not been reported in the literature. Rather, investigators have focused more on the deleterious effects that ankle swelling has on tissue healing, and functional status. Recently, however, the occurrence of transient peroneal nerve and tibial nerve dysfunction associated with inversion ankle injuries has been reported. Nitz et al found a high incidence (86% and 83% respectively) of peroneal and posterior tibial nerve injury in grade III ankle sprains.(72) Kleinrensink et al also demonstrated peroneal nerve conduction slowing in subjects with ankle inversion injuries. They postulated that traction forces on the nerves and ankle swelling resulted in a prolonged recovery from severe inversion injury.(54)

Ankle inversion injuries have been postulated to result in proprioceptive deafferentation of ligaments and tendinous structures on the lateral side of the ankle.(25, 53) An increase in the reaction time of the peroneal muscles resulting from delay of afferent signals from damaged or inflamed ligamentous, capsular, and muscle afferent receptors

could contribute to altered biomechanics in the presence of an inversion injury.(25, 55, 56, 62, 88)

Considering the aforementioned studies, the possibility of a significant relationship between acute ankle swelling and the reflex response of the dynamic ankle stabilizers seems plausible. A significant association between these two factors may provide clinicians with greater insight into the proper management of acute ankle inversion injuries.

Statement of the Problem

The problem addressed by this study was to determine what, if any relationship exists between the amount of ankle swelling, as a result of inversion injury, and the H-reflex responses of two specific muscles that aide in providing closed chain stability to the ankle.

Purpose

The purpose of this study was to answer the following questions:

1. Is there a relationship between a measured amount of acute ankle swelling and the H-reflex response of the peroneus longus and flexor digitorum longus muscles?
2. Is there a relationship between inversion ankle injury severity, as defined by level of function, and the

H-reflex response of the peroneus longus and flexor digitorum longus muscles?

Scope of the Study

This research, conducted from September 1995 through February 1996, investigated ankle swelling and H-reflex responses in normal control and injured subject groups. Side-to-side ankle girth measurements, H-reflex amplitudes, H-reflex latencies, and level of function were the measured outcomes.

All subjects volunteered to participate in the study and were required to read and sign a consent form (Appendix A) prior to participation. Minor subjects were required to obtain signed parental consent and read and sign an assent form (Appendix A) prior to participation. Subjects were free to withdraw from the study at any time without penalty. Subjects were not compensated for their participation in the study. Subjects were recruited by the principal investigator from undergraduate physical therapy students, university students, intercollegiate athletes, intramural athletes, high school athletes, and recreational non-university athletes. All subjects were between the ages of 15 and 41 years of age.

Subjects comprised two groups, control and injury. The control group consisted of 11 healthy males and 9 healthy females with no recent history (<3 years) of significant lower extremity injury. Individuals in the injury group

consisted of 16 males and 4 females with a history of inversion ankle injury (< 10 days), no history of acute fracture (chip fracture excluded) or bilateral lower extremity injury.

Both groups underwent identical testing procedures. A Cadwell 5200-A EMG/NCV testing unit (Cadwell Laboratories, Inc., 909 North Kellogg Street, Kennewick, Washington, 99336) was used to record H-reflex responses in both limbs of all subjects. A Gulick controlled tension tape measure (Lafayette Instruments, 3700 Sagamore Parkway North, Lafayette, IN 47903) was used to record figure-8 ankle girth measurements in all subjects. Testing of the subjects in the injury group took place within 10 days of the ankle inversion injury and consisted of one testing session of approximately 45 minutes in duration. Testing of the subjects in the control group took place during one session of approximately 45 minutes, Monday through Sunday at times scheduled for the subject's convenience.

All subjects initially underwent a functional level rating, using a modified Lateral Ankle Sprain Functional Evaluation Scale. (Appendix B). Subjects then underwent measurement of ankle girth with the figure-8 measurement technique. The order of limb testing was randomly assigned. Following girth measurements, the temperature of both feet was assessed with an electric thermister (Yellow Springs Instrument Co., Inc., Yellow Springs, Ohio). Order of limb

and muscle testing was then randomly assigned for the electroneuromyographic testing. H-reflexes were electrically recruited from both the flexor digitorum longus and peroneus longus muscle in each limb. The latency and baseline-peak amplitude for each response was calculated and recorded. Data collection and testing took place at one of several facilities: University of Kentucky Physical Therapy Laboratory, University of Kentucky Sports Medicine Clinic, University of Kentucky Nutter Training Room, Frankfort Physical Therapy Clinic, Biokinetics Inc. of Paducah, KY.

Definition of Terms

H-reflex - the latent compound muscle action potential evoked by weak electrical stimulation of afferent fibers of a mixed peripheral nerve. Originally described by Hoffman in 1918.(38)

Open-Chain - A combination of several joints united successfully where the end segment is free --- as when the limb is in swing phase of gait.(32)

Closed-Chain - A combination of several joints united successfully where the end segment is not free --- as when the limb is in support phase of gait.(32)

Figure-8 - the girth measurement technique unique to quantification of ankle swelling.

Swelling - term used to describe the soft tissue manifestation of a combination of joint effusion and interstitial edema.

De-afferentation - disruption in articular afferent impulse transmission and interference of the afferent neural codes to the CNS.

De-efferentation - Motor denervation as a result of neurogenic inflammation or direct nerve trauma.(73)

Limitations

Limitations in this study included:

1. Data was collected by two different investigators.
2. Subjects were instructed to remain relaxed during the electroneuromyographic testing procedure.
3. Surface electrodes were used rather than monopolar needle electrodes.
4. Some of the injured subjects may have received rehabilitative measures prior to testing.

Delimitations

Delimitations of this study include:

1. Injured subjects were no greater than 10 days post ankle inversion injury.
2. Control subjects had no history of lower extremity injuries for 3 years prior to the study.
3. All subjects were active in some form of athletics (collegiate, intramural, or recreational) at the time of their participation in the study.

Hypotheses

The research hypotheses tested in this study were: 1) a relationship exists between the amount of acute ankle swelling and the H-reflex response of the peroneus longus muscle; 2) a relationship exists between the amount of acute ankle swelling and the H-reflex response of the flexor digitorum longus muscle; 3) a relationship exists between the functional level of individuals with an acute inversion ankle injury and the H-reflex response of the peroneus longus muscle; 4) a relationship exists between the functional level of individuals with an acute inversion ankle injury and the H-reflex response of the flexor digitorum longus muscle.

The null hypotheses tested in this study were: 1) no relationship exists between the amount of acute ankle swelling and the H-reflex response of the peroneus longus muscle; 2) no relationship exists between the amount of acute ankle swelling and the H-reflex response of the flexor

digitorum longus muscle; 3) no relationship exists between the functional level of individuals with an acute inversion ankle injury and the H-reflex response of the peroneus longus muscle; 4) no relationship exists between the functional level of individuals with an acute inversion ankle injury and the H-reflex response of the flexor digitorum muscle.

CHAPTER 2

LITERATURE REVIEW

This review will focus on information pertinent to both ankle injuries and the H-reflex. The review will include discussions of ankle ligamentous anatomy, articular injury and neurologic dysfunction, quantification of ankle swelling, and the significance of the H-reflex.

Introduction

Ankle injuries, by way of inversion, are reported to be one of the most common injuries in high risk sports (basketball, soccer, football, volleyball). (21, 28, 83) Ankle injuries are by far the most commonly seen musculoskeletal injury in the emergency room. (18, 28) Inversion trauma is the reported mechanism of injury in 85% of diagnosed ankle sprains. The literature reports that most ankle sprains initially tend to be treated poorly. (5, 108) The high incidence of recurrent sprains associated with complaints of functional instability may be indicative of the lack of a comprehensive assessment of the severity and extent of the initial injury. The mechanoreceptors of the ankle, like those of many synovial joints, may be susceptible to

distortion or inflammation associated with a traumatic inversion injury.(25, 73, 76, 77) As a prime source of joint afferent input, mechanoreceptors play a key role in the modulation of protective muscular reflex responses, their subsequent disruption could result in a compromise of neuromuscular and proprioceptive responses to perturbation.(91)

Joint effusion, both chronic and acute, has been shown to produce inhibition of the quadriceps muscles in human subjects and alterations in the quadriceps H-reflex.(23, 42, 53, 98) Likewise, the acute and inflammatory responses associated with joint injury have been shown to affect a variety of joint afferent receptors, including alpha and gamma motoneurons in animals and humans.(36, 72)

To date, much of the research involving joint mechanoreceptor activity, proprioception, and muscle inhibition in the lower limbs has focused on the knee joint. Because the knee joint works in close concert with the foot and ankle in the lower kinetic chain, studies involving the knee joint may provide insight into the relationships between joint mechanoreceptors, proprioception, and muscle inhibition at the level of the ankle. Hence, the knee joint is the focus of a great deal of the literature reviewed in this chapter.

In this chapter, the relevant anatomical structures associated with ankle inversion trauma are reviewed briefly. Following this, pertinent literature is reviewed regarding past research into the effects of swelling and inflammation on neuromuscular reflexes and functional stability of the lower limb. Additionally, the significant literature pertaining to the significance of the H-reflex and the quantification of swelling are reviewed. These reviews will provide the theoretical foundation for investigating the relationship between acute ankle swelling and the H-reflex of the ankle invertor and evertor musculature.

Review of Relevant Anatomy

Ligamentous structures

As described by Kapandji, the lateral ligament complex or "collateral ligament" is composed of three separate ligaments arising from the tip of the distal fibula, two attaching below the talus, and one attaching to the calcaneus.(52) The anterior talofibular ligament (ATFL) runs obliquely inferior and anterior from the anterior border of the lateral malleolus to insert on the anterior and lateral aspect of the talus. The ligament blends with and actually forms part of the thin capsule of the lateral ankle.(6, 83, 96) The posterior talofibular ligament (PTFL) runs more horizontal and posterior than oblique from the posteromedial

aspect of the lateral malleolus to insert on the posterolateral tubercle of the talus. Both the ATFL and PTFL also have a medial orientation.(75) The calcaneofibular ligament (CFL) runs obliquely and posteriorly from the most distal tip of the lateral malleolus and inserts to the lateral surface of the calcaneus. The ligament is intimate with the inner wall of the sheath of the peroneal tendons which pass directly inferior to the lateral malleolus.(75) Directly inferior and parallel to the CFL is the lateral talocalcaneal ligament, running from the lateral tubercle of the talus obliquely and posterior to the lateral surface of the calcaneus. Unlike the lateral collateral ligaments, it is primarily associated with stability of the subtalar joint.(100)

Early and recent radiographic studies of individuals with acute ankle inversion injuries confirm the significance of the ATFL as the most commonly injured structure.(7, 96) Magnetic Resonance Imaging (MRI) of ankles with acute edema resulting from ankle inversion injuries shows the intimate relationship between the ATFL and the anterior lateral portion of the joint capsule.(96) The CFL is said to be extra-articular but intimately associated with the posterior aspect of the peroneal tendon sheath.(83) Although it plays a significant role in the control of calcaneal stability during inversion, the CFL rarely appears as an isolated injury with inversion trauma. Likewise, tearing of the PTFL

is most often associated with injuries involving forced dorsiflexion, rather than inversion stress. (86)

Joint innervation

As a synovial joint, the ankle receives dual innervation from primary and accessory articular nerves. (27, 114) Both types of articular nerves have been found to terminate as encapsulated and unencapsulated mechanoreceptors embedded in the superficial and deep layers of joint capsular and ligamentous tissues. (26, 53, 73, 76, 93) Mechanoreceptors have been the subject of intense microphysiological and histological scrutiny in an attempt to provide classification of these tissues according to both structure and function. Typically the mechanoreceptor ending is surrounded by specialized epithelial cells and "encapsulated" in order to specialize the response properties of the receptor. Receptors which lack such specialized encapsulation are referred to as free nerve endings and are sensitive to noxious and non-noxious mechanical stress as well as noxious biochemical stimuli. (87) Mechanoreceptors are activated by changes in the receptor ending membrane potential in response to a variety of sensory stimuli, both mechanical and chemical. The resultant generated potential is converted into a specific neural signal from the parent afferent axon fiber with a specific response frequency. These responses are summated with other afferent impulses at the level of the

spinal cord corresponding to the peripheral nerve of the parent axon.(87, 94) The continuous excitation of mechanoreceptors via these afferent pathways may result in receptor accommodation manifested in a decrease in the impulse frequency.(76)

Joint mechanoreceptors have been classified by Freeman and Wyke into four types.(26) Type I receptors are found in the superficial layers of the joint capsule and other fibrous connective tissues. They are thinly encapsulated and sensitive to linear capsular stretching, direction and speed, amplitude and velocity of changes in joint position, and intracapsular pressure changes. Type I receptors are slow to adapt, and have a low mechanical threshold.(26, 94, 114) Type II mechanoreceptors are thickly encapsulated and are located in the fibrous layer of the capsule, between the capsule and the synovial membrane. They are highly sensitive to changes in velocity with initiation and cessation of joint movement, as well as changes in ligamentous tissue tension.(87, 114) Type III mechanoreceptors are found in both the intrinsic (i.e. cruciate) and extrinsic (i.e. collateral) ligaments. They are also thickly encapsulated, and are referred to as Golgi tendon organ (GTO) like receptors.(87, 114) They have a high threshold of activation, are slow to adapt, and are most active at the end of range of joint movements. When activated they may also serve to inhibit agonistic muscular activity.(76) Type IV

mechanoreceptors are found throughout the joint in a variety of tissues. They are bare, unencapsulated endings of both myelinated and unmyelinated axons and are most sensitive to pain, inflammation, and other chemical or mechanical noxious stimuli, rather than position sense or reflex generation.(53, 87) Knee ligamentous tissue has been shown to contain primarily the rapidly adapting Type II receptors.(94) The highest densities of mechanoreceptors in the anterior cruciate ligament has been found near the tibial insertion. Neural elements are reported to constitute 1% of the total area of this ligament.(53, 74)

In addition to the contribution of afferent input from the joint mechanoreceptors, the spinal cord also receives significant afferent input via the GTOs located within the myotendinous junction of the muscles that provide dynamic stability to the ankle joint. Like joint mechanoreceptors, the GTOs are encapsulated receptor organs. They are highly sensitive to any degree of change in tension in the individual muscle fibers to which they are attached.(67) Recent studies indicate that the GTO functions in parallel fashion with both joint, muscle, and cutaneous mechanoreceptors to monitor all thresholds of muscle tension, length, and velocity of movement in relation to spatiotemporal orientation.(67) They are especially sensitive to concentric muscle activation forces.(67, 74)

Muscle mechanoreceptors (muscle spindles) provide afferent information with regards to muscle lengthening (both rate and magnitude). Investigation of small muscles that act across joints in parallel with larger muscles, "parallel muscle combinations", have revealed higher muscle spindle densities in these smaller, less powerful muscles.(74, 81) In some instances Nitz and Peck found smaller muscles to have a three fold increase in spindle density when compared to larger parallel muscles.(74) These smaller muscles have been postulated to be serving to correct or modify major joint movements, possibly providing kinesthetic and proprioceptive feedback to the CNS.(4, 9, 74)

The role of cutaneous afferent neuronal input as related to joint kinesthesia and proprioception remains unclear. Slowly adapting cutaneous afferents have been shown to signal joint movement in the intermediate ranges of joint position in the fingers.(41) These same afferent receptors, when stimulated, provide sensations of skin stretching or flutter, and often no sensation, as opposed to distinct position sense.(41) In most experiments in which attempts have been made to block cutaneous afferent input, total peripheral anesthesia has been used, making it difficult to sort out the role of cutaneous afferent from other peripheral afferent structures.(33)

Articular Injury and Neurologic Dysfunction

Proprioception involves the culmination of afferent neural input from mechanoreceptors found in the joint capsule, skin, muscles, tendons, and ligaments, to the central nervous system (CNS). (87) Mechanoreceptor neural signals synapse in the spinal cord with interneurons and are influenced by inhibitory or facilitory input from supraspinal and propriospinal pathways prior to influencing lower motoneuron efferent responses. Peripheral mechanoreceptor input is critical to the CNS internal loop control system for the monitoring and adjusting of the threshold of interneurons from cortical control centers and thus influencing proprioceptive, kinesthetic, and reflexive muscle splinting. (67) Kinesthesia, which is the conscious awareness of joint position and movement, is most critical in the ability to maintain postural balance through maintaining body center of gravity. Although the CNS requires the integration of input from vestibular and visual systems with that from muscle mechanoreceptors to maintain balance, there is debate whether or not joint or cutaneous mechanoreceptor input influences are important for conscious awareness of joint positioning. Reflexive muscular splinting is the coordination of motor unit activation in muscles surrounding a joint in an effort to provide added joint stability and maintain optimal muscle length-tension relationships with closed chain activities. The impairment of normal reflexive muscle

splinting at the ankle has been theorized to result from the formation of post traumatic scar tissue within the joint capsule.(87, 114) Changes in joint capsular tension can influence the activation threshold of the muscle spindle adjacent to the joint, via their musculotendinous insertions into the joint capsule.(29, 87, 114)

Ligamentous Injury

Functional instability, as described by Freeman et al, was attributed to the sensation of instability associated with functional activities in subjects with a history of ankle ligamentous injury. They used the term articular deafferentation to describe the disruption of articular afferent responses as a result of mechanoreceptor damage.(25) The subsequent diminished reflex response in muscles surrounding the joint could result from a decrease in proprioceptive input to the CNS or an increase in the activation of inhibitory interneurons within the spinal cord.(73) Johansson et al. have evaluated the input at the knee and concluded that the knee ligament mechanoreceptors cause a direct increase in the level of response in the gamma efferent muscle spindle receptors, and thus serve to influence joint stabilization via muscle firing under moderate loads as a means of joint protection.(47)

A direct ligament-muscle reflex arc from the ACL in cats and humans has been established by Solomonow et al. Human

subjects with ACL deficiency showed an increase in facilitation of reflex hamstring activation, and an increase in inhibition of reflex quadriceps activation during loaded open-chain knee extension. They concluded that an interruption of this arc secondary to ligamentous injury, initiates a slower reflex arc dependent upon muscle and joint mechanoreceptors which influences the inhibition of the quadriceps muscles.(97) Closed-chain perturbation of the knee in ACL deficient human subjects has recently been shown to slow reflex quadriceps and hamstring activation.(113) Corrigan et al. have also shown that diminished proprioceptive responses occur following ACL rupture.(12) Stener et al. found that stress applied to ruptured knee medial collateral ligaments increased the activation of knee joint agonist (hamstring) muscles but stress applied to intact medial collateral ligaments elicited no agonist muscle responses, implying that ligament pain and pressure receptors are responsible for muscle reflex splinting.(99)

In the human ankle joint attempts to establish a link between ligamentous mechanoreceptors and a protective muscular response have produced conflicting results. The reflexive response of the peroneal muscles at the onset of inversion perturbation has been studied in subjects with normal ankles. Konradsen et al. found no significant difference in peroneal reaction time between normal ankles and ankles without afferent input secondary to regional

anesthesia. They suggested that intact muscular afferent mechanoreceptors in ankles with ligamentous damage would provide sufficient afferent neural information to allow for reflexive dynamic stabilization through proximal ankle musculature.(57) An earlier study by Konradsen of subjects with complaints of functional instability secondary to ankle injury showed a significant increase in peroneal reaction time with sudden inversion stress. However, neither the severity of injury or ligamentous integrity of the subjects involved in the study were adequately addressed.(55)

A similar study assessed the peroneal reaction time to inversion stress in both post-operative ankle reconstruction and post-injury ankle sprain subjects. Post-operative subjects were at least 6 months from time of surgery, and post-injury subjects were at least 3 months from injury. Although the post-injury group showed no side-to-side reduction in peroneal response time, there was a trend towards a delayed response in the post-operative ankles.(49) The effects of ACL reconstructive surgery on ligamentous mechanoreceptors has been shown to be deleterious up to 6 months following surgery in animal models.(30) Delayed peroneal response times to inversion perturbation has also recently been found to be present in individuals with chronic functional instability of at least 12 months.(62)

Feuerbach et al. attempted the isolated abolishment of the ATFL and CFL mechanoreceptors in normal ankles. They

found no significant differences between the subjects in the anesthetized and non-anesthetized groups with regards to the ability to replicate active ankle positioning in the open-chain, suggesting that ligamentous mechanoreceptors fail to play a significant role in the ability to sense joint positioning.(24) Functional instability has been correlated with a decreased ability to maintain unilateral balance in standing, but not in subjects with acute ankle sprains.(104-106) Postural instability in subjects with functional instability does not seem to be related to the level of mechanical instability.(106) Since postural stability relies heavily on both joint kinesthetic receptors and visual and vestibular input, it is possible that stabilometry is an inadequate tool for assessing the dynamic mechanoreceptor response systems associated with functional and mechanical instability.(43, 112)

Neural Injury

The combined effects of joint deafferentation and the disruption of ligamentous restraints has been shown to lead to significant joint dysfunction and articular cartilage damage in canine knees.(77, 78) The fact that a loss of both joint mechanoreception and ligamentous stability is required to accelerate the rate of mechanical and functional instability indicates that muscular protective responses

alone are not sufficient to provide adequate joint stabilization in the presence of trauma.(73)

The significance influence of joint inflammation with regards to joint afferent responses may often be overlooked.(112) The term neurogenic inflammation has been used to describe the denervating effects that biogenic amines, such as histamines, and other neurotransmitters (substance P, vasoactive intestinal polypeptides) may have on neural tissues secondary to local inflammatory responses.(58, 73) The initial inflammatory response phase subsequent to tissue trauma may last for up to 7 days, adequate time to initiate the deleterious effects of neurogenic inflammation within joint neural structures.(3, 73) Acute joint inflammation has been shown to influence the level of excitability of joint mechanoreceptors within as little as 1-2 hours of induced inflammatory substances.(36) Acute non-inflammatory joint effusion has been found to have no immediate effects on knee joint position sense, indicating that long term and acute inflammatory conditions, not merely the presence of joint effusion, effect joint mechanoreception.(65) Chronic inflammation may adversely affect protective neuromuscular function by increasing the afferent sensitivity to nociceptive impulses and subsequently alter the integration of other afferent input at the spinal level.

Muscle de-efferentation, responsible for muscle denervation, is also believed to be associated with neurogenic inflammation.(73) Nitz et al. reported the presence of moderate to severe denervation of muscles supplied by the peroneal and tibial nerves in 31 individuals who had sustained Grade III ankle inversion injuries. They also noted significant gastrocnemius muscle atrophy in the majority of their subjects.(72) Kleinrensink et al. reported decreased superficial and deep peroneal motor nerve conduction velocities in subjects with acute (4-8 days) ankle inversion injuries (Grade I - Grade III). Contralateral differences in nerve conduction velocities persisted up to 5 weeks in the distal segment of the deep peroneal nerve. Stretching of the nerve was suggested as the mechanism of nerve injury.(54) Articular nerve fibers have lower tensile strength than collagen fibers and may be susceptible to tearing with inversion injuries.(5, 25, 26) Invertor musculature weakness has been documented in individuals with ankle functional instability and decreased balance abilities, possibly linked to tibial nerve injury or selective reflex inhibition.(88)

Joint Swelling

The significant influence that post-injury joint swelling, has on ligamentous, capsular, and articular mechanoreceptors must be considered when investigating

inhibition of protective muscular responses.(23, 53, 110, 115) Quantification of joint swelling can be correlated to severity of joint injury and extent of the inflammatory response.(71) A linear relationship has been shown to exist between the amount of joint effusion and intra-articular pressure.(15, 80, 98) Prolonged intra-articular pressure in saline infused knee joints produces capsular laxity, as observed by the hysteresis phenomenon, within a period of 2 hours.(80) Joint effusion associated with a lateral ankle ligamentous injury may produce a ballooning of the anterior lateral capsule, secondary to the development of positive omnivectorial pressure and the development of an edema pocket around bony concavities.(109, 110) The confluent relationship between the ATFL and the joint capsule may lead to the elongation of the disrupted ligamentous fibers and deformation of the lateral capsular tissues.(112) Type I mechanoreceptors embedded within the fibrous capsular tissues and in ligaments would likely be influenced by changes in joint capsular pressure and ligamentous deformation.(76, 87, 115) Tension on the joint capsule associated with arthrotomy sutures has been postulated to evoke afferent impulses from these same receptors in the knee, and may be responsible for post-operative reflex quadriceps inhibition.(115)

In the decerebrate cat knee, joint effusion has been shown to impair the patellar reflex by inhibition of the monosynaptic arc from the ipsilateral quadriceps muscle.(17)

Inhibition of the knee extensor muscles secondary to joint effusion has been demonstrated in normal, and post-operative, human knees.(15, 23, 53, 98) Fahrer et al. found that aspiration of fluid from chronically effused knee joints produced a 13.6% increase in isometric extensor strength. Local intra-articular anesthetizing of the same aspirated knees produced an additional 8% increase in quadriceps strength, they proposed that both pressure and non-pressure (i.e. pain) mediated responses are responsible for muscle inhibition.(23) In contrast, Jones et al. found that aspiration of fluid from chronically inflamed knee joints did not improve quadriceps strength, suggesting that either joint capsule deformation or chronic neurogenic changes rather than effusion may be responsible for afferent inhibitory influences of joint extensor muscles.(50)

Three studies have examined the relationship of joint volume/pressure to the quadriceps H-reflex.(42, 53, 98) Kennedy et al. monitored the knee for changes in joint pressure, fluid volume, and H-reflex responses from the vastus medialis, lateralis, and rectus femoris during progressive saline infusion. They reported progressive decreases in H-reflex amplitudes with increased knee joint pressure and fluid volume. Anesthesia of joint mechanoreceptors improved the H-reflex amplitudes that had been reduced by joint distention. No change of the decreased H-reflex amplitude was noted with prolonged (30 minutes)

effusion and selective inhibition of the vastus medialis was suggested by the authors.(53) Spencer et al. repeated this study, but attempted to establish a threshold for quadriceps H-reflex inhibition. They found that the greatest effects of reflex inhibition were correlated with 20-30 ml of saline for the vastus medialis and 50-60 ml for both the vastus lateralis and rectus femoris. As in the previous study, intra-articular anesthetic did not further reduce H-reflex amplitudes.(98) Iles et al. investigated the effects of saline induced joint effusion on the quadriceps H-reflex at rest and during voluntary quadriceps isometric contraction with the knee in full extension. They reported significant reductions in H-reflex amplitudes during both conditions. Inhibition of the H-reflex by stimulation of Ib GTO afferents in the tibial nerve (from the gastrocnemius/soleus) was also increased by knee effusion. This implies a linkage of the Ib and joint afferent pathways. (42) These studies suggest that minimal capsular distention may account for afferent modulation of spinal reflexive motor responses, and subsequent compromise of proprioceptive mechanisms.

Patients with lateral ankle injuries consistently allow their injured ankle to assume a plantar flexed and inverted position when non-weight bearing.(110) The spontaneous assumption of flexed positioning in the presence of joint effusion has been reported in both upper and lower extremity peripheral joints.(22, 80, 110, 115) Joint positioning to

minimize the effects of intra-articular pressure could be responsible for spontaneous joint positioning.(22, 115) Reflex inhibition of agonist and facilitation of antagonist secondary to type I mechanoreceptor stimulation with stretching of the anterior joint capsule has also been suggested.(16, 115) Studies in the inflamed cat knee joint have shown that animals adopt joint positions that reduce nociceptive input as a result of changes in alpha and gamma motoneuron excitability thresholds.(36)

Quantification of Ankle Joint Swelling

Physical therapists have attempted to quantify joint swelling as a means of evaluating the effectiveness of the treatment of joint inflammation.(82, 95, 110) The methods that have employed have not served to differentiate between intracapsular joint effusion and extracapsular (intercellular) edema, but have attempted to provide the clinician with a single quantitative measure of one aspect of the tissue inflammatory response. As noted by Esterson, the measurement of swelling at the ankle joint has been attempted with calipers across the malleoli, but this method lacks specificity for measuring swelling at or near the injured ligaments.(21) Plethysmography, as noted by Nilsson et al., is a more sophisticated method for measuring limb volume, but is much too time consuming and often impractical for clinical research.(70) Water displacement volumetry has

been employed by many researches and clinicians as a means of objectively assessing the effects of various treatments for ankle sprains.(1, 2, 31, 82, 95) Nielson et al. studied the use of water displacement volumetry for determining side-to-side differences and daily variations of the ankle and foot volume in normal human subjects. They found that the right extremity often produced a slightly greater volume than the left, however no correlation to limb dominance was found. Additionally, the investigators found that the absolute volume of each limb varied from day-to-day, and affected both limbs equally. The investigators deemed that the measurement technique was "accurate" but provided no reliability data or "Gold Standard" measurement for quantification of ankle and foot volume.(70) Water displacement volumetry, the disk model method, and the frustum sign model were compared as methods for quantifying volume of the lower leg, minus that of the foot and ankle. The researchers determined that water volumetric measurement was highly subjective to methodological failure.(101) No reliability studies have been reported on ankle caliper measurements or water volumetric measurements. Computed tomographic scan and MRI have been used to distinguish between normal ankle anatomy and the anatomy of ankles with pathology, but have not been used to compare methods of ankle joint measurement.(11, 96)

The use of an ordinary tape measure has been the standard device for quantifying circumferential ankle girth.

Circumferential measurement of ankle edema using a tape measure and circumscribing the ankle at the medial and lateral malleoli has been found to have a high degree of interrater reliability.(59) Esterson was the first to propose that a figure-of-eight tape measurement technique be used to measure swelling across several ligamentous structures common to ankle sprains.(21) Although he reported that the procedure could be easily reproduced, no reliability data were provided. Recently, intratester and intertester reliability of this technique was reported to be highly reliable (.99 and .99) in subjects with normal healthy ankles.(102) The validity of the aforementioned methods of quantifying ankle swelling has not been addressed in the literature.

Significance of the H-Reflex

The H-reflex was originally described by Hoffman in 1918, and was further evaluated and named by Magladery and McDougal in the 1950s.(48) The reflex is a latent compound motor action potential wave elicited by electrical stimulation of the muscle nerve. Mediated over the Ia afferent pathway, the H-reflex is a monosynaptic reflex response that can be directly compared to the response produced by the stretch reflex.(20) In adult humans, the response is elicited regularly in the calf muscles, is clinically used to assess the integrity of the first sacral

nerve root, and is useful in studies of peripheral neuropathies.(48, 63, 90) Normative data have been published comparing the Soleus H-reflex to those elicited in the vastus medialis and flexor carpi radialis muscles.(90) Neurophysiologically, the H-reflex has been useful in studies of the changes in motoneuron excitability, muscle reaction time, and the period before movements.(14, 42, 66, 68, 70, 89) Standardized methodologies for soleus H-reflex testing have been developed by Hugon and Johnson et al. Hugon advocated the use of bipolar electrodes, while Johnson et al. recommended a monopolar technique.(40, 48) Maryniak et al. studied the effect of recording electrode location on latency and amplitude measurements of the soleus H-reflex. They demonstrated that distally placed recording electrodes (surface) produced increased H-reflex amplitudes and latencies of responses to stimulation of the tibial nerve at the popliteal fossa.(63) In a more recent study, posterior compartment H-reflexes were recorded with intramuscular monopolar electrodes. The authors reported that cross talk between the compound muscle action potentials of the soleus, flexor hallucis Longus, and flexor digitorum longus is a possibility.(64)

Joint effusion, and agonist and antagonistic muscle contraction influence H-reflex amplitudes.(42, 48, 53, 63, 66, 90, 98) Joint manipulation at the level of the sacrum has been shown to decrease the soleus H-reflex amplitude,

even in the presence of local anesthesia.(68) Contralateral neck rotation can enhance H-reflex amplitudes, while ipsilateral rotation can inhibit the response.(103) Local muscle cooling has been shown to decrease H-reflex amplitudes of the gastrocnemius muscle.(107) Depression of the H-reflex response may also occur when the frequency of stimulation is greater than one every five seconds.(40) Variability in the latency of the H-reflex response is compatible with a spinal synaptic delay, in patients with peripheral and acute proximal neuropathy.(48) Johnson and Braddom suggested that H-reflex amplitude studies were not practical or clinically useful, citing the time required to obtain reliable amplitude measurements as a factor.(48) Jankus et al. studied the normal limits of side-to-side H-reflex amplitude variability. They noted that side-to-side H-reflex amplitudes were more variable than latencies, and that complete subject relaxation and similar electrode placement are critical factors in obtaining symmetrical responses.(46) Sabbahi et al. found side-to-side H-reflex latencies to be more consistent than amplitudes when elicited by femoral nerve stimulation and recorded in the vastus medialis muscle.(90)

Functional Rating of Ankle Injuries

Traditionally the severity of an ankle ligament injury has been linked to the severity of soft tissue damage.(45) A variety of grading or clasification schemes have been used to

describe the extent of ankle ligament injuries, each with their own criteria for the classification of the injury. (10, 39, 72, 79) Along with the ankle stability tests (ie. anterior drawer, talar tilt) other more subjective signs and symptoms such as swelling and pain frequently play a significant role in the classification of ankle sprains. (92) Terms such as grade I, grade II, and grade III are often used synonymously with mild, moderate, and severe. While this terminology may accurately reflect the degree of mechanical instability, their association with a distinct level of functional impairment may be less accurate. (111) Tropp et al. did not find a high degree of association between mechanical and functional instability in male soccer players. The authors did not report the degree of mechanical instability, but did associate mechanical instability with a positive anterior drawer test. (106) Rijke et al. conducted a post-traumatic follow-up of 20 individuals with lateral ligament injuries and defined function in terms of passive inversion stress testing. They found that surgically treated patients had recovered a greater amount of function than non-surgically treated patients. However, neither closed chain or dynamic open chain tests were performed. (85) Liu and Jacobson utilized an eight category ankle scoring system in an attempt to rate the function of patients who underwent lateral ankle reconstructive surgery. They included the objective measures of range of motion (dorsi and plantar flexion), anterior drawer and talar tilt radiological

testing, as well as the subjective measures of pain, functional instability, and level of functional activity.(61) Task oriented functional rating scales associated with recovery from ankle ligamentous injury have been published by three different authors. Linde et. al. rated ankle function based on pain, swelling, and mobility. They incorporated tasks such as wieght bearing ability, and return to work or sport.(60) Hocutt incorporated tasks such as walking, stair climbing, running, and jumping in a functional assesment of sprains of a similar severity. The authors reported on the number of days from injury to the performance of each of these tasks without pain.(37) Kaikkonen et. al. developed a 100 point scoring system for the evaluation of functional recovery following an ankle injury. Testing included a subjective assessment (recovery of function), clinical measurements (range of motion, and laxity), functional stabilty, muscle strength (dorsi and plantar flexion), and balance. They found that the test could significantly differentiate between excellent and poor or fair recovery in subjects with a history of grade III inversion sprains who had undergone surgical lateral ligament reconstruction. The mean time between operation and testing was seven years.(51) Wilkerson et. al. devised an 11 point functional scale to asses the effects of the use cryotherapy and compression on acute grade II ankle inversion ankle sprains. Weight bearing, walking, jogging, running, and a zigzag hopping test were used to aide in the assignment of a functional level to

the patients throughout the rehabilitation period. They reported a strong linear relationship between days to recovery and level of function.(111)

Summary

The inversion ankle sprain is a common and significant injury associated with the majority of sports which include abrupt closed chain actions. Inversion ankle injury leads to disruption of the ATFL and confluent lateral capsule, both of which are likely to be rich in mechanoreceptors. Ligamentous, capsular, and synovial mechanoreceptors play an important role in protective reflex and proprioceptive responses. Disruption of these structures may lead to alterations in afferent mechanoreceptor responses. Muscle and tendon mechanoreceptors have been linked to joint stabilization during dynamic and postural strategies, and may also be influenced by inversion trauma. Acute and chronic inflammation and subsequent mechanoreceptor deafferentation has been shown to affect mechanoreceptor excitability levels and influence motoneuron responses. Direct trauma to articular nerve fibers could be an additional factor in the inhibition of reflex responses. Capsular distention as a result of knee joint effusion has been linked to quadriceps inhibition and decreases in H-reflex amplitudes. Similar inhibition of dynamic stabilizers of the ankle may occur with joint swelling as associated with ankle inversion sprains.

Swelling that occurs as the result of ankle sprain injury may be quantified best using the figure-of-eight measurement technique, which has been shown to be reliable and easy to use in the clinical setting. The H-reflex is also a clinically relevant tool that can be used to assess changes in motoneuron excitability and the integrity of the Ia afferent pathway. A correlation between the amount of ankle swelling and the H-reflex responses in the lateral and medial ankle dynamic stabilizers seems plausible given the relevant anatomy, joint pathology, and previously established correlation in the knee joint.

CHAPTER 3

METHOD

This chapter describes the subjects, methodology, and statistical analysis used in this study. This study investigated the relationship between the H-reflex response of the peroneus longus and flexor digitorum longus muscles and the amount of ankle swelling associated with an acute inversion ankle sprain.

Subjects

A total of 40 volunteer subjects participated in the study. A control group (n=20) consisted of 11 males, and 9 females, between the ages of 19 and 41 years, with a mean age of 26 years. All individuals in the control group had no history of significant lower extremity injury within the past 3 years. Individuals with a history of lower extremity surgery, cardiac pace makers, neurological, circulatory disorders, diabetes, and/or prolonged alcohol abuse were excluded from both the control and study groups. The injury group (n=20), consisted of 16 males, and 4 females, between the ages of 15 and 41 years, with a mean age of 23 years. All subjects in the injury group had a history of acute (less than 10 days post-injury) inversion ankle injury.

Individuals with acute fractures (except minor lateral malleolus chip fractures), and/or bilateral lower extremity injury were excluded from the study group. Subjects in the control group were recruited from a university entry level physical therapy program. Subjects in the injury group were recruited through the university athletic training and sports medicine facilities, as well as through local out-patient physical therapy clinics.

All subjects participated in either recreational, intramural, or collegiate athletic programs, although all of the inversion injuries studied did not involve athletics in the mechanism of injury. Six subjects from the control group and 4 subjects from the injury group were eliminated from the study because of the inability to elicit the H-reflex response in the FDL muscle of one or both limbs. Table 1 presents the descriptive statistics for gender and age. Each of the control and study group subjects read and signed a University of Kentucky IRB approved consent form prior to participation in the study. Subjects less than 18 years of age read and signed a University of Kentucky IRB approved assent form. An approved parental consent form was signed by the parent or legal guardian of each of the minor subjects. These documents explain the role of the subject, possible risks and benefits, and details the subject's rights. Appendix A contains the approved consent and assent forms. In addition, each subject received a full verbal explanation

TABLE 1

SUBJECT DEMOGRAPHICS (AGE AND GENDER)				
	CONTROL		INJURY	
	MALE	FEMALE	MALE	FEMALE
MEAN	25.25	26.17	20.92	31.33
STD DEV	5.23	7.76	3.62	11.93
MIN	20.00	19.00	15.00	18.00
MAX	36.00	41.00	29.00	41.00

of the testing procedures, risks, benefits, and rights, prior to participation.

Testing Procedure

1. Functional Level Evaluation

Each subject was evaluated for their current level of function prior to electroneurophysiological testing. Subjects were evaluated using a modified Lateral Ankle Sprain Functional Evaluation Scale, developed by Wilkerson (Appendix B).(109) The scale allowed the researcher to assign a functional level (0-10) to each subject, based on gait characteristics, functional activities (i.e. unilateral hopping, zigzag hopping), anterior drawer and talar tilt tests, and objective signs and symptoms. Level 0, corresponded to the lowest level of function, while Level 10 corresponded to normal functional gait. Additionally, a grade (I, II, or III) was assigned to the injured ankle, based on the grade associated with the functional level, as defined by the evaluation scale. The scale was modified by omitting isokinetic analysis of invertor and evertor muscle strength testing as a part of the objective criteria for level 7 through level 10. In addition to functional level and severity grade the following information was also recorded for the injury group subjects: 1) the side (left or right) of the injury 2) the number of days since the ankle injury;

3) whether or not a brace was used by the subject; 4) type of care received prior to testing.

2. Quantification of Ankle Swelling

The figure-of-eight measurement technique was used to quantify objectively the amount of swelling of each ankle studied (Fig. 1). The intrarater and interater reliability of this technique both were found to be high (.99 and .96) in a pilot study conducted by the researcher of the present study.(35) The order of ankle measurement was randomized using a random number table. Subjects were instructed to sit in a long leg sitting style on a treatment table in such a manner as to allow both ankles to be free of any contact with the surface of the table. The ankle to be measured was positioned in neutral (0° of dorsiflexion/plantarflexion) and the position confirmed with a hand held goniometer. The subject was instructed to maintain this position throughout the measurement procedure. Landmarks for measurement were marked on the ankle with a skin pencil. The following landmarks were used:

1. Navicular tuberosity
2. Base of the 5th metatarsal
3. Distal tip of the medial malleolus
4. Distal tip of the lateral malleolus

5. Tibialis anterior (TA) tendon, superior to the insertion point and level with the distal tip of the medial malleolus

Once the landmarks had been identified, a Guillick controlled tension tape measure (Layfayette Instruments, 3700 Sagamore Parkway North, Layfayette, IN 47903) was placed around the ankle using the following procedure:

1. The beginning of the tape was placed at the mark identifying the TA tendon.
2. The tape was then drawn medially across the instep and placed just distal to the tuberosity of the navicular.
3. The tape was then pulled across the plantar surface of the foot, and upwards just proximal to the base of the 5th metatarsal.
4. Continuing in an upwards direction, the tape was pulled across the TA tendon, and brought just inferior to the distal tip of the medial malleolus.
5. The tape was continued posteriorly across the achillies tendon and around the posterior aspect of the ankle.
6. The tape was placed just inferior to the distal tip of the lateral malleolus.

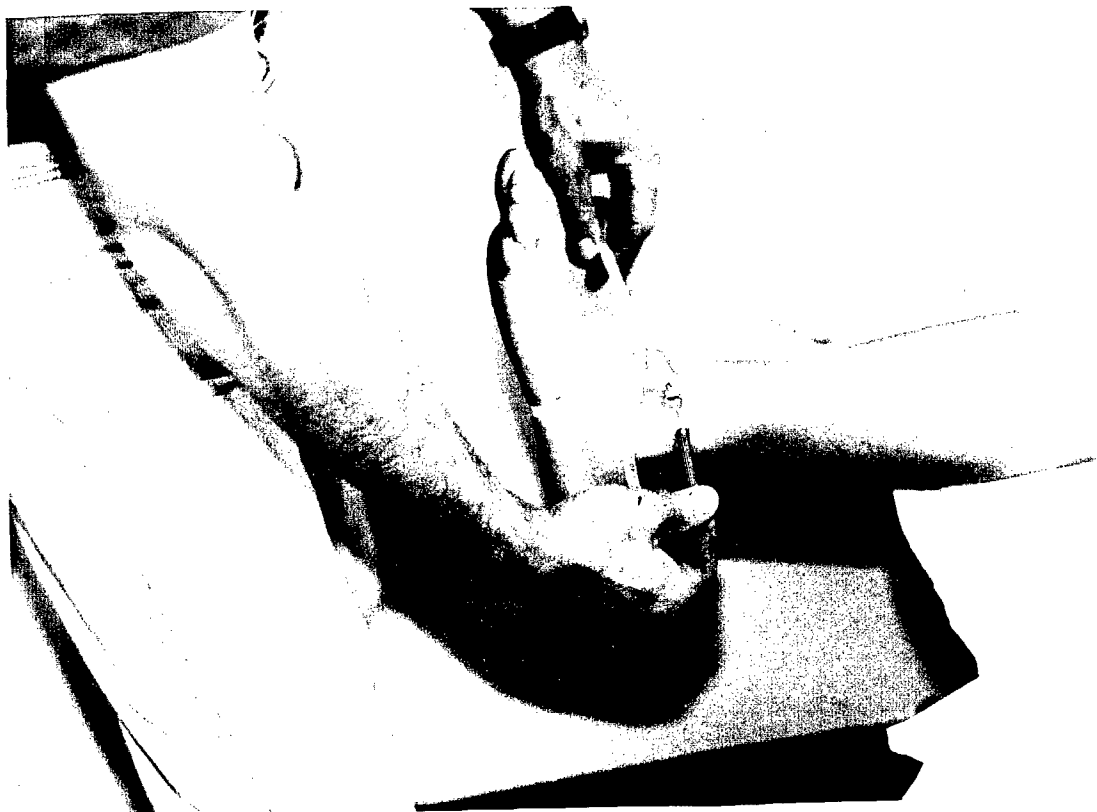


FIGURE 1: Figure-of-eight measurement technique.

7. The tape was brought back to the beginning point on the TA tendon and the measurement recorded in centimeters.

The tape was removed from the ankle and the procedure repeated; three separate measurements were recorded for each ankle. The same procedure was then used to measure the contralateral ankle.

3. H-reflex Testing

The testing for the peroneus longus and flexor digitorum H-reflex responses was initiated immediately following the figure-of-eight measurements. A pilot study of the test re-test interater reliability of the H-reflex testing of these two muscles had been conducted prior to the study with 5 healthy volunteer subjects. The results of the pilot testing had shown that the peroneus longus H-reflex responses had a higher reliability coefficient than those of the flexor digitorum longus (Tab. 2). The poor reliability of the flexor digitorum longus H-reflexes response was attributed to the inability to consistently palpate the flexor digitorum muscle belly of two of the pilot study subjects, who had small legs. Although the FDL latency measurements were identical in 3 of the 5 subjects, they differed by 4.1ms and 8.2ms in these two particular subjects. Additionally, the that the method of electrode fixation and muscle belly palpation could be modified to improve significantly the

TABLE 2

TEST-RETEST H-REFLEX PILOT DATA (N=5)

<u>VARIABLE</u>	<u>ICC</u>
PL-LAT	0.99
PL-AMP	0.79
FDL-LAT	0.02
FDL-AMP	0.60

reliability, and therefore elected to continue utilize the surface electrode procedure for the study.

The order of the two muscles to undergo H-reflex testing in each limb was determined using a random number table. The same order of limb testing was maintained from the figure-of-eight testing procedure. Subjects were instructed to lie prone on the treatment table, avoiding any contact of the ankle joint and the table. The subject was instructed to lie with his or her head in an anatomically neutral position throughout the testing procedure. A pillow was placed under both legs, just inferior to the knee joint line for patient comfort and the facilitation of stimulation at the popliteal fossa. The temperature of each limb was recorded with an electric thermistor (Yellow Springs Instrument Co., Inc., Yellow Springs, Ohio). The disk lead of the thermistor was placed over the dorsal aspect of the 1st metatarsal of each foot and secured with tape. After a period of 3 minutes, the skin temperature was recorded in Celsius, and the lead removed from each foot.

Electrode placement

A large 2 cm disk ground electrode was taped in place over the medial aspect of the gastrocnemius muscle of the limb to be tested at a point 1/2 way in between the medial malleolus and the popliteal crease. The small 1 cm disk surface reference electrode was taped in place over the

Achilles tendon of the same limb at 5 cm proximal to the insertion point at the calcaneus (Fig. 2). Depending upon the order of the muscle H-reflex responses to be tested, one of the following recording electrode placement procedures was then followed:

Flexor Digitorum Longus

The site for the placement of the recording electrode was located by first having the subject flex the knee to 90°. The subjects ankle was maintained in a neutral position by the investigator and the subject was instructed to flex his or her toes while the researcher palpated the muscle belly along the medial aspect of the leg. The point of electrode placement was then marked by the examiner with a skin pencil. Using an obstetric caliper, the distance in centimeters was measured from the distal tip of the medial malleolus to the site of the recording electrode (Fig. 3). This distance was recorded for use to determine the location of a symmetrical recording electrode site on the contra-lateral limb. The small disk recording electrode was then secured over the site with tape.

Peroneus Longus

The site for the placement of the recording electrode was located by first having the subject flex the knee to 90°.

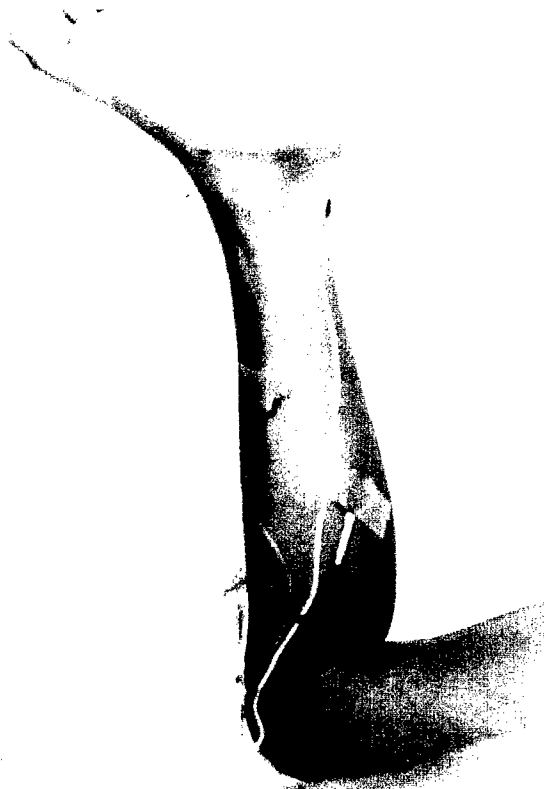


FIGURE 2: Electrode placement (shown for FDL muscle).

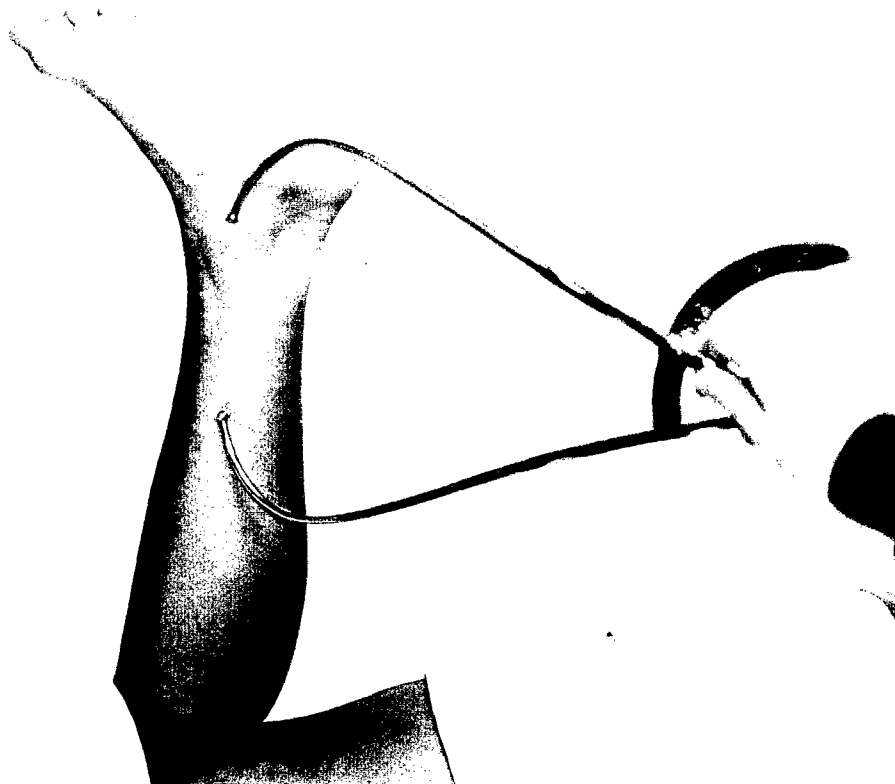


FIGURE 3: Caliper measurement for FDL recording electrode.

The subjects ankle was maintained at 90° of dorsiflexion by the researcher and the subject was instructed to evert his or her ankle and foot while the researcher palpated the muscle belly along the lateral aspect of the leg, approximately 5 centimeters distal to the neck of the fibular head. The point of electrode placement was marked by the researcher with a skin pencil. Using an obstetric caliper, the distance in centimeters was measured from the distal tip of the lateral malleolus to the site of the recording electrode (Fig. 4). This distance was recorded for use to determine the location of a symmetrical recording electrode site for the same muscle on the contralateral limb. The small disk recording electrode was then secured over the site with tape.

Nerve Stimulation

All electroneurophysiologic testing was performed using a Cadwell 5200-A EMG/NCV unit (Cadwell Laboratories, Inc., 909 North Kellogg Street, Kennewick, Washington, 99336). The site for tibial or peroneal nerve stimulation was located in the popliteal fossa at the level of the popliteal crease. The researcher aligned the web space between the thumb and index finger of his left hand with the popliteal crease. The bipolar stimulator, held in the right hand, was aligned in the popliteal fossa so that the cathode was proximal to the anode. The anode was aligned with the level of the web space of the left hand along the popliteal crease.

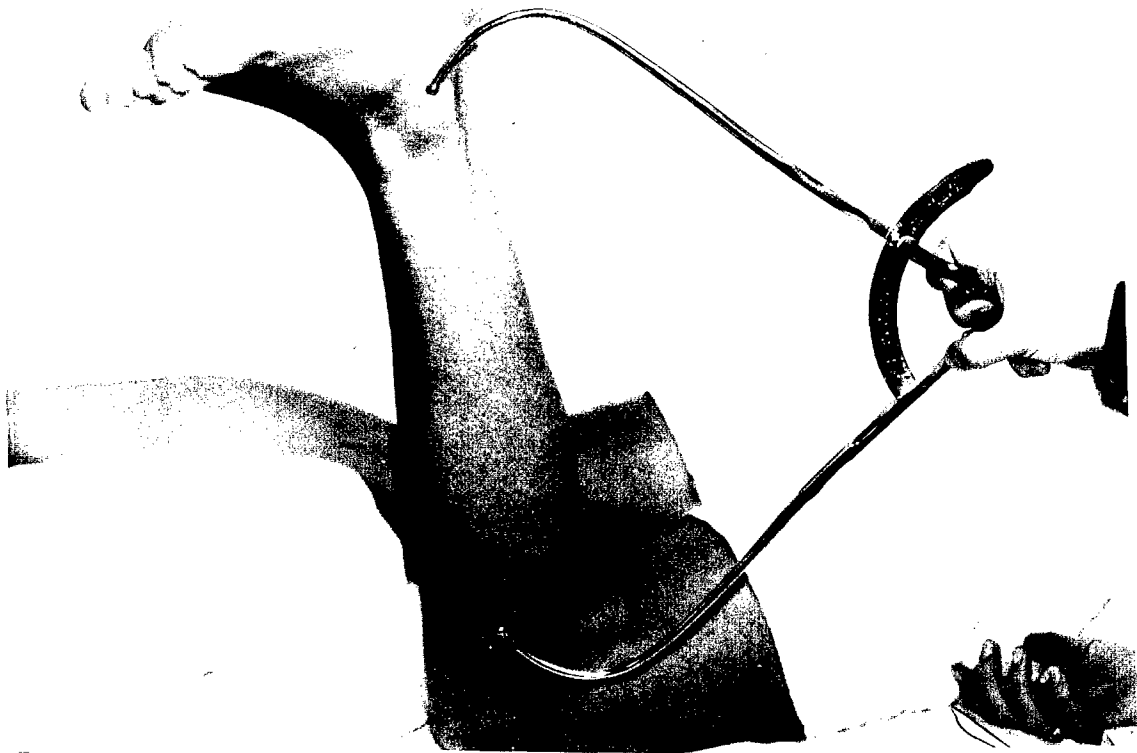


FIGURE 4: Caliper measurement for PL recording electrode.

The stimulator was positioned slightly medially in the popliteal fossa for tibial nerve stimulation, and slightly laterally for peroneal nerve stimulation (Fig. 5). The stimulation parameters were set as follows:

Sweep velocity - 10 milliseconds/division

Sensitivity - 200 - 2000 μ Volts/division

Duration - 1.0 milliseconds

Pulse width - 150 μ Seconds

Prior to stimulation, the subject was given verbal instruction to attempt to remain relaxed. With the sensitivity of the machine set at 200 μ V/division, the stimulus was applied to the nerve with the hand held stimulator at an intensity just greater than that required to evoke a minimal motor response. At least three responses were elicited. The interval between sequential stimuli was no less than 30 seconds. Once the maximum H-reflex amplitude was elicited, the latency was measured and recorded in milliseconds (Fig. 6). Without changing the position or the intensity of the stimulator, the sensitivity was then adjusted to 2000 μ V/division, and the response was again elicited. At this point the amplitude of the response was measured from the base line to the highest peak and recorded in millivolts. The distance from the stimulating



FIGURE 5: Stimulation of tibial nerve at popliteal fossa.

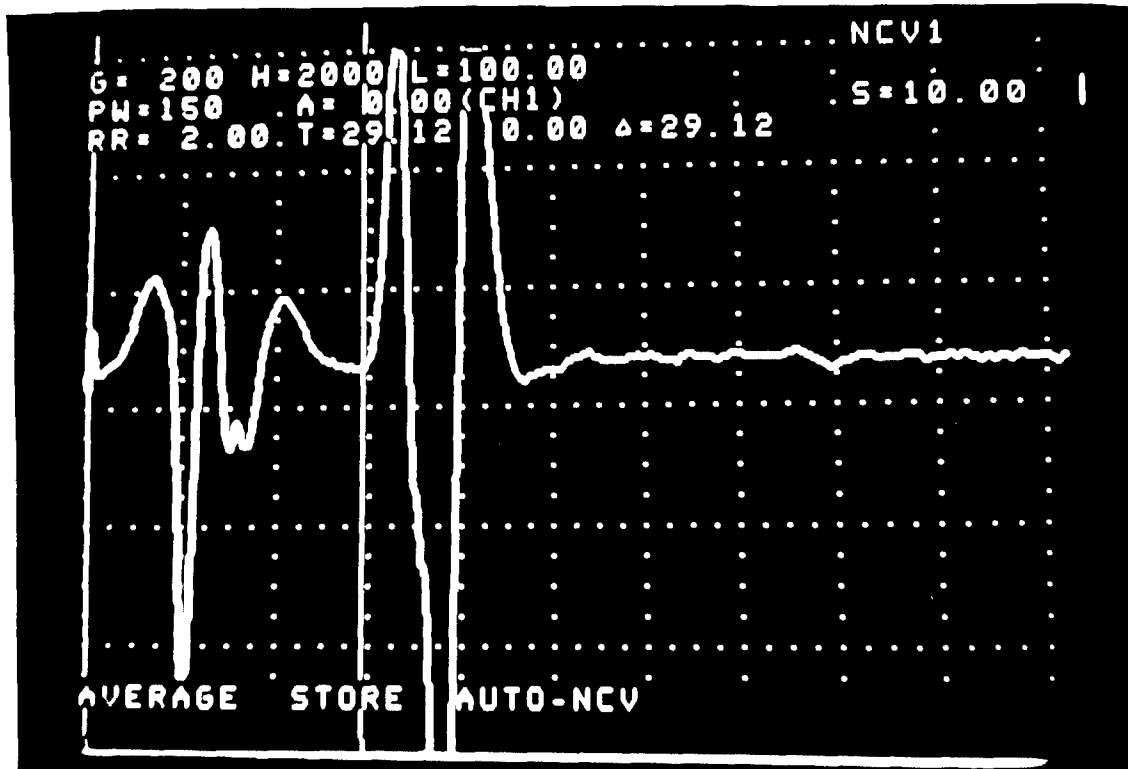


FIGURE 6: Maximal H-reflex response of PL muscle.

cathode site to the recording site was then measured with the obstetric caliper and recorded in centimeters for the purpose of reproducing a symmetrical distance and stimulation site for the same muscle H-reflex on the contralateral limb.

The electrode set up and stimulation procedure was repeated for the same muscle (peroneus longus or flexor digitorum longus) H-reflex on the contralateral limb. Once testing was completed for either the peroneus longus or flexor digitorum longus muscles on both limbs, the examiner repeated the electrode placement procedure for the second muscle H-reflex to be tested, this time beginning with the most recent limb tested. This was done in order to facilitate the testing sequence.

Analysis of Data

A SAS computer program was used to perform all statistical analysis of the data. Descriptive statistics (mean, standard deviation (SD), and range) were computed for subject demographics (age and gender). Descriptive statistics were also computed for the following variables: Number of days from the inversion injury (DFI), functional level, severity grade (I, II, or III), PL latency, PL amplitude, FDL latency, FDL amplitude, and figure-of-eight girth for each limb. These are presented in Table 3.

TABLE 3

INJURY		GROUP		CHARACTERISTICS		DAYS FROM		INVOLVED		USE OF		TYPE OF		FUNCTIONAL		GRADE	
SUBJECT #	#	INJURY	INJURY	SIDE	SIDE	BRACE	BRACE	CARE	CARE	LEVEL	LEVEL	GRADE	GRADE				
1	1	L	L	Y	M	2	2										
2	4	L	L	N	S	3	1										
3	10	R	R	Y	M	3	1										
4	3	R	R	N	M	2	2										
5	6	L	L	N	M	3	1										
7	7	R	R	Y	M	4	1										
8	3	R	R	N	S	5	1										
10	7	R	R	N	M	4	1										
11	9	L	L	N	S	3	1										
12	10	L	L	Y	S	2	2										
13	5	R	R	Y	S	3	1										
14	3	L	L	Y	S	2	2										
15	10	R	R	Y	M	8	1										
16	10	L	L	N	M	8	1										
17	2	L	L	Y	M	1	2										
18	7	R	R	Y	M	1	2										
MEAN	6.06					3.38	1.38										
STD DEV	3.15					2.09	0.50										
MIN	1.00					1.00	1.00										
MAX	10.00					8.00	2.00										

Type of Care: M = modality treatment received
S = self care only

The interclass correlation coefficient (ICC) was used to analyze reliability of the figure-of-eight and H-reflex measurements in two separate pilot studies.

The Pearson Product Moment Correlation was used to assess the relationship between the side-to-side (involved - uninvolved) differences in latency, differences in amplitude, differences in figure-or-eight girth, DFI, functional level, and severity grade for the injury group.

The paired t-test procedure was used to analyze differences in latency, amplitude, and figure-of-eight girth measurements between the limbs for each group. A standard two-tailed t-test procedure was used to compare the means of the side-to-side differences in latency, amplitude, and figure-of-eight girth of the subjects in the injury and control groups. Limb dominance was not assessed in this study among either the control or injury groups, and the right minus left values of the control subjects was arbitrarily used as the side-to-side difference values for the two-tailed t-test comparisons with the injury group involved minus uninvolved differences.

A multiple regression analysis procedure was used to determine the predictability of side-to-side differences in latency, amplitude or figure-of-eight girth based on the injury group subjects gender, DFI, functional level, severity grade, use of a brace, or type of care received. Because of

the small sample size in the injury group, The Fisher's exact test and the two-tailed t-test were used to test for any statistically significant association between the independent variables of gender, use of a brace, severity grade, functional level, and type of care received. The Chi-square goodness of fit test was not used because of the small frequency (<5) of occurrences in the cells of the Chi-square table. A probability level of .05 was used to determine significance in all statistical analysis.

CHAPTER 4

RESULTS AND DISCUSSION

This chapter will present the results of this study and provide discussion as to their clinical significance.

Results

Injury Group Characteristics

The inversion ankle sprain occurred equally (n=8) among either the right or left limb. There was near equal frequency of occurrence (n=9) of the use of a brace among the injured subjects. The majority of the subjects received some form of clinical modality treatment prior to the time of data collection. The treatment varied from cryotherapy to electrical stimulation. The remaining subjects all administered some form of self-care prior to the time of data collection. Self-care ranged from benign neglect of the injury to the R.I.C.E. (rest, ice, elevation, and compression) scenario. Results of the two tailed t-tests used to analyze differences in the means of the injury characteristics of side of the involved limb, use of a brace, type of care received prior to testing, DFI, functional level and

severity grade are shown in Table 4. The difference between the mean functional level of the subjects who sustained a grade I sprain and those who sustained a grade II sprain was statistically significant. The Fisher's exact test did not reveal any statistically significant associations between the means of any of the other injury characteristic variables (Tab. 5).

Figure-of-Eight Measurements

Descriptive statistics for the figure-of-eight measurements of both ankles of subjects in the injury and control groups are presented in Table 6. The paired t-test showed a statistically significant difference in the mean differences in the limb figure-of-eight measurements of both the control and injury group subjects. The results are shown in Table 7, and illustrated in Figure 7. The two-tailed t-test also revealed a statistically significant ($p=.0001$) difference between the mean side-to-side difference in figure-of-eight girth measurements of the injury and control group. Multiple regression analysis failed to show any predictive value of side-to-side difference in figure-of-eight girth based on the independent variables of gender, severity grade, functional level, DFI, use of a brace, or type of care received.

TABLE 4

TWO TAILED T-TEST
INJURY GROUP CHARACTERISTICS (P VALUES)

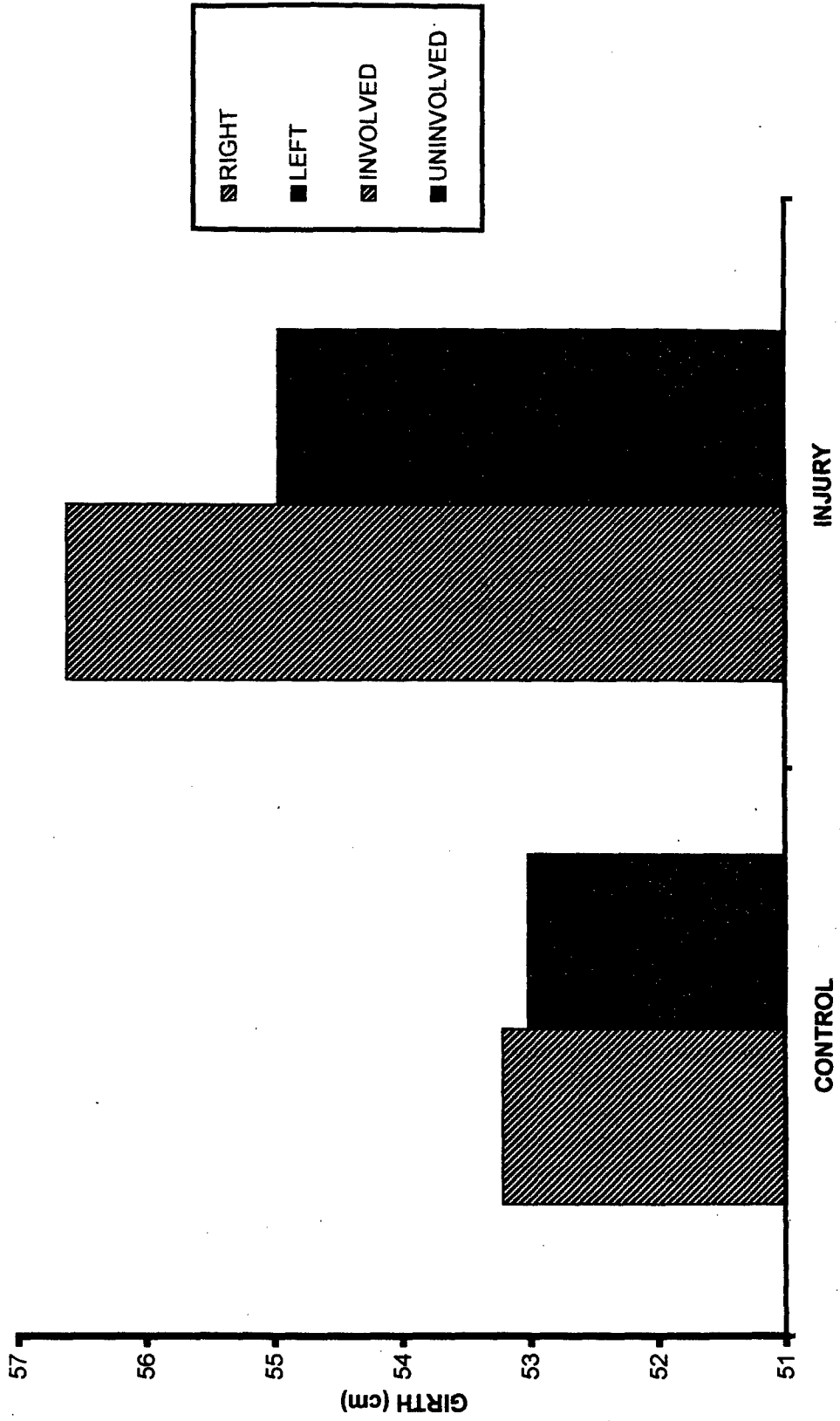
	<u>FUNCTIONAL LEVEL</u>	<u>DAYS FROM INJURY</u>
SEVERITY GRADE	0.006	0.089
USE OF BRACE	0.308	0.947
TYPE OF CARE	0.597	0.711
GENDER	0.357	0.585

TABLE 5

FISHER'S EXACT TEST
INJURY CHARACATERISTICS (P values)

	GENDER	BRACE	CARE	GRADE
GENDER		0.212	1.00	0.518
BRACE			1.00	0.145
CARE				1.00
GRADE				

FIGURE 7: MEAN FIG-8 MEASUREMENTS



H-Reflex Measurements

Descriptive statistics for the peroneus longus (PL) and flexor digitorum longus (FDL) H-reflex latency and amplitude measurements for the subjects of both groups are presented in Table 8. The paired t-test found no statistically significant differences between the control group right and left limb PL-lat, PL-amp, FDL-lat, FDL-amp measurements. Among the injury group subjects, a statistically significant difference was found to exist between the involved and uninvolved FDL-lat measurements. The difference in FDL-lat was positive, indicating a prolonged FDL latency in the injured limb of the injury group subjects. The difference between the involved and uninvolved PL-lat measurement was not statistically significant. The results of the paired t-test for the H-reflex measurements for both groups are presented in Table 9 and Table 10.

The two-tailed t-test revealed a statistically significant difference between the mean side-to-side differences in PL-lat for the injury and control group. No statistical difference was found between the side-to-side differences in PL-amp, FDL-lat, and FDL-amp. The results are summarized in Table 11.

Multiple regression analysis failed to show any predictive value of side-to-side differences in PL-lat, PL-amp, FDL-lat, or FDL-amp, based on the independent variables

TABLE 9

PAIRED T-TEST CONTROL H-REFLEX MEASUREMENTS

VARIABLE	MEAN	S.E.M	P
PL-LAT	-0.471	0.247	0.079
PL-AMP	64.142	158.1	0.693
FDL-LAT	0.308	0.343	0.385
FDL-AMP	28.071	120.324	0.233

TABLE 10

PAIRED T-TEST INJURY H-REFLEX MEASUREMENTS

VARIABLE	MEAN	S.E.M	P
PL-LAT	1.813	0.888	0.059
PL-AMP	-265.063	306.693	0.401
FDL-LAT	1.041	0.364	0.012
FDL-AMP	1.656	0.249	0.534

TABLE 11
 TWO-TAILED T-TEST COMPARISON OF SIDE-TO-SIDE H-REFLEX
 DIFFERENCES BETWEEN INJURY AND CONTROL GROUPS

VARIABLE	MEAN (SD)		P
	INJURY	CONTROL	
DIFF IN PL -LAT	1.812 (3.550)	-.471 (.924)	0.024
DIFF IN PL-AMP	-265.063 (1226.770)	64.143 (594.861)	0.351
DIFF IN FDL-LAT	1.041 (1.457)	.308 (1.282)	0.157
DIFF IN FDL-AMP	-44.813 (281.230)	28.071 (450.215)	0.606

of gender, severity grade, functional level, DFI, use of a brace, or type of care received.

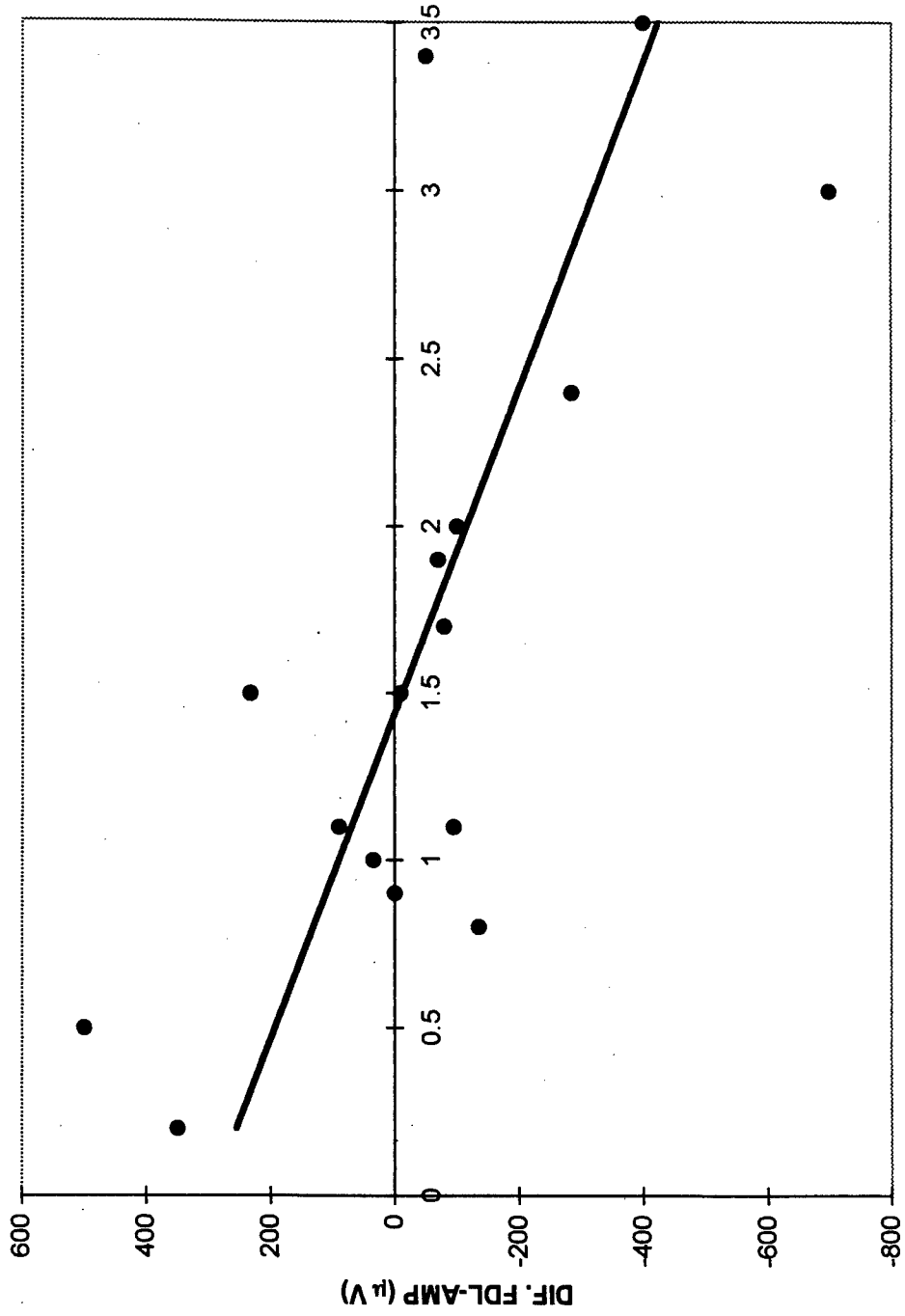
The Pearson Product Moment Correlation showed statistically significant correlations ($r=-.73$, $p=.001$) between the mean side-to-side difference (involved-uninvolved) in FDL-amp and the mean side-to-side difference in the figure-of-eight measurements for subjects within the injury group. The correlation relationship between these two variables was inverse, reflecting a tendency for the injured limb FDL H-reflex amplitude to decrease as the amount of swelling in that same injured ankle increased. The side-to-side difference in FDL-lat and the number of days from the inversion injury were also statistically significant ($r=-.61$, $p=.01$) and inversely correlated, indicating that the involved FDL H-reflex latency decreased as the number of days from the onset of the injury increased. These relationships are shown in Figure 8 and Figure 9. No significant correlations between the functional level, DFI, the use of a brace, type of care received, the side-to-side differences in PL-lat, PL-amp, FDL-lat, or FDL-amp were found to exist.

Discussion

Swelling and the H-Reflex Response

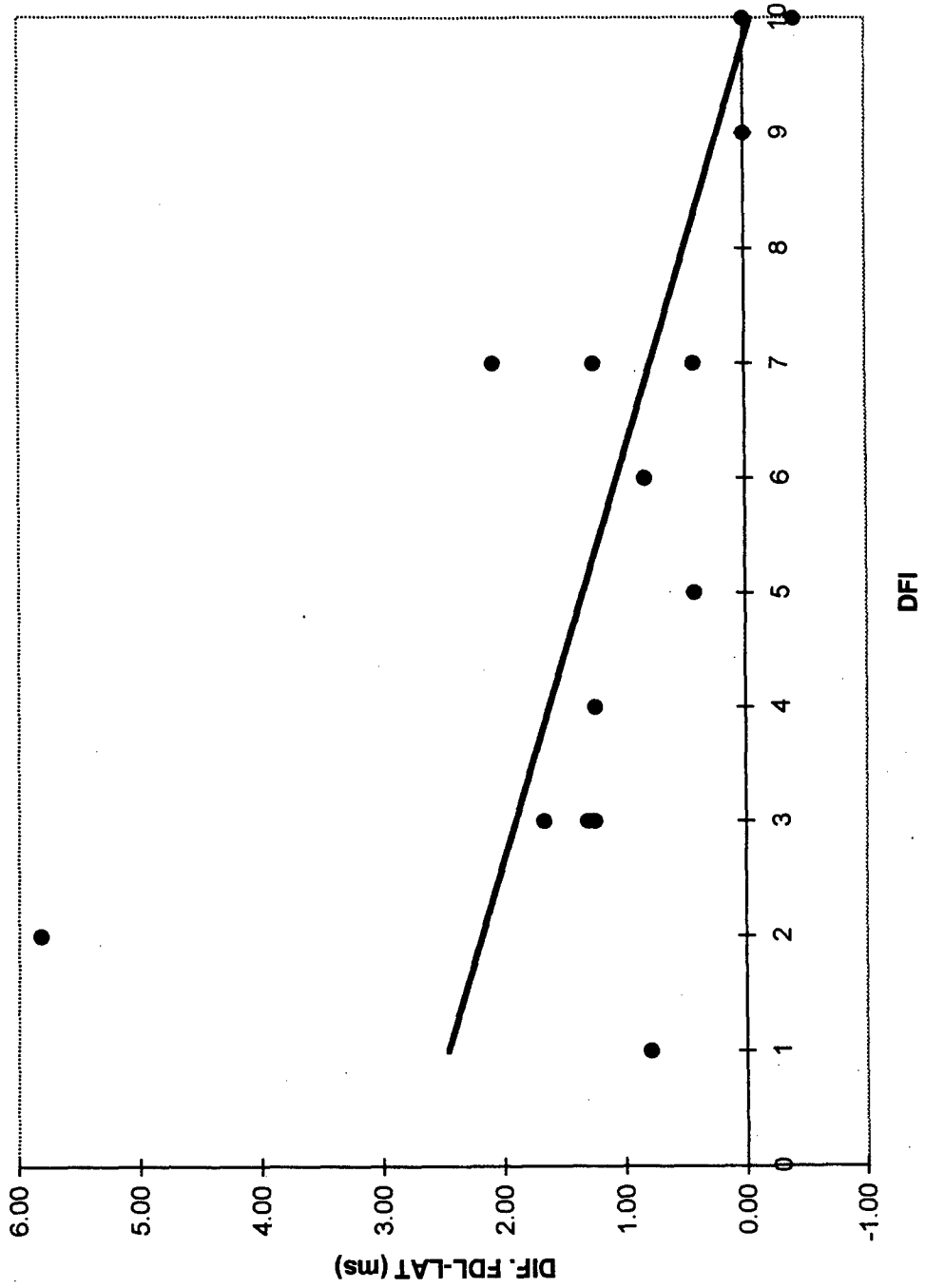
The apparent amount of ankle swelling, in the injured ankles was measured by figure-of-eight girth, was

FIGURE 8: DIFFERENCE IN FDL-AMP VS. DIFFERENCE IN FIG-8 (INJURY GROUP)



DIF. FIG-8 (cm)

FIGURE 9: DIFFERENCE IN FDL-LAT VS. DAYS FROM INJURY



significantly correlated with a decrease in the FDL H-reflex amplitude in the injured ankles. The apparent inhibitory influence of increased ankle joint mechanoreceptor activity upon the afferent neural feedback through the Ia pathway is similar to the findings of previous studies involving knee joint effusion and the H-reflex.(15, 23, 42, 53, 98) In each of the previous knee studies the degree of reflex inhibition of the knee joint extensors (quadriceps) was also found to be significantly related to the degree of joint effusion. Spencer et al. suggested that the type I slowly adapting mechanoreceptors stimulated by an increased capsular pressure, are primarily responsible for the decrease in H-reflex amplitude of the knee joint extensor muscles. They discounted the influence of the type IV receptors, as the introduction of lidocaine into the effused knee joint had no significant effect upon the already decreased amplitude of the quadriceps H-reflex.(98)

In contrast to the present study and the previous knee studies, Petrik et al. found an increase in the gastroc-soleus H-reflex amplitude in ankles with saline induced (10cc) effusion. They proposed that the effusion was responsible for a facilitation of the gastroc-soleus muscle complex so as to enhance postural stability.(84) The relationship between the decrease in the invertor H-reflex amplitude and the degree of joint swelling found in this study may also have a functional explanation. In the

presence of significant ankle swelling, many patients allow their injured ankle to adopt a relative position of ankle plantar flexion and inversion.(110) Any attempted weight bearing upon the overly inverted calcaneus would most likely result in an increase in the amount of inversion stress to the injured ankle at heel-strike.(57) Any increased inversion stress by way of joint loading in the presence of compromised joint proprioception could have deleterious effects on the injured lateral structures.(105) An increase in the reflex inhibition of the invertor muscles, as seen in the present study, may play a role in decreasing the degree of calcaneal inversion just prior to heel-strike and minimize the stress on the lateral ligaments.

The lack of a significant relationship between the side-to-side PL H-reflex amplitude and the side-to-side figure-of-eight girth measurements may indicate that joint swelling selectively influences invertor muscles through the afferent response of the type I mechanoreceptors. Previous reports of H-reflex measurements of both the agonist and antagonist muscles in the presence of joint effusion have not been published.

The subjects in the present study had partially torn at least one, and possibly two, of the lateral ankle ligaments. A reflex inhibition of the ankle invertor musculature associated with increased ankle swelling and inflammation could be mediated by a ligamentous-muscular reflexive

response. Stener et al. investigated human subjects with partial MCL tears and found an inhibition of hip abductor and knee extensor protective muscle reflex responses when a valgus stress was applied to the knee joint. They did not comment on the degree of joint effusion, and suggested that a ligamentous-muscular reflex response was probable.(99) The H-reflex response has not been studied previously in subjects with known ligamentous injury.

In previous studies in which the H-reflex was found to have a relationship with joint effusion, the amount of intra-articular volume was directly assessed either by aspiration or by use of an intra-articular pressure transducer.(15, 23, 42, 53, 84, 98) The method of quantifying joint swelling in the present study was indirectly assessed by figure-of-eight girth measurement, and although this has been shown to be reliable for assessing girth in subjects with uninjured ankles, it has not been validated against intra-articular ankle joint volume measurements in clinical studies.(102) This leaves room for further investigation of the validity of the figure-of-eight measurement technique. In the present study however, the mean side-to-side difference in the figure-of-eight measurement of the injury group ($1.66 \pm .99$) was significantly different from the mean side-to-side difference in the figure-of-eight measurement control group ($.20 \pm .07$), indicating some degree of sensitivity for

distinguishing between the amount of swelling in injured and non-injured ankles.

Jankus et al. have examined the side-to-side variability of the gastroc-soleus complex H-reflex, and have found amplitude to have a greater variability than latency.(46) The standard error of the means of the amplitude measurements in this study were extremely high, indicating a wide variability for the amplitude measurements, and may explain the lack of significance between the side-to-side differences in the PL and FDL amplitude measurements when comparing the injured and control groups. Both the PL and FDL muscles amplitude measurements showed a high degree of variability for the injury and control group subjects. This could have been related to the use of surface electrodes (as opposed to needle electrodes) to record the H-reflexes. Maryniak et al. found monopolar needle electrodes to produce larger and more reliable H-reflex amplitude measurements in the FDL muscle when compared to the use of surface electrodes. They reported a mean FDL amplitude of $910 \mu\text{V} \pm 57$ for the needle electrode H-reflex.(64) The mean FDL H-reflex amplitude of the control subjects in this study was $654.5 \mu\text{V} \pm 840$, substantially lower, and more variable.

Functional Level and H-Reflex Response

A relationship between the H-reflex latency or amplitude measurements and the functional level of the injury group subjects was not established by the results of this study. Previously, a decrease in H-reflex amplitude has only been shown to be related to a decrease in the open-chain muscular contraction activity of the quadriceps muscles, as monitored by surface EMG electrodes. (42, 53, 115) Petrik et al. demonstrated that the changes in the gastroc-soleus H-reflex with ankle effusion were significant enough to influence (enhance) closed-chain activity as measured by stabilometry. (84) Stabilometry studies of individuals with a history of acute ankle sprains have shown that these individuals tend to have reduction of involved limb stability. (13, 34) However, neither of these two authors commented on the amount of swelling associated with the acute ankle sprains in their subjects.

One possible explanation for the lack of a significant finding of a relationship between the functional level of injured subjects and the H-reflex measurements in the present study may be a lack of validity of the functional level scale used in this study. While the functional level assessment used in this study was similar to that used by Wilkerson and Horn-Kingery, it had not undergone clinical testing for validity prior to use in this study. (111) The closed-chain functional components of the rating system used in this study

did not include the use of an instrumented measuring device, as is used with a stabilometry assessment. The mean functional level of the injured subjects in this study was 3.4 ± 2.1 and represents the lower end of the functional level scale. The functional task used to assess functional capacity at this level of the scale relied heavily upon the observation of activities such as gait, hopping, and jogging. The significant influence that any measurable amount of H-reflex inhibition may have had upon these types of functional tasks may have been compensated for by proximal or contralateral limb synergy patterns that were overlooked by the researchers. Although the severity grade of the ankle sprain could be explained by the functional level, the functional level did not have any other statistically significant association with the characteristics of the injury group subjects. The significant association between severity grade and functional level was expected, as the severity grade of the ankle sprain was a factor used in determining the functional level. Hence, these two variables were not truly independent.

Comparison of Amplitude and Latency Measurements

The involved limb of the injury group subjects did show a statistically significant increase in the mean latency of the FDL H-reflex response when compared to the uninvolved limb ($33.34 \text{ ms} \pm 4.23$ Vs. $31.30 \text{ ms} \pm 3.32$). However, when

the mean difference between the involved and uninvolved FDL H-reflex latency response was compared to the mean difference between the right and left FDL H-reflex latency response for the control group ($1.04 \text{ ms} \pm 1.46$ Vs. $.31 \text{ ms} \pm 1.28$), no statistically significant difference was found. This would indicate that the amount of slowing of the FDL latency response between the uninjured and injured limb was in fact minimal, and possibly insignificant as related to the ankle sprain injury.

The mean PL H-reflex latency of the involved limb was also increased when compared to the uninvolved limb, but the increase was not statistically significant, ($33.17 \text{ ms} \pm 3.25$ Vs. $31.36 \text{ ms} \pm 2.91$). However, a comparison of the mean side-to-side differences in PL H-reflex latency between the injury and control groups did show a statistically significant difference between the two groups ($1.81 \text{ ms} \pm 3.55$ Vs. $-.47 \text{ ms} \pm .92$). One possible explanation for a lack of significance between the involved and uninvolved limb PL latency responses is that the responses may have been affected bilaterally by way of a neural injury that was associated with the inversion trauma. Nitz has suggested that joint induced neurogenic inflammation may be responsible for motor de-efferentation and a loss of protective muscular responses.(73) The effects that the potent neurotransmitters that are associated with

joint inflammation have upon the joint afferent mechanoreceptors has been documented.(36, 58) Additionally, the introduction of an acute experimental inflammatory substance into the paw of a rat has been shown to produce inflammation in the contralateral paw within a matter of 3 to 5 hours. Levine et al. maintain that this symmetrical response is mediated through connections across the spinal cord.(58) Although a direct quantification of the severity of joint inflammation was not undertaken in the present study, severity of joint inflammation has been shown to be directly related to the degree of joint effusion.(71) The findings of a symmetrical decrease in the PL H-reflex latency among the injury group subjects in this study support the findings of Brunt et al.. They measured PL muscle activation using surface EMG in control and ankle sprain patients during lateral perturbation. They reported a bilateral delay in the postural response PL muscle activation latency among the subjects with a recent (< 12 mo.) history of a grade II ankle sprain.(8) The bilateral effect of ankle sprain injury on PL reaction time is controversial in the literature, with several authors reporting no significant increase in PL muscle activation response time in the uninjured limb.(44, 49, 69) Because the previous studies examined PL latency via muscle onset activation during rapid ankle inversion stress testing, it is likely that both the muscle spindle Ia, Ib, and tendon II afferent pathways contributed to the reflexive motor response of the PL muscles. Since the H-reflex involves

only Ia afferent pathway, a direct comparison between H-reflex latencies and muscle stretch or tendon stretch mediated muscle activation latencies is limited.(19)

An increase in the H-reflex response latency is thought to be an early indicator of peripheral neural injury or represent a delay in the central synaptic reflex arc.(48) This study's finding of an increase in the PL H-reflex latency response supports the findings of previous studies that have documented peroneal nerve injury in patients who have sustained inversion ankle sprains.(72) Nitz et al. reported that 17% of grade II and 86% of grade III patients had moderate to severe denervation in the muscles supplied by the peroneal nerve. A proximal nerve stretch injury with subsequent axonotomesis was postulated to be responsible.(72) Kleinrensink et al. found significant decreases in the motor nerve conduction velocities of the deep and superficial peroneal nerves in subjects with either a grade II or grade III inversion sprain injury, 4-8 days post-trauma. They reported that the nerve injury lasted up to 5 weeks post-trauma.(54) Proximal nerve stretch injury could possibly have contributed to the increases in PL H-reflex latency seen in the present study. The injured subjects in the present study had a less severe injury (grade I or grade II) than subjects who sustained peroneal nerve injury in the previously mentioned studies. However, H-reflex testing is thought to be more sensitive to small nerve fiber injury, and

may be able to provide a means of earlier detection of nerve injury in ankle sprains of less severity.(48) A resolving neurogenic inflammation of the tibial nerve may also provide some explanation for the inverse relationship between the FDL H-reflex latency of the involved limb and the number of days from injury.

CHAPTER 5

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

FOR FURTHER STUDY

This chapter will summarize the purpose, methodology, and results of this study. Conclusions will be outlined based on the study findings. Additionally, recommendations for further studies of the relationship between acute ankle swelling and the H-reflex will be discussed.

Summary

The purposes of this study were: 1) to determine if a relationship between a measured amount of acute ankle swelling and the H-reflex response of the peroneus longus and flexor digitorum longus muscles exists; 2) to determine if a relationship between inversion ankle injury severity, as defined by level of function, and the H-reflex response of the peroneus longus and flexor digitorum longus muscles exists.

The total number of participants in this study was forty. The control group consisted of 20 healthy volunteers (11 male and 9 female, age 18-41 years) with no recent (< 3 years) history of lower extremity injury. The injury group consisted of 20 volunteers (16 male and 4 female, age 15-41 years) with a history of an acute (<10 days from injury) unilateral inversion ankle injury. Ten subjects (6 control and 4 injury) were eliminated from the study because of the inability to elicit the H-reflex of the FDL muscle in one or both limbs.

Each subject was evaluated for their current level of function and severity grade (injury group only) prior to electroneurophysiological testing. Subjects were evaluated using a modified lateral ankle sprain functional evaluation scale. Gait characteristics, functional activities (i.e. unilateral hopping, zigzag hopping), anterior drawer and talar tilt tests, and objective signs and symptoms were used to assign a functional level (0-10) and a severity grade of I, II, or III to each subject. In addition to functional level and severity grade the following information was also recorded for the injury group subjects: 1) the side (left or right) of the injury 2) the number of days since the ankle injury; 3) whether or not a brace was used by the subject; 4) type of care received prior to testing.

The figure-of-eight measurement technique was used to quantify objectively the amount of swelling of each ankle

studied. The order of ankle measurement was randomized using a random number table. Each ankle was measured three times, using a tape measure that was placed over the identified anatomical landmarks.

Both limbs of each subject underwent electroneuromyographic testing in order to elicit and record the H-reflex from the PL and FDL muscles. With the sensitivity of the testing unit set at 200 μ V, a minimum of 3 attempts were made to elicit the H-reflex response from the PL and FDL muscles of each limb. The latency of the clearest response elicited was measured and recorded. The sensitivity was then adjusted to 2000 μ V. The response was again elicited, at the same intensity, and the largest amplitude of the response was measured and recorded.

The statistical significance of results from the data analyses were determined at a $p < .05$ level. The Pearson Product Moment Correlation was used to assess the relationship between the side-to-side differences in latency, differences in amplitude, differences in figure-of-eight girth, and the injury characteristics of the injury group subjects. The results of the analysis revealed: 1) a significant inverse correlation between the side-to-side difference in the FDL muscle H-reflex response amplitude measurement and the side-to-side difference in the figure-of-eight girth measurement; 2) a significant inverse

correlation between the side-to-side difference in the FDL muscle H-reflex response latency and the number of days from the inversion injury; and 3) no significant correlations between functional level and the side-to-side differences in either the PL or FDL muscle H-reflex response amplitude or latency measurements. Therefore, the amount of ankle swelling associated with an acute ankle inversion injury is related to a decrease in the H-reflex response amplitude in the flexor digitorum longus muscle of that same ankle, supporting the second hypothesis of this study.

The side-to-side difference in the figure-of-eight measurements of both the control and injury group subjects was analyzed using the paired t-test and were statistically significant for both groups. The two-tailed t-test was also used to analyze the difference between the mean side-to-side difference in figure-of-eight girth for the injury and control groups. The results of this test were highly significant ($p=.0001$), indicating that the figure-of-eight measurement technique was able to distinguish between the injured and uninjured ankles in this study.

The paired t-test was used to analyze the side-to-side differences of the PL-lat, PL-amp, FDL-lat, FDL-amp measurements in both injury and control groups. No statistically significant differences between the control group right and left limb PL or FDL H-reflex measurements were found, indicating a high degree of symmetry within the

control subjects. A significant increase in the H-reflex FDL latency measurements of the involved limbs of the injury group subjects was found to exist. However, the implications of this finding was minimized, because the two-tailed t-test failed to show any significant difference between the side-to-side differences in the H-reflex FDL latency measurements of the control and injury groups. The paired t-test failed to show a significant difference between the H-reflex PL latency measurements of the involved and uninvolved limbs of the injury group subjects. However, the two-tailed t-test did show a significant difference between the side-to-side differences in the H-reflex PL latency measurements of the control and injury groups, indicating that the peroneal nerve of the injured subjects may have been affected bilaterally.

The predictability of the of side-to-side differences in latency, amplitude or figure-of-eight girth based on the injury group characteristics (gender, severity grade, functional level, DFI, use of a brace, type of care received prior to the study) was analyzed using a multiple regression analysis procedure. This procedure failed to show any significant predictive models for these variables. The Fisher's exact test and the two-tailed t-test were used to test for any statistically significant association of differences between the means of the independent variables of gender, use of a brace, severity grade, functional level, and type of care received. The two-tailed t-test did reveal that

there was a significant association between the severity grade of the injury and the functional level of the injured subjects. This was expected, as a component of the functional rating scale was the assessment of severity grade.

Conclusions

Within the scope of this study, the following conclusions can be made:

1. An increase in ankle swelling, as the result of an acute ankle inversion injury, is related to a decrease in the H-reflex amplitude of the ipsilateral flexor digitorum longus muscle.
2. The relationship between the functional level of individuals who have sustained an acute ankle inversion injury, and the H-reflex measurements of the flexor digitorum longus and peroneus longus muscles could not be established in this study.
3. Individuals with a history of an acute ankle inversion, grade I or grade II sprain, may also have an injury of the ipsilateral peroneal nerve with involvement of the contralateral peroneal nerve.
4. The figure-of-eight girth measurement technique is clinically useful in quantifying side-to-side differences in ankle girth for individuals with an acute ankle inversion sprain injury.

Recommendations for Further Study

This study represents the first attempt to establish a relationship between acute ankle swelling, secondary to inversion injury, and the H-reflex of the ankle invertor and evertor musculature. The results of this study raise several questions that should be addressed by further research. The clinical implications of the findings of this study are limited by the fact that the study was not of an experimental design, and therefore unable to demonstrate cause and effect of the variables measured. There remains, however, a need for the further investigation of the variables themselves, without experimental manipulation.

Further investigation of the reliability and validity of the clinical assessment of the H-reflex in the peroneal and flexor digitorum longus muscles is needed. The author recommends the use of needle electrodes as a possible means of decreasing the variability of the amplitude measurements in the smaller muscles of the leg.

The clinical significance of the influence of a lateral ankle ligamentous injury upon the ankle invertor musculature needs to be further addressed. As pointed out in the discussion of this study, the finding of the involvement of the invertor muscles in association with a lateral ankle inversion injury has been previously documented by only a small number of researchers.

The impact of neural injuries associated with ankle sprain injuries upon closed chain function needs to be further investigated. The duration and severity of a peroneal or tibial nerve injury that may be associated with an inversion ankle sprain injury should also be clarified.

APPENDIX A

**CONSENT TO PARTICIPATE IN A RESEARCH STUDY
(Injury Group)**

THE UNIVERSITY OF KENTUCKY

TITLE OF STUDY: A STUDY OF H-REFLEXES IN SUBJECTS WITH
ACUTE ANKLE INVERSION INJURIES

PRINCIPAL INVESTIGATORS:

Cliff Hall, P.T.- Phone (H) (606) 527-3118, (digital pager)
741-4983

Arthur J Nitz, P.T., Ph.D.- Phone (W) (606) 323-5274

Jase Pinerola, P.T. - Phone (W) (502) 443-0378

Darren Johnson, M.D. - Phone (W) (606) 323-5535, x-250

I, _____, freely and
voluntarily agree

to participate in a research project under the direction of
Cliff Hall, P.T., Jase Pinerola, P.T., Arthur J Nitz, P.T.,
PhD. and medical supervision of Dr. Darren Johnson.

PURPOSE:

I understand that I have injured my ankle, having partially
or completely torn one or more of the ligaments around the
ankle joint (commonly known as an ankle sprain.)

I understand that the purpose of this study is to determine
if the swelling produced by an ankle sprain effects the
conduction capabilities of the nerves in and around the ankle
joint.

DURATION AND LOCATION:

My participation in this study will last approximately for 30 to 45 minutes. Additionally I may be asked to participate in a follow-up portion of the study, approximately 10 days following the first study. The follow-up portion of the study will last approximately for 30 to 45 minutes. The study will be conducted at one of the following locations: University of Kentucky Nutter Athletic Training Facility, University of Kentucky Sports Medicine Clinic, (both located on the U.K. Campus), Frankfort Physical Therapy Clinic (Frankfort, KY), Biokinetics Inc. (Paducah, KY). I will be asked to participate at the location most convenient to me.

PROCEDURES:

I have been told that during the course of this study, I will be subjected to standard electrodiagnostic testing of the nerves in both of my legs. I have also been told that I will be subjected to measurements of the size of both of my ankles. The electrodiagnostic testing will involve the taping of small surface electrodes over the muscles of my legs. A series of brief electrical stimuli will be administered to the back of each leg during the testing. If selected to participate in the follow-up study, the same identical testing will be performed once again on each leg. In addition, measurements of the amount of swelling in my ankle will be taken with a measuring tape.

EXCLUSIONS:

I should not participate in this study if I have been told by a physician that I have a significant ankle fracture. Also, I should not participate in this study if any of the following apply to me:

- I have an injury to both legs or ankles
- I have a history of a nervous system disease
- I have a cardiac pace maker device
- I have a history of diabetes or long term alcohol abuse

RISK/DISCOMFORTS:

I have been told that during the study I may experience a very brief amount of discomfort during the electrodiagnostic testing. I have been told that this discomfort is not of long term duration. I also understand that there may be risks or discomforts which are yet unknown.

BENEFITS:

I have been told that I will receive no direct benefit from my participation in this study, as it is not a treatment of my condition. However, findings of this study may provide me with an indication of the severity of my ankle injury. My participation may help sports medicine clinicians better understand how to rehabilitate individuals with ankle sprains.

CONFIDENTIALITY:

Every effort will be made to maintain the confidentiality of my study records. The data from the study may be published; however, I will not be identified by name. My identity will remain confidential unless disclosure by law is required.

RIGHT TO REFUSE:

I understand that I do not have to take part in this study, and my refusal to participate will involve no penalty or loss of rights to which I am entitled. I may withdraw from the study at any time without penalty or loss of benefits to which I am entitled.

FINANCIAL COST AND PAYMENTS TO THE SUBJECT:

I understand that I will incur no financial cost for the participation in this study. I understand that I will not receive any monetary payments for my participation in this study.

COMPENSATION IN CASE OF INJURY:

I understand that in the event of an injury resulting from the research procedures, no form of compensation (i.e. payment) is available from the University of Kentucky. Medical treatments may be provided at my own expense; or at the expense of my health care insurer (i.e. Medicare, Medicaid BC/BS) which may or may not provide coverage. If I have any questions, I should contact my insurer.

OFFER TO ANSWER QUESTIONS:

If I have any questions about this study, I may call Cliff Hall at 741-4983 (digital pager, requires dialing number, and entering your phone number at the tone) or at (606) 527-3118 (home; area code required.)

If I have any questions about my rights as a research subject, I may call the U.K. patient advocate at (606) 323-8951.

If a research related injury occurs, I will call the University of Kentucky Sports Medicine Clinic at (606) 323-5535, extension 250.

SIGNATURES:

I UNDERSTAND MY RIGHTS AS A RESEARCH SUBJECT AND I VOLUNTARILY CONSENT TO PARTICIPATE IN THIS STUDY. I HAVE READ AND UNDERSTAND THE CONTENTS OF THIS FORM AND HAVE RECEIVED A COPY.

_____ Date ____/____/____

Signature of Research Subject

_____ Date ____/____/____

Signature of Witness

I have explained and defined in detail the research procedures to which the subject has consented to participate.

_____ Date ____/____/____

Signature of Investigator

CONSENT TO PARTICIPATE IN A RESEARCH STUDY
(CONTROL GROUP)

THE UNIVERSITY OF KENTUCKY

TITLE OF STUDY: A STUDY OF H-REFLEXES IN SUBJECTS WITH ACUTE ANKLE INVERSION INJURIES

PRINCIPAL INVESTIGATORS:

Cliff Hall, P.T.- Phone (H) (606) 527-3118, (digital pager) 741-4983

Arthur J Nitz, P.T., Ph.D.- Phone (W) (606) 323-5274

Jase Pinerola, P.T. - Phone (W) (502) 443-0378

Darren Johnson, M.D. - Phone (W) (606) 323-5535, x-250

I, _____, freely and voluntarily agree to participate in a research project under the direction of Cliff Hall, P.T., Jase Pinerola, P.T., Arthur J Nitz, P.T., Ph.D. and medical supervision of Dr. Darren Johnson.

PURPOSE:

I understand that I am being asked to participate in this study because I have not had a significant lower extremity injury within the last 3 years, and am in essentially good health. I understand that I will be a part of a control group of subjects without an ankle injury.

I understand that the purpose of this study is to determine if the swelling produced by an ankle sprain effects the conduction capabilities of the nerves in and around the ankle joint.

DURATION AND LOCATION:

My participation in this study will last approximately for 30 to 45 minutes. The study will be conducted at one of the following locations: University of Kentucky Nutter Athletic Training Facility, University of Kentucky Sports Medicine Clinic, (both located on the U.K. Campus), Frankfort Physical Therapy Clinic (Frankfort, KY), Biokinetics Inc. (Paducah, KY). I will be asked to participate at the location most convenient to me.

PROCEDURES:

I have been told that during the course of this study, I will be subjected to standard electrodiagnostic testing of the nerves in both of my legs. I have also been told that I will be subjected to measurements of the size of both of my ankles. The electrodiagnostic testing will involve the taping of small surface electrodes over the muscles of my legs. A series of brief electrical stimuli will be administered to the back of each leg during the testing. In addition, measurements of my ankle will be taken with a measuring tape.

EXCLUSIONS:

I should not participate in this study if I have sustained any significant lower extremity injury within the past 3 years. Also, I should not participate in this study if any of the following apply to me:

- I have a history of a nervous system or circulatory disease
- I have a cardiac pace maker device
- I have a history of diabetes or long term alcohol abuse

RISK/DISCOMFORTS:

I have been told that during the study I may experience a very brief amount of discomfort during the electrodiagnostic testing. I have been told that this discomfort is not of long term duration. I also understand that there may be risks or discomforts which are yet unknown.

BENEFITS:

I have been told that I will receive no direct benefit from my participation in this study, as it is not a treatment of my condition. My participation may help sports medicine clinicians better understand how to rehabilitate individuals with ankle sprains.

CONFIDENTIALITY:

Every effort will be made to maintain the confidentiality of my study records. The data from the study may be published; however, I will not be identified by name. My identity will remain confidential unless disclosure by law is required.

RIGHT TO REFUSE:

I understand that I do not have to take part in this study, and my refusal to participate will involve no penalty or loss of rights to which I am entitled. I may withdraw from the study at any time without penalty or loss of benefits to which I am entitled.

FINANCIAL COST AND PAYMENTS TO THE SUBJECT:

I understand that I will incur no financial cost for the participation in this study. I understand that I will not receive any monetary payments for my participation in this study.

COMPENSATION IN CASE OF INJURY:

I understand that in the event of an injury resulting from the research procedures, no form of compensation (i.e. payment) is available from the University of Kentucky. Medical treatments may be provided at my own expense; or at the expense of my health care insurer (i.e. Medicare, Medicaid BC/BS) which may or may not provide coverage. If I have any questions, I should contact my insurer.

OFFER TO ANSWER QUESTIONS:

If I have any questions about this study, I may call Cliff Hall at 741-4983 (digital pager, requires dialing number, and entering your phone number at the tone) or at (606) 527-3118 (home; area code required.)

If I have any questions about my rights as a research subject, I may call the U.K. patient advocate at (606) 323-8951.

If a research related injury occurs, I will call the University of Kentucky Sports Medicine Clinic at (606) 323-5535, extension 250.

SIGNATURES:

I UNDERSTAND MY RIGHTS AS A RESEARCH SUBJECT AND I VOLUNTARILY CONSENT TO PARTICIPATE IN THIS STUDY. I HAVE READ AND UNDERSTAND THE CONTENTS OF THIS FORM AND HAVE RECEIVED A COPY.

_____ Date ____/____/____
Signature of Research Subject

_____ Date ____/____/____
Signature of Witness

I have explained and defined in detail the research procedures to which the subject has consented to participate.

_____ Date ____/____/____
Signature of Investigator

PARENTAL CONSENT TO CHILD'S PARTICIPATION IN
A RESEARCH STUDY (Injury Group)

THE UNIVERSITY OF KENTUCKY

TITLE OF STUDY: A STUDY OF H-REFLEXES IN SUBJECTS WITH
ACUTE ANKLE INVERSION INJURIES

PRINCIPAL INVESTIGATORS:

Cliff Hall, P.T.- Phone (H) (606) 527-3118, (digital pager)
741-4983

Arthur J Nitz, P.T., Ph.D.- Phone (W) (606) 323-5274

Jase Pinerola, P.T. - Phone (W) (502) 443-0378

Darren Johnson, M.D. - Phone (W) (606) 323-5535, x-250

I, _____, freely and
voluntarily agree to allow my
child, _____ to participate in
a research project under the direction of Cliff Hall, P.T.,
Jase Pinerola, P.T., Arthur J Nitz, P.T.,PhD.and medical
supervision of Dr. Darren Johnson.

PURPOSE:

I understand that my child has an injured ankle, having
partially or completely torn one or more of the ligaments
around the ankle joint.(commonly known as an ankle sprain.)
I understand that the purpose of this study is to determine
if the swelling produced by an ankle sprain effects the
conduction capabilities of the nerves in and around the ankle
joint.

DURATION AND LOCATION:

My child's participation in this study will last approximately for 30 to 45 minutes. Additionally he or she may be asked to participate in a follow-up portion of the study, approximately 10 days following the first study. The follow-up portion of the study will last approximately for 30 to 45 minutes. The study will be conducted at one of the following locations: University of Kentucky Sports Medicine Clinic, (both located on the U.K. Campus), Frankfort Physical Therapy Clinic (Frankfort, KY), Biokinetics Inc. (Paducah, KY). My child will be asked to participate at the location most convenient.

PROCEDURES:

I have been told that during the course of this study, my child will be subjected to standard electrodiagnostic testing of the nerves in both legs. I have also been told that my child will be subjected to measurements of the size of both of my child's ankles. The electrodiagnostic testing will involve the taping of small surface electrodes over the muscles of the legs. A series of brief electrical stimuli will be administered to the back of each leg during the testing. If selected to participate in the follow-up study, the same identical testing will be performed once again on each leg. In addition, measurements of the amount of swelling in the ankle will be taken with a measuring tape.

EXCLUSIONS:

My child should not participate in this study if he or she has been told by a physician that they have a significant ankle fracture. Also, they should not participate in this study if any of the following apply:

- They have an injury to both legs or ankles
- They have a history of a nervous system disease
- They have a cardiac pace maker device
- They have a history of diabetes or long term alcohol abuse

RISK/DISCOMFORTS:

I have been told that during the study my child may experience a very brief amount of discomfort during the electrodiagnostic testing. I have been told that this discomfort is not of long term duration. I also understand that there may be risks or discomforts which are yet unknown.

BENEFITS:

I have been told that my child will receive no direct benefit from his or her participation in this study, as it is not a treatment of their condition. However, findings of this study may provide my child with an indication of the severity of the ankle injury. Their participation may help sports medicine clinicians better understand how to rehabilitate individuals with ankle sprains.

CONFIDENTIALITY:

Every effort will be made to maintain the confidentiality of the child's study records. The data from the study may be published; however, my child will not be identified by name. The child's identity will remain confidential unless disclosure by law is required.

RIGHT TO REFUSE:

I understand that I do not have to allow my child to take part in this study, and my refusal to allow he or she to participate will involve no penalty or loss of rights to which he or she is entitled. My child may withdraw from the study at any time without penalty or loss of benefits to which he or she is entitled.

FINANCIAL COST AND PAYMENTS TO THE SUBJECT:

I understand that neither I nor my child will incur any financial cost for the participation in this study. I understand that neither I nor my child will receive any monetary payments for his or her participation in this study.

COMPENSATION IN CASE OF INJURY:

I understand that in the event of an injury resulting from the research procedures, no form of compensation (i.e. payment) is available from the University of Kentucky. Medical treatments may be provided at my own expense; or at the expense of my child's health care insurer (i.e. Medicare, Medicaid BC/BS) which may or may not provide coverage. If I have any questions, I should contact my child's insurer.

OFFER TO ANSWER QUESTIONS:

If I have any questions about this study, I may call Cliff Hall at 741-4983 (digital pager, requires dialing number, and entering your phone number at the tone) or at (606) 527-3118 (home; area code required.)

If I have any questions about my child's rights as a research subject, I may call the U.K. patient advocate at (606) 323-8951.

If a research related injury occurs, I will call the University of Kentucky Sports Medicine Clinic at (606) 323-5535, extension 250.

SIGNATURES:

I UNDERSTAND MY CHILD'S RIGHTS AS A RESEARCH SUBJECT AND I VOLUNTARILY CONSENT TO ALLOW MY CHILD TO PARTICIPATE IN THIS STUDY. I HAVE READ AND UNDERSTAND THE CONTENTS OF THIS FORM AND HAVE RECEIVED A COPY.

Research Subjects name (Printed)

Date ____/____/____

Signature of Research Subject

Parent/Legal Guardian (Printed)

Parent/Legal Guardian Signature

Date ___/___/___

Signature of Witness

Date ___/___/___

I have explained and defined in detail the research procedures to which the subject has consented to participate.

Signature of Investigator

Date ___/___/___

ASSENT FORM FOR MINOR SUBJECTS (Injury Group)

THE UNIVERSITY OF KENTUCKY

Title of Study: A Study of H-Reflexes in Subjects with Acute Ankle Inversion Injuries

Principle Investigators:

Cliff Hall, Physical Therapist

Arthur J. Nitz, Physical Therapist

Jase Pineroloa, Physical Therapist

Dr. Darren Johnson, Orthopedic Surgeon

1. I, _____, agree to be a part of a research study. The physical therapist in charge of this study is Mr. Cliff Hall. I also know that two other physical therapists, Mr. Art Nitz and Mr. Jase Pinerola, are working with Mr. Hall on this research and may also be performing test on my legs and ankles. Dr. Darren Johnson, an Orthopedic Surgeon with the University of Kentucky Sports Medicine Clinic may also be helping the physical therapists with the study.

2. I understand that I have injured some of the ligaments in one of my ankles and that this injury is called an ankle "sprain." I also understand that some of the swelling in my ankle may cause a temporary loss of muscle strength in the muscles around my ankle. The physical therapist has asked me to be a part of this study to try and find out why the ankle muscles sometimes get weak when someone like me sprains their ankle. The physical therapist has told me that he wants to find out if some of the nerves in my leg that control my ankle muscles are "slowed down" because of the ankle injury.

3. The physical therapist has told me that it will take about 30-45 minutes for him to conduct the research test on my legs. He has also told me that I may be asked to come back in to have the same test done again in about 10 days. I understand that I will have the test done at one of the following locations: University of Kentucky Sports Medicine Clinic, Frankfort Physical Therapy Clinic (Frankfort, KY), Biokinetics Inc. (Paducah, KY).

4. The physical therapist has explained to me that this study will involve the use of a machine that measures the speed of the conduction of impulses down the nerves in the back of my legs. The measurements **do not** involve the use of needles, but I understand that I will feel an electric "buzz" type sensation with the use of this machine. This sensation may at times be uncomfortable for a few seconds, but this discomfort usually does not last any longer. I also understand that the physical therapist will be using a tape measure to measure the swelling in my ankle.

5. This research will not help me get better from my ankle sprain any faster, but it will help physical therapists and doctors better treat people with ankle sprains in the future.

6. I know that I do not have to be a part of this study unless I want to. If I decide not to be a part of this study at any time I will call the physical therapist and let him know. Whether or not I decide to be in this study, I will still get the same care from the physical therapist for my ankle sprain as anyone else with an ankle sprain.

7. My physical therapist has explained this paper to me and I have been able to ask questions. I will get a copy of this paper to help me remember the things which we talked about. I have decided to be a part of this research study.

Signatures:

Subjects name (printed)

Subject's Signature/ Date

Parent/Guardian (printed)

Parent/Guardian Signature/Date

Signature of Witness/Date

I have explained and defined in detail in understandable terms the research procedures to which the subject has consented to participate.

Signature of Investigator/Date

APPENDIX B

SUBJECT DATA FORM

DATE: __/__/__ TIME: _____ LOCATION: _____

NAME: _____ AGE: _____ SEX: M F

DAY__ OF INJURY CONTROL# _____ INJURY# _____

INJURED SIDE L R

TREATMENT: SELF CARE ONLY MODALITY CARE BRACE

FUNCTIONAL LEVEL 1 2 3 4 5 6 7 8 9 10 GRADE I II III

1ST SIDE _____ TEMP _____2ND SIDE _____ TEMP _____

FIG-8 ___ + ___ + ___ /3= _____

FIG-8 ___ + ___ + ___ /3= _____

H-REFLEX DATA

H-REFLEX DATA

P.LONGUSP.LONGUS

LATENCY _____ AMP _____

LATENCY _____ AMP _____

FD.LONGUSFD.LONGUS

LATENCY _____ AMP _____

LATENCY _____ AMP _____

LATERAL ANKLE SPRAIN FUNCTIONAL EVALUATION SCALE**LEVEL 0 - Grade III****Functional Capacity:**

* Total inability to bear weight on injured extremity when unsupported.

* Continuous use of 2 crutches, with minimal or no weightbearing on injured extremity.

Clinical Presentation:

* Positive anterior drawer and/or talar tilt.

* Severe edema on lateral and medial aspects of ankle and on dorsum of foot.

* Diffuse pain with extreme tenderness over ATFL and CTFL.

* Painful active or passive motion in all directions with minimal joint movement.

LEVEL 1 - Grade II+**Functional Capacity:**

* Significant apprehension/pain when attempting to bear weight on unsupported injured extremity.

* Capable of 50-75% WB on injured extremity while wearing ankle support and using crutches.

LEVEL 1 (Cont.)

Clinical Presentation:

* Significant edema/ecchymosis on lateral and medial aspects of ankle.

* Possible pitting edema on forefoot (several days post-injury).

* Tenderness localized primarily to ATFL.

* Small amplitude of ankle movement possible without pain, but range of active/passive motion significantly limited by discomfort.

* Unable to actively dorsiflex to neutral position, but possible to passively position in neutral.

LEVEL 2 - Grade II

Functional Capacity:

* Unable to walk on unsupported injured ankle without apprehension and obvious limping.

* Unable to perform unilateral tip-toe heel raise on unsupported injured ankle.

* Capable of 100% WB (no crutches or cane) while wearing ankle support, but abnormal walking gait clearly evident.

LEVEL 2 (Cont.)

Clinical Presentation:

- * Significant edema/ecchymosis on lateral aspect of ankle and minor edema on medial aspect.

- * Tenderness localized primarily to ATFL.

- * Small amplitude of subtalar movement possible without pain, but range of active/passive motion significantly limited by discomfort.

- * Relatively large amplitude of active and passive PF/DF.

- * Able to actively dorsiflex to neutral position.

LEVEL 3 - Grade I+

Functional Capacity:

- * Capable of 100% WB on injured extremity with symmetrical walking gait when wearing ankle support.

- * Capable of unilateral tip-toe heel raise on unsupported injured ankle.

- * Unable to perform unilateral vertical hopping on injured extremity without ankle support.

LEVEL 3 (Cont.)

Clinical Presentation:

- * Moderate edema/ecchymosis on lateral aspect of ankle (enlarged malleolus appearance).

- * Tenderness completely localized to ATFL.

- * Relatively large amplitude of subtalar movement possible without pain, but end-range inversion limited by discomfort.

- * Pain-free and full range of passive PF/DF.

- * Able to actively dorsiflex beyond neutral position.

LEVEL 4 - Grade I

Functional Capacity:

- * Capable of 100% WB on injured extremity with symmetrical walking gait and no support.

- * Capable of unilateral vertical hopping on injured extremity without ankle support.

- * Capable of straight-ahead jogging (<50% max speed) with ankle support for at least 100m and without significant pain/limping.

- * Unable to run at >80% max speed with good running form and without pain/apprehension.

LEVEL 4 (Cont.)

Clinical Presentation:

- * Minor edema on anterior margin of fibular malleolus.
- * Mild tenderness completely localized to ATFL.
- * Full-range pain-free active/passive PF/DF.
- * Pain-free active subtalar motion within 50% of normal range (comparison to range of uninvolved extremity).
- * Discomfort elicited by forced passive inversion beyond 75% of normal range.

LEVEL 5

Functional Capacity:

- * Capable of symmetrical straight-ahead running with ankle support (>80% max speed for 50m).
- * Unable to perform unilateral zigzag hopping test on supported injured extremity without pain/apprehension or >50% performance deficit compared with performance of uninjured extremity.

Clinical Presentation:

- * Normal surface contours of foot and ankle (concavity of anterior and posterior gutters).

LEVEL 5 (Cont.)

- * Ecchymosis over fibular malleolus and possibly on lateral aspect of leg musculature.
- * Pain-free active subtalar motion through >50% normal range.

LEVEL 6

Functional Capacity:

- * Able to perform unilateral zigzag hopping test on supported injured extremity without pain/apprehension and <50% performance deficit compared with performance of uninjured extremity.
- * Able to perform figure-8 running and box drill (lateral shuffle, backward run, lateral shuffle, forward run).
- * Unable to perform sport-specific or job-specific movements/tasks without pain/apprehension.

Clinical Presentation:

- * Normal surface contours of foot and ankle.
- * Decreased area and proximal migration of ecchymosis.
- * Pain-free active subtalar motion through >50% normal range.

LEVEL 7

Functional Capacity:

* Capable of "limited" participation in athletic/recreational/ occupational activity at <80% of pre-injury speed/agility while wearing ankle support.

* Unilateral zigzag hopping test performance on supported injured extremity: <40% deficit.

Clinical Presentation:

* Normal surface contours of foot and ankle.

* Continued proximal migration of ecchymosis.

* Pain-free active subtalar motion through >75% normal range.

LEVEL 8

Functional Capacity:

* Unrestricted participation in stressful athletic/recreational/ occupational activity at <90% pre-injury agility/speed with ankle support.

* Unilateral zigzag hopping test performance on supported injured extremity: <30% deficit.

Clinical Presentation:

* Normal surface contours of foot and ankle.

LEVEL 8 (Cont.)

- * Continued proximal migration and dissipation of ecchymosis.
- * Pain-free active subtalar motion through >75% normal range.

LEVEL 9

Functional Capacity:

- * Unrestricted participation in stressful athletic/recreational/ occupational activity at >90% pre-injury agility/speed with ankle support.
- * Unilateral zigzag hopping test performance on supported injured extremity: <20% deficit.

Clinical Presentation:

- * Minimal or no tenderness over ATFL.
- * Pain free active subtalar motion through >90% normal range.

LEVEL 10

Functional Capacity:

- * Normal unrestricted participation in stressful athletic/recreational/ occupational activity at 100% pre-injury agility/speed without an ankle support.

Clinical Presentation:

- * No tenderness.
- * 100% range; pain-free active subtalar motion

APPENDIX C

INJURY GROUP DATA

OBSERVATION	SUBJECT	INVOLVED		INVOLVED		INVOLVED		INVOLVED		INVOLVED		UNINVOLVED	
		PL-LAT	PL-AMP	FDL-LAT	FDL-AMP	FDL-LAT	FDL-AMP	FIGURE-8	PL-LAT	PL-AMP	FIGURE-8	PL-LAT	PL-AMP
1		30.36	475.00	34.90	687.00	58.00	29.95						
2		34.11	1320.00	28.28	1405.00	54.00	33.69						
3		36.60	463.00	24.12	50.00	51.70	35.77						
4		31.20	500.00	34.11	287.00	61.00	30.36						
5		31.21	1387.00	29.95	85.00	57.30	33.69						
6		35.36	30.00	37.44	28.00	57.50	29.53						
7		39.52	200.00	36.19	215.00	56.60	26.19						
8		33.69	195.00	28.70	530.00	52.40	30.36						
9		36.19	75.00	31.20	825.00	55.60	33.69						
10		30.78	2500.00	28.70	1900.00	53.50	29.95						
11		30.36	6100.00	32.86	6100.00	59.00	29.95						
12		27.04	1800.00	30.78	5700.00	59.00	27.04						
13		32.86	1800.00	33.69	1400.00	61.50	33.44						
14		36.19	475.00	33.28	490.00	58.80	35.36						
15		35.36	400.00	42.01	100.00	57.70	34.11						
16		29.95	400.00	31.20	40.00	52.50	28.70						

INJURY GROUP DATA (CONT.)

OBSERVATION	SUBJECT	UNINVOLVED		UNINVOLVED		UNINVOLVED		UNINVOLVED		DIFFERENCE	
		PL-AMP	FDL-LAT	FDL-AMP	FIGURE-8	PL-LAT	PL-AMP	DIFFERENCE	PL-LAT	DIFFERENCE	PL-AMP
1		450.00	34.11	337.00	57.80	0.41		25.00			
2		1412.00	27.04	1500.00	52.90	0.42		-92.00			
3		250.00	24.12	50.00	50.80	0.83		213.00			
4		775.00	32.80	54.00	59.50	0.84		-275.00			
5		350.00	29.12	220.00	56.50	-2.48		1037.00			
6		125.00	35.36	38.00	56.00	5.83		-95.00			
7		275.00	34.52	125.00	55.50	13.33		-75.00			
8		1200.00	28.28	600.00	50.50	3.33		-1005.00			
9		100.00	31.20	1110.00	53.20	2.50		-25.00			
10		1900.00	29.12	1400.00	53.00	0.83		600.00			
11		5200.00	32.44	6200.00	57.00	0.41		900.00			
12		6200.00	29.53	6400.00	56.00	0.00		-4400.00			
13		1700.00	33.69	1800.00	58.00	-0.58		100.00			
14		1362.00	33.28	455.00	57.80	0.83		-887.00			
15		762.00	36.19	150.00	54.30	1.25		-362.00			
16		300.00	29.95	120.00	50.80	1.25		100.00			

INJURY GROUP DATA (CONT.)

OBSERVATION	SUBJECT	DIFFERENCE		DIFFERENCE	
		FDL-LAT	FDL-AMP	FDL-LAT	FIGURE-8
1	1	0.79	350.00		0.20
2	2	1.24	-95.00		1.10
3	3	0.00	0.00		0.90
4	4	1.31	233.00		1.50
5	5	0.83	-135.00		0.80
6	7	2.08	-10.00		1.50
7	8	1.67	90.00		1.10
8	10	0.42	-70.00		1.90
9	11	0.00	-285.00		2.40
10	12	-0.42	500.00		0.50
11	13	0.42	-100.00		2.00
12	14	1.25	-700.00		3.00
13	15	0.00	-400.00		3.50
14	16	0.00	35.00		1.00
15	17	5.82	-50.00		3.40
16	18	1.25	-80.00		1.70

CONTROL GROUP DATA

OBSERVATION	SUBJECT	PL-LAT		PL-AMP		PL-LAT		PL-AMP		PL-LAT		PL-AMP	
		RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT
1	1	24.12	26.62	837.00	1037.00	24.12	26.62	837.00	1037.00	24.12	26.62	837.00	1037.00
2	2	27.87	27.87	250.00	1950.00	27.87	27.87	250.00	1950.00	27.87	27.87	250.00	1950.00
3	3	27.04	27.04	1975.00	1825.00	27.04	27.04	1975.00	1825.00	27.04	27.04	1975.00	1825.00
4	4	25.37	25.37	1300.00	550.00	25.37	25.37	1300.00	550.00	25.37	25.37	1300.00	550.00
5	6	30.36	30.36	962.00	1150.00	30.36	30.36	962.00	1150.00	30.36	30.36	962.00	1150.00
6	7	29.53	31.61	1225.00	900.00	29.53	31.61	1225.00	900.00	29.53	31.61	1225.00	900.00
7	8	32.03	32.03	300.00	300.00	32.03	32.03	300.00	300.00	32.03	32.03	300.00	300.00
8	9	30.36	30.36	1300.00	1225.00	30.36	30.36	1300.00	1225.00	30.36	30.36	1300.00	1225.00
9	10	29.95	29.53	850.00	737.00	29.95	29.53	850.00	737.00	29.95	29.53	850.00	737.00
10	11	36.60	37.44	1400.00	887.00	36.60	37.44	1400.00	887.00	36.60	37.44	1400.00	887.00
11	15	32.44	32.38	1360.00	700.00	32.44	32.38	1360.00	700.00	32.44	32.38	1360.00	700.00
12	16	34.11	35.77	775.00	250.00	34.11	35.77	775.00	250.00	34.11	35.77	775.00	250.00
13	18	33.28	33.28	512.00	550.00	33.28	33.28	512.00	550.00	33.28	33.28	512.00	550.00
14	20	30.78	30.78	400.00	487.00	30.78	30.78	400.00	487.00	30.78	30.78	400.00	487.00

CONTROL GROUP DATA (CONT.)

OBSERVATION	SUBJECT	FDL-LAT		FDL-AMP		FDL-LAT		FDL-AMP		FDL-LAT		FDL-AMP	
		RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT
1		29.12	29.12	1388.00	29.12	1537.00	0.00						
2		29.53	29.12	2150.00	29.12	2950.00	0.41						
3		27.87	28.54	2575.00	28.54	1800.00	-0.67						
4		30.00	30.36	50.00	30.36	75.00	-0.36						
5		27.45	27.45	500.00	27.45	925.00	0.00						
6		38.20	39.10	50.00	39.10	100.00	-0.90						
7		30.78	31.61	900.00	31.61	875.00	-0.83						
8		38.27	38.27	75.00	38.27	100.00	0.00						
9		37.85	37.85	150.00	37.85	200.00	0.00						
10		29.95	29.95	1137.00	29.95	50.00	0.00						
11		37.02	37.02	50.00	37.02	75.00	0.00						
12		35.77	33.28	230.00	33.28	125.00	2.49						
13		29.95	29.53	85.00	29.53	135.00	0.42						
14		33.28	29.53	20.00	29.53	20.00	3.75						

FDL-AMP
{R-L}

FDL-LAT
{R-L}

FDL-AMP
LEFT

FDL-LAT
LEFT

FDL-AMP
RIGHT

FDL-LAT
RIGHT

OBSERVATION
SUBJECT

FDL-AMP
LEFT

FDL-LAT
{R-L}

FDL-AMP
{R-L}

CONTROL GROUP DATA (CONT.)

OBSERVATION	SUBJECT	FIGURE-8 RIGHT	FIGURE-8 LEFT	FIGURE-8 {R-L}
1	1	52.20	51.70	0.50
2	2	55.50	55.40	0.10
3	3	50.90	50.70	0.20
4	4	48.70	48.30	0.40
5	6	48.60	48.30	0.30
6	7	51.30	51.40	-0.10
7	8	54.40	54.20	0.20
8	9	54.10	54.00	0.10
9	10	48.50	48.50	0.00
10	11	53.10	53.20	-0.10
11	15	56.00	56.20	-0.20
12	16	58.00	57.20	0.80
13	18	58.40	58.10	0.30
14	20	55.40	55.10	0.30

APPENDIX D

A STUDY OF H-REFLEXES IN SUBJECTS WITH ACUTE ANKLE INVERSION
INJURIES

The relationship between joint effusion and reflex muscle inhibition has been studied most frequently in the human knee. DeAndrade et al demonstrated significant quadriceps femoris weakness in 14 subjects with a human plasma induced knee joint effusion. They proposed that a reflexive inhibitory afferent pathway is present that accounts for quadriceps inhibition arising from stimulation of the type I joint mechanoreceptors. They urged caution when rehabilitating patients in the presence of knee joint effusion.(6) In a similar study, Fahrner et al. demonstrated a decrease in the EMG activity and isometric strength of the quadriceps muscle in the effused knee joint, and suggested that reflexive muscle inhibition may be directly responsible for muscle weakness.(9)

The H-reflex has been useful in studies of the changes in motoneuron excitability, muscle reaction time, and the time immediately before the initiation of movement.(5, 16, 33, 34, 36, 48) Kennedy et al and Spencer et al, both measured electrically evoked Hoffmann reflexes (H-reflexes) in the quadriceps muscles of human knees that had been infused with saline.(23, 50) Both studies demonstrated decreased levels of motoneuron pool excitability via a

reduction in quadriceps H-reflex amplitudes. Spencer et al found that as little as 20-30 ml of joint effusion produced a significant reduction in the vastus medialis H-reflex amplitude. Iles et al investigated the effects of saline induced joint effusion on the quadriceps H-reflex at rest and during voluntary quadriceps isometric contraction with the knee in full extension. They reported significant reductions in H-reflex amplitudes during both conditions.(16)

Recently investigators reported on the effects of a saline induced ankle effusion upon the H-reflex of the gastroc-soleus muscles. A significant increase in the H-reflex amplitude was reported with a 10cc ankle effusion.(44) The relationship between ankle joint effusion and the H-reflex of the muscles that assist with ankle inversion and eversion has not been reported in the literature. Investigators have focused more on the deleterious effects that ankle swelling has on tissue healing, and functional status. The occurrence of transient peroneal and tibial nerve dysfunction associated with inversion ankle injuries has been reported. Nitz et al found a high incidence (86% and 83% respectively) of peroneal and posterior tibial nerve injury in grade III ankle sprains.(38) Kleinrensink et al also demonstrated peroneal nerve conduction slowing in subjects with ankle inversion injuries. Contralateral differences in nerve conduction velocities persisted up to 5 weeks in the distal segment of the deep peroneal nerve. They postulated

that traction forces on the nerves combined with ankle swelling resulted in a prolonged recovery from severe inversion injury.(24) Articular nerve fibers have lower tensile strength than collagen fibers and may be susceptible to tearing with inversion injuries.(1, 10, 11) Invertor musculature weakness has been documented in individuals with ankle functional instability and decreased balance abilities, possibly linked to tibial nerve injury or selective reflex inhibition.(47) Ankle inversion injuries have also been postulated to result in proprioceptive deafferentation of ligaments and tendinous structures on the lateral side of the ankle.(10)

The significant influence that the degree of post-injury joint swelling, has on ligamentous, capsular, and articular mechanoreceptors has been investigated.(9, 23, 60) A linear relationship has been shown to exist between the amount of joint effusion and the level of intra-articular pressure.(6, 42, 50) Prolonged intra-articular pressure in saline infused knee joints produces capsular laxity, as observed by the hysteresis phenomenon, within a period of 2 hours.(42) Joint effusion associated with a lateral ankle ligamentous injury may produce a ballooning of the anterior lateral capsule, secondary to the development of positive omnivectorial pressure and the development of an edema pocket around boney concavities.(56, 57) The confluent relationship between the ATFL and the joint capsule may lead to the

elongation of the disrupted ligamentous fibers and deformation of the lateral capsular tissues.(59) Type I mechanoreceptors have been found to be embedded within the fibrous capsular tissues and in ligaments of synovial joints, and would likely be influenced by changes in joint capsular pressure and ligamentous deformation.(40, 46, 60) Damaged and inflamed ligamentous and capsular tissues may produce a decrease in peroneal muscle reaction time resulting from a delay of afferent signals from joint mechanoreceptors.(10, 25, 26, 31, 47)

Traditionally the severity of an ankle ligament injury has been linked to the severity of soft tissue damage.(18) A variety of grading or clasification schemes have been used to describe the extent of ankle ligament injuries, each with their own criteria for the clasification of the injury.(3, 15, 38, 41) Along with the ankle stability tests (ie. anterior drawer, talar tilt) other more subjective signs and symptoms such as swelling and pain frequently play a significant role in the clasification of ankle sprains.(49) Terms such as grade I, grade II, and grade III are often used synonymously with mild, moderate, and severe. While this terminology may accurately reflect the degree of mechanical instability, their association with a distinct level of functional imparment may be less accurate.(58) Tropp et al did not find a high degree of association between mechanical and functional instability in male soccer players. The

authors did not report the degree of mechanical instability, but did associate mechanical instability with a positive anterior drawer test.(55) Rijke et al conducted a post-traumatic follow-up of 20 individuals with lateral ligament injuries and defined function in terms of passive inversion stress testing. They found that surgically treated patients had recovered a greater amount of function than non-surgically treated patients. However, neither closed chain or dynamic open chain testing were performed.(45) Liu and Jacobson utilized an eight category ankle scoring system in an attempt to rate the function of patients who underwent lateral ankle reconstructive surgery. They included the objective measures of range of motion (dorsi and plantar flexion), anterior drawer and talar tilt radiological testing, as well as the subjective measures of pain, functional instability, and level of functional activity.(30) Task oriented functional rating scales associated with recovery from ankle ligamentous injury have been published by three different authors. Linde et al rated ankle function based on pain, swelling, and mobility. They incorporated tasks such as wieght bearing ability, and return to work or sport.(29) Hocutt incorporated tasks such as walking, stair climbing, running, and jumping in a functional assesment of sprains of a similar severity. The authors reported on the number of days from injury to the performance of each of these tasks without pain.(14) Kaikkonen et al developed a 100 point scoring system for the evaluation of functional

recovery following an ankle injury. Testing included a subjective assessment (recovery of function), clinical measurements (range of motion, and laxity), functional stability, muscle strength (dorsi and plantar flexion), and balance. They found that the test could significantly differentiate between excellent and poor or fair recovery in subjects with a history of grade III inversion sprains who had undergone surgical lateral ligament reconstruction. The mean time between operation and testing was seven years.(22)

Wilkerson et al devised an 11 point functional scale to assess the effects of the use cryotherapy and compression on acute grade II ankle inversion ankle sprains. Weight bearing, walking, jogging, running, and a zigzag hopping test were used to assign the functional level to the patients throughout the rehabilitation period. They reported a strong linear relationship between days to recovery and level of function.(58)

With the aforementioned studies in mind, the possibility of a significant relationship between acute ankle swelling and the reflex response of the dynamic ankle stabilizers seems plausible. A significant association between these two factors may provide clinicians with greater insight into the proper management of acute ankle inversion injuries. A clinically useful means of assessing the level of functional impairment that is associated with an acute ankle inversion injury may also provide relevant data regarding if a

relationship exists between swelling and reflex muscle inhibition.

Methods

Subjects

A total of 40 volunteer subjects participated in the study. A control group (n=20) consisted of 11 males, and 9 females, between the ages of 19 and 45 years, with a mean age of 26 years. All individuals in the control group had no history of significant lower extremity injury within the past 3 years. Individuals with a history of lower extremity surgery, cardiac pace makers, neurological, circulatory disorders, diabetes, and/or prolonged alcohol abuse were excluded from both the control and study groups. The injury group (n=20), consisted of 16 males, and 4 females, between the ages of 15 and 41 years, with a mean age of 23 years. All subjects in the injury group had a history of acute (less than 10 days post-injury) inversion ankle sprain injury. Individuals with acute fractures (excluding typical fibular chip fractures), and/or bilateral lower extremity injury were excluded from the study group. Subjects in the control group were recruited from a university entry level physical therapy program. Subjects in the injury group were recruited through the university athletic training and sports medicine facilities, as well as through local out-patient physical

therapy clinics. All subjects participated in either recreational, intramural, or collegiate athletic programs.

Six subjects from the control group and 4 subjects from the injury group were eliminated from the study because of the inability to record an H-reflex response from one or both limbs. Each of the control and study group subjects read and signed an IRB approved consent form prior to participation in the study.

Procedure

1. Functional Level Evaluation

Each subject was evaluated for their current level of function prior to electroneurophysiologic testing. Subjects were evaluated using a modified version of the Lateral Ankle Sprain Functional Evaluation Scale, developed by Wilkerson (56). The scale allowed the researcher to assign a functional level (0-10) to each subject, based on gait characteristics, functional activities (ie. unilateral hopping, zigzag hopping), anterior drawer and talar tilt tests, and objective signs and symptoms. Level 0, corresponded to the lowest level of function, while Level 10 corresponded to normal functional gait. Additionally, a grade (I, II, or III) was assigned to the injured ankle, based on the grade associated with the functional level, as defined by the evaluation scale.

2. Quantification of Ankle Swelling

The figure-of-eight measurement technique, as developed by Esterson, was utilized to objectively quantify the amount of swelling of each ankle studied. The technique was demonstrated to have a high intrarater and interater reliability in a recently published study.(8, 52) The order of ankle measurement was randomized using a random number table. Subjects were measured while sitting in a long leg sitting style on a treatment table in such a manner as to allow both ankles to be free of any contact with the surface of the table. The ankle to be measured was positioned in neutral (0° of dorsiflexion/plantarflexion) and the position confirmed with a hand held goniometer. The subject was instructed to maintain this position throughout the measurement procedure. Landmarks for measurement, as described by Esterson, were identified and marked on the ankle with a skin pencil. A Guillick controlled tension tape measure (Layfayette Instruments, 3700 Sagamore Parkway North, Layfayette, IN 47903) was placed around the ankle in the figure-of-eight manner, using the identified landmarks. Each ankle was measured 3 times, and the average of the 3 measurements used to quantify ankle girth.

3. H-reflex Testing

Following the figure-of-eight measurement, the order of the two muscles to undergo H-reflex testing in each limb was

randomly determined. The same order of limb testing was maintained from the figure-of-eight testing procedure. Subjects were instructed to lie prone on the treatment table, avoiding any contact of the ankle joint and the table. The subject was instructed to lie with his or her head in an anatomically neutral position throughout the testing procedure. A pillow was placed under both legs, just inferior to the knee joint line for patient comfort and the facilitation of stimulation at the popliteal fossa. The temperature of each limb was measured with an electric thermistor (Yellow Springs Instrument Co., Inc., Yellow Springs, Ohio). The disk lead of the thermistor was placed over the dorsal aspect of the 1st metatarsal of each foot and secured with tape. After a period of 3 minutes, the skin temperature was recorded in Celsius, and the lead removed from each foot.

Electrode placement

Surface electrodes were used for all tests. A large 2 cm disk ground electrode was taped in place over the medial aspect of the gastrocnemius muscle of the limb to be tested at a point 1/2 way in between the medial malleolus and the popliteal crease. The small 1 cm disk surface reference electrode was taped in place over the achilles tendon of the same limb at 5 cm proximal to the insertion point at the calcaneus.

The site for the placement of the recording electrode was located by first having the subject flex the knee to 90°. The subject's ankle was maintained in a neutral position by the researcher. The flexor digitorum longus muscle was chosen as the inverter muscle to be tested because of its superficial location and ease of palpation.(43) For the location of the muscle belly of the flexor digitorum longus, the subject was instructed to flex his or her toes while the researcher palpated along the medial aspect of the leg at approximately one half of the distance between the medial malleolus and the popliteal crease. The point of electrode placement was then marked by the examiner with a skin pencil. Using an obstetric caliper, the distance in centimeters was measured from the distal tip of the medial malleolus to the site of the recording electrode. This distance was recorded for use to determine the location of a symmetrical recording electrode site on the contra-lateral limb. The small disk recording electrode was then secured over the site with tape. For the location of the muscle belly of the peroneus longus, the subject was instructed to evert his or her ankle and foot while the researcher palpated along the lateral aspect of the leg, approximately 5 centimeters distal to the neck of the fibular head. The point of electrode placement was marked by the researcher with a skin pencil. Using an obstetric caliper, the distance in centimeters was measured from the distal tip of the lateral malleolus to the site of the

recording electrode. The small disk recording electrode was then secured over the site with tape.

Nerve Stimulation

All electroneurophysiologic tests were performed using a Cadwell 5200-A EMG/NCV testing unit (Cadwell Laboratories, Inc., 909 North Kellogg Street, Kennewick, Washington, 99336). The site for tibial or peroneal nerve stimulation was located in the popliteal fossa at the level of the popliteal crease. The researcher aligned the web space between the thumb and index finger of his left hand with the popliteal crease. The bipolar stimulator, held in the right hand, was aligned in the popliteal fossa so that the cathode was proximal to the anode. The anode was aligned with the level of the web space of the left hand along the popliteal crease. The stimulator was positioned slightly medially in the popliteal fossa for tibial nerve stimulation, and slightly laterally for peroneal nerve stimulation.

The stimulation parameters were set as follows:

Sweep velocity - 10 milliseconds/division

Sensitivity - 200 - 2000 μ Volts/division

Duration - 1.0 milliseconds

Pulse width - 150 μ Seconds

Prior to stimulation, the subject was given verbal instruction requesting them to remain relaxed. With the sensitivity width set at 200 μ Volts/division, The stimulus was applied to the nerve with the hand held stimulator at an intensity just greater than that required to evoke a minimal motor response. A minimum of 3 responses were elicited. The interval between sequential stimuli was no less than 30 seconds. Once the maximum H-reflex amplitude was elicited, the latency was measured and recorded in milliseconds. Without changing the position or the intensity of the stimulator, the sensitivity was then adjusted to 2000 μ Volts/division, and the response was again elicited. At this point the amplitude of the response was measured from the base line to the highest peak and recorded in millivolts. The distance from the stimulating cathode site to the recording site was then measured with the obstetric caliper and recorded in centimeters for the purpose of reproducing a symmetrical distance and stimulation site for the same muscle H-reflex on the contralateral limb. The electrode set up and stimulation procedure was then repeated for the same muscle (peroneus longus or flexor digitorum longus) H-reflex on the contralateral limb. Once testing was completed for the same muscle on both limbs, the researcher then repeated the electrode set up procedure for the second muscle H-reflex to be tested, beginning with the most recent limb tested. This was done in order to facilitate the testing sequence.

Analysis of Data

A SAS computer program was used to perform all statistical analysis of the data. Analysis included descriptive statistics (mean, standard deviation (SD), and range). These were computed for subject demographics (age and gender), and for the following variables: Number of days from the inversion injury (DFI), functional level, severity grade (I, II, or III), peroneus longus latency (PL-lat), peroneus longus amplitude (PL-amp), flexor digitorum longus latency (FDL-lat), flexor digitorum amplitude (FDL-amp), and the figure-of-eight girth for each limb. The Pearson Product Moment Correlation was used to assess the relationship between the side-to-side (involved-uninvolved) differences in latency, differences in amplitude, differences in figure-of-eight girth, DFI, functional level, and severity grade for the injury group.

The paired t-test procedure was used to analyze differences in latency, amplitude, and figure-of-eight girth measurements between the limbs for each group. A standard two-tailed t-test procedure was used to compare the means of the side-to-side differences in latency, amplitude, and figure-of-eight girth of the subjects in the injury and control groups. Limb dominance was not assessed in this study, among either the control or injury groups, and the right minus left values of the control subjects was arbitrarily used as the side-to-side difference values for

the two-tailed t-test comparisons with the injury group involved minus uninvolved differences.

A multiple regression analysis procedure was used to determine the predictability of side-to-side differences in latency, amplitude or figure-of-eight girth based on the injury group subjects gender, DFI, functional level, severity grade, use of a brace, or type of care received. Because of the small sample size in the injury group, The Fisher's exact test and the two-tailed t-test were used to test for any statistically significant association between the independent variables of gender, use of a brace, severity grade, functional level, and type of care received. The Chi-square goodness of fit test was not used because of the small frequency (<5) of occurrences in the cells of the Chi-square table. A probability level of .05 was used to determine significance in all statistical analysis.

RESULTS

Injury Group Characteristics

The inversion ankle sprain occurred equally (n=8) among either the right or left limb. There was near equal frequency of occurrence (n=9) of the use of a brace among the injured subjects. The majority of the subjects received some form of clinical modality treatment prior to the time of data collection. The treatment varied from cryotherapy to

electrical stimulation. The remaining subjects all administered some form of self-care prior to the time of data collection. Self-care ranged from benign neglect of the injury to the R.I.C.E. (rest, ice, elevation, and compression) scenario. The difference between the mean functional level of the subjects who sustained a grade I sprain and those who sustained a grade II sprain was statistically significant. The Fisher's exact test did not reveal any statistically significant associations between the means of any of the other injury characteristic variables.

Figure-of-eight Measurements

The paired t-test showed a statistically significant difference in the mean side-to-side difference in the figure-of-eight measurements of both the control and injury group subjects. The two-tailed t-test also revealed a statistically significant ($p=.0001$) difference between the mean side-to-side difference in figure-of-eight girth for the injury and control group. Multiple regression analysis failed to show any predictive value of side-to-side difference in figure-of-eight girth based on the independent variables of gender, severity grade, functional level, DFI, use of a brace, or type of care received.

H-Reflex Measurements

The paired t-test found no statistically significant differences between the control group right and left limb PL-lat, PL-amp, FDL-lat, FDL-amp measurements. Among the injury group subjects, a statistically significant difference was found to exist between the involved and uninvolved FDL-lat measurements. The difference in FDL-lat was positive, indicating a prolonged FDL latency in the injured limb of the injury group subjects. The difference between the involved and uninvolved PL-lat measurement was not statistically significant. The two-tailed t-test revealed a statistically significant difference between the mean side-to-side differences in PL-lat for the injury and control group. No statistical difference was found between the side-to-side differences in PL-amp, FDL-lat, and FDL-amp. Multiple regression analysis failed to show any predictive value of side-to-side differences in PL-lat, PL-amp, FDL-lat, or FDL-amp, based on the independent variables of gender, severity grade, functional level, DFI, use of a brace, or type of care received.

The Pearson Product Moment Correlation showed statistically significant correlations ($r=-.73$, $p=.001$) between the mean side-to-side difference(involved-uninvolved) in FDL-amp and the mean side-to-side difference in the figure-of-eight measurements for subjects within the injury group. The correlation relationship between these two

variables was inverse, reflecting a tendency for the injured limb FDL H-reflex amplitude to decrease as the amount of swelling in that same injured ankle increased. The side-to-side difference in FDL-lat and the number of days from the inversion injury were also statistically significant ($r=-.61$, $p=.01$) and inversely correlated, indicating that the involved FDL H-reflex latency decreased as the number of days from the onset of the injury increased. No significant correlations between the functional level, DFI, the use of a brace, type of care received, the side-to-side differences in PL-lat, PL-amp, FDL-lat, or FDL-amp were found to exist.

Discussion

Swelling and the H-Reflex Response

The increased amount of ankle swelling, as measured by figure-of-eight girth, in the injured ankles was significantly correlated with a decrease in the FDL H-reflex amplitude in the injured ankles. The apparent inhibitory influence of increased ankle joint mechanoreceptor activity upon the afferent neural feedback through the Ia pathway is similar to the findings of previous studies involving knee joint effusion and the H-reflex. (6, 9, 16, 23, 50) In each of the previous knee studies the degree of reflex inhibition of the knee joint extensors (quadriceps) was also found to be significantly related to the degree of joint effusion. Spencer et al suggested that the type I slowly adapting

mechanoreceptors stimulated by an increased capsular pressure, are primarily responsible for the decrease in H-reflex amplitude of the knee joint extensor muscles. They discounted the influence of the type IV receptors, as the introduction of lidocaine into the effused knee joint had no significant effect upon the already decreased amplitude of the quadriceps H-reflex.(50)

In contrast to the present study and the previous knee studies, Petrik et al found an increase in the gastroc-soleus H-reflex amplitude in ankles with saline induced (10cc) effusion. They proposed that the effusion was responsible for a facilitation of the gastroc-soleus muscle complex so as to enhance postural stability. (44) The relationship between the decrease in the invertor H-reflex amplitude and the degree of joint swelling found in this study may also have a functional explanation. In the presence of significant ankle swelling, many patients allow their injured ankle to adopt a relative position of ankle plantar flexion and inversion.(57) Any attempted weight bearing upon the overly inverted calcaneus would most likely result in an increase in the amount of inversion stress to the injured ankle at heel-strike.(27) Any increased inversion stress by way of joint loading in the presence of compromised joint proprioception could have deleterious effects on the injured lateral structures.(54) An increase in the reflex inhibition of the invertor muscles, as seen in the present study, may play a

role in decreasing the degree of calcaneal inversion just prior to heel-strike and minimize the stress on the lateral ligaments.

The lack of a significant relationship between the side-to-side PL H-reflex amplitude and the side-to-side figure-of-eight girth measurements may indicate that joint swelling selectively influences invertor muscles through the afferent response of the type I mechanoreceptors. Previous reports of H-reflex measurements of both the agonist and antagonist muscles in the presence of joint effusion have not been published.

The subjects in the present study had partially torn at least one, and possibly two, of the lateral ankle ligaments. A reflex inhibition of the ankle invertor musculature associated with increased ankle swelling and inflammation could be mediated by a ligamentous-muscular reflexive response. Stener et al investigated human subjects with partial MCL tears and found an inhibition of abductor and extensor protective muscle reflex responses when a valgus stress was applied to the knee joint. They did not comment on the degree of joint effusion, and suggested that a ligamentous-muscular reflex response was probable.(51) The H-reflex response has not been studied previously in subjects with known ligamentous injury.

In previous studies in which the H-reflex was found to have a relationship with joint effusion, the amount of intra-articular volume was directly assessed either by aspiration or an intra-articular pressure transducer. (6, 9, 16, 23, 44, 50) The method of quantifying joint swelling in the present study was indirectly assessed by figure-of-eight girth measurement, and although this has been shown to be reliable for assessing girth in subjects with uninjured ankles, it has not been validated against intra-articular ankle joint volume measurements in clinical studies.(52) This leaves room for further investigation of the validity of the figure-of-eight measurement technique. In the present study however, the mean side-to-side difference in the figure-of-eight measurement of the injury group ($1.66 \pm .99$) was significantly different from the mean side-to-side difference in the figure-of-eight measurement control group ($.20 \pm .07$), indicating some degree of sensitivity for distinguishing between the amount of swelling in injured and non-injured ankles.

Jankus et al have examined the side-to-side variability of the gastroc-soleus complex H-reflex, and have found amplitude to have a greater variability than latency.(19) The standard error of the means of the amplitude measurements in this study were high, indicating a wide variability for the amplitude measurements, and may explain the lack significance between the side-to-side differences in the PL

and FDL amplitude measurements when comparing the injured and control groups. Both the PL and FDL muscles amplitude measurements showed a high degree of variability for the injury and control group subjects. This could have been related to the use of surface electrodes (as opposed to needle electrodes) to record the H-reflexes. Maryniak et al. found monopolar needle electrodes to produce larger and more reliable H-reflex amplitude measurements in the FDL muscle when compared to the use of surface electrodes. They reported a mean FDL amplitude of $910 \mu\text{V} \pm 57$ for the needle electrode H-reflex (32) The mean FDL H-reflex amplitude of the control subjects in this study was $654.5 \mu\text{V} \pm 840$, substantially lower, and more variable.

Functional Level and H-Reflex Response

A relationship between the H-reflex latency or amplitude measurements and the functional level of the injury group subjects was not established in this study. Previously, a decrease in H-reflex amplitude has only been shown to be related to a decrease in the open-chain muscular contraction activity of the quadriceps muscles, as monitored by surface EMG electrodes.(16, 23, 60) Petrik et al demonstrated that the changes in the gastroc-soleus H-reflex with ankle effusion were significant enough to influence (enhance) closed-chain activity as measured by stabilometry.(44) Stabilometry studies, performed by both Guskiewicz et al. and

Cornwall et al. of individuals with a history of acute ankle sprains have shown that these individuals tend to have reduction of involved limb stability.(4, 12) However, neither of these two authors commented on the amount of swelling that was associated with the acute ankle sprains in their subjects.

One possible explanation for the lack of a significant finding of a relationship between the functional level of injured subjects and the H-reflex measurements in the present study may be a lack of validity of the functional level scale used in this study. While the functional level assessment used in this study was similar to that used by Wilkerson and Horn-Kingery, it had not undergone clinical testing for validity prior to use in this study.(58) The closed-chain functional components of the rating system used in this study did not include the use of an instrumented measuring device, as is used with a stabilometry assessment. The mean functional level of the injured subjects in this study was 3.4 ± 2.1 and represents the lower end of the functional level scale. The functional tasks used to assess functional capacity at this level of the scale relied heavily upon the observation of activities such as gait, hopping, and jogging. The significant influence that any measurable amount of H-reflex inhibition may have had upon these types of functional tasks may have been compensated for by proximal or contralateral limb synergy patterns that were overlooked by

the researchers. Although the severity grade of the ankle sprain could be explained by the functional level, the functional level did not have any other statistically significant association with the characteristics of the injury group subjects. The significant association between severity grade and functional level was expected, as the severity grade of the ankle sprain was a factor used in determining the functional level. Hence, these two variables were not truly independent.

Comparison of Amplitude and Latency Measurements

The involved limb of the injury group subjects did show a statistically significant increase in the mean latency of limb ($33.34 \text{ ms} \pm 4.23$ Vs. $31.30 \text{ ms} \pm 3.32$). However, when the FDL H-reflex response when compared to the uninvolved the mean difference between the involved and uninvolved FDL H-reflex latency response was compared to the mean difference between the right and left FDL H-reflex latency response for the control group ($1.04 \text{ ms} \pm 1.46$ Vs. $.31 \text{ ms} \pm 1.28$), no statistically significant difference was found. This would indicate that the amount of slowing of the FDL latency response between the uninjured and injured limb was in fact minimal, and possibly insignificant as related to the ankle sprain injury.

The mean PL H-reflex latency of the involved limb was also increased when compared to the uninvolved limb, but the increase was not statistically significant, ($33.17 \text{ ms} \pm 3.25$ Vs. $31.36 \text{ ms} \pm 2.91$). However, a comparison of the mean side-to-side differences in PL H-reflex latency between the injury and control groups was statistically significant ($p=.024$). One possible explanation for a lack of significance between the involved and uninvolved limb PL latency responses is that the responses may have been affected bilaterally by way of a neural injury that was associated with the inversion trauma. Nitz has suggested that joint induced neurogenic inflammation may be responsible for motor de-efferentation and a loss of protective muscular responses.(39) The effects that the potent neurotransmitters that are associated with joint inflammation have upon the joint afferent mechanoreceptors have been documented.(13, 28) Additionally, the introduction of an acute experimental inflammatory substance into the paw of a rat has been shown to produce inflammation in the contralateral paw within 3 to 5 hours. Levine et al. maintain that this symmetrical response is mediated through connections across the spinal cord.(28) Although a direct quantification of the severity of joint inflammation was not undertaken in the present study, severity of joint inflammation has been shown to be directly related to the degree of joint effusion.(37) The findings of a symmetrical decrease in the PL H-reflex latency among the injury group

subjects in this study support previous ankle sprain studies. Tropp et al reported no significant side-to-side differences in stabilometry readings in 25 male soccer players with an acute inversion ankle sprain injury. The mean stabilometry value for the injured limb of the players was $332 \pm 88 \text{ mm}^2$, compared to the mean value of $215.6 \pm 54.6 \text{ mm}^2$ for a normal reference group of players on which they had reported previously study.(53, 54) Brunt et al measured PL muscle activation using surface EMG in control and ankle sprain patients during lateral perturbation. They reported a bilateral delay in the postural response PL muscle activation latency among the subjects with a recent (< 12 mo.) history of a grade II ankle sprain.(2) The bilateral effect of ankle sprain injury on PL reaction time is controversial in the literature, with several authors reporting no significant increase in PL muscle activation response time in the uninjured limb.(17, 21, 35) Because the previous studies examined PL latency via muscle onset activation during rapid ankle inversion stress testing, it is likely that both the muscle spindle Ia, Ib, and tendon II afferent pathways contributed to the reflexive motor response of the PL muscles. Since the H-reflex involves only Ia afferent pathway, a direct comparison between H-reflex latencies and muscle stretch or tendon stretch mediated muscle activation latencies is limited.(7)

An increase in the latency of the H-reflex response is thought to be an early indicator of peripheral neural injury or represent a delay in the central synaptic reflex arc.(20) The increase in the PL H-reflex latency response supports the findings of previous studies that have documented peroneal nerve injury in patients who have sustained inversion ankle sprains.(38) Nitz et al reported that 17% of grade II and 86% of grade III patients had moderate to severe denervation in the muscles supplied by the peroneal nerve. A proximal nerve stretch injury with subsequent axonotomesis was postulated to be responsible.(38) Kleinrensink et al. found significant decreases in the motor nerve conduction velocities of the deep and superficial peroneal nerves in subjects with either a grade II or grade III inversion sprain injury, 4-8 days post-trauma. They reported that the nerve injury lasted up to 5 weeks post-trauma.(24) Proximal nerve stretch injury could possibly have contributed to the increases in PL H-reflex latency seen in the present study. The injured subjects in the present study had less severe injury (grade I or grade II) than subjects who sustained peroneal nerve injury in the previously mentioned studies. However, H-reflex testing is thought to be more sensitive to small nerve fiber injury, and may be able to provide a means of earlier detection of nerve injury in ankle sprains of less severity. (20) A resolving neurogenic inflammation of the tibial nerve may also provide some explanation for the inverse

relationship between the in the FDL H-reflex latency of the involved limb and the number of days from injury.

CONCLUSIONS

This study represents the first attempt to establish a relationship between acute ankle swelling, secondary to inversion sprain injury, and the H-reflex of the ankle invertor and evertor musculature. An increase in ankle swelling, as the result of an acute ankle inversion sprain injury, was found to be related to the reflex inhibition of the ipsilateral flexor digitorum longus muscle. The clinical significance of the influence of a lateral ankle ligamentous injury upon other ankle invertor muscles needs to be further addressed. As pointed out in the discussion, the finding of inhibition of the invertor muscles in association with a lateral ankle inversion injury is a recent finding in the literature and has been documented by only a small number of researchers. Clinicians should be aware of the need to focus on strengthening both the evertor and invertor musculature when rehabilitating ankle ligamentous injuries. The timely reduction of acute swelling may also decrease the inhibitory afferent mechanoreceptor activity in the ankle joint. A relationship between the functional level of individuals who have injured the lateral ligaments at the ankle and the H-reflex measurements of the flexor digitorum longus and peroneus longus muscles could not be established in this study. The objective quantification of dynamic closed chain

functional ability for individuals with ankle sprain injuries remains a challenge for the clinician. Additional investigation of the reliability and validity of the clinical assessment of the H-reflex in the ankle invertor and evertor musculature is also needed. It is possible that the use of needle electrodes will be a means of decreasing the variability of the amplitude measurements in the smaller muscles of the leg. The results of this study suggest that individuals with a history of an acute ankle inversion sprain, grade I or grade II, may also sustain an injury to the ipsilateral peroneal nerve and involvement of the contralateral peroneal nerve. The duration and severity of a peroneal or tibial nerve injury that may be associated with an inversion ankle sprain injury is at present unknown. During the early stages of rehabilitation the presence of a bilateral neural impairment in the lower leg may have an impact upon the clinicians choice of closed chain rehabilitation exercises. Additionally, this study found the figure-of-eight girth measurement technique to be clinically useful in quantifying side-to-side differences in ankle girth for individuals with ankle swelling, secondary to soft tissue trauma.

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Staff Physical Therapist

United States Air Force

USAF Academy Hospital

USAF Academy, Colorado, 1986-1987

Staff Physical Therapist

Rehabilitation Services of Lake Charles

Lake Charles, Louisiana, 1987-1988

Director of Physical Therapy

Industrial Rehabilitation and Sports Medicine
Clinic

Nacogdoches, Texas, 1988-1991

Clinical Team Chief

United States Air Force

Wilford Hall Medical Center

San Antonio, Texas, 1991-1994

Certifications: Board Certified Specialist in Sports Physical
Therapy, 1993