

**EFFECTS OF FATIGUE & GENDER ON PERONEAL  
REFLEXES AFTER ANKLE INVERSION**

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# **EFFECTS OF FATIGUE & GENDER ON PERONEAL REFLEXES FOLLOWING SUDDEN ANKLE INVERSION**

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(Abstract)

An estimated 23,000 ankle injuries occur every day in the U.S. Ankle sprains account for 85% of all ankle injuries and inversion ankle sprains account for 85% of all ankle sprains. There is growing evidence that suggests gender and fatigue may increase the risk for inversion ankle sprains. Investigating the effects of fatigue and gender on peroneal reflex response after ankle inversion may help explain the differences in sprain rates with fatigue and gender. Therefore, the purpose of this study was to investigate the effects of fatigue and gender on peroneus brevis and peroneus longus reflexes after ankle inversion. A “trap-door” platform was used to elicit peroneal reflexes from sixteen males and fifteen females by suddenly inverting the ankle to 20°. Five unfatigued peroneal reflex measurements were performed before and after a fatigue protocol that attempted to fatigue the ankle evertors over 12 minutes to 75% of the unfatigued MVC torque. Results showed that reflex delay was not affected by fatigue, gender, or their interaction. PL reflex amplitude was not affected by fatigue or gender but was affected by their interaction. Results showed that PL reflex amplitude decreased by 11.3% in males and increased 22.1% in females with fatigue. A secondary analysis attempted to rule out extraneous factors that could have contributed to the differences in reflex response, but no experimental explanations were found. The differences in PL reflex amplitude were attributed to biomechanical, physiological, and anatomical differences between males and females.

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## DEDICATION

TO MOM & DAD  
YOU ARE THE REASON FOR ALL MY SUCCESSES

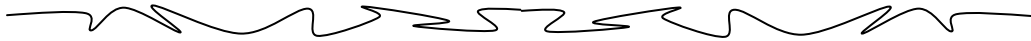
TO LAUREN  
YOU ARE THE BEST TWIN A SISTER COULD EVER HAVE

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**CHAPTER 1**

**INTRODUCTION**



## **1.1 Background**

In collegiate volleyball and basketball, ankle injuries have accounted for 21%-33% of all injuries over the past 21 years [1]. Numerous other epidemiological studies of volleyball [2, 3], basketball, soccer, and running have reported similar ankle injury rates [4]. According to NCAA reports of specific injuries, the ankle is among the top three most injured joints for almost every sport played at the collegiate level [1]. For the general U.S. population including collegiate athletics, it has been estimated that 23,000 ankle injuries occur every day in the U.S. [5] amounting to over 8 million ankle injuries a year. Of these ankle injuries, approximately 75% to 85% are ankle sprains [6, 7]. Studies have shown that the amount of time missed because of ankle sprains averages less than one month suggesting that it is not the severity of ankle sprains but the incidence that is the real problem [8]. According to statistics from 1984, the diagnosis and rehabilitation of an ankle sprain is estimated to cost anywhere from \$300-\$900 [9], which comes to over \$2 billion annually [9, 10]. This is roughly the money spent on coronary bypass surgical grafting in the U.S. [9].

## **1.2 Types and Grades of Ankle Sprains**

Clinicians use three different grades to diagnosis the severity of an ankle sprain. A grade I ankle sprain involves the stretching of ligaments and in the extreme cases some mild tearing of the ligaments. A grade II ankle sprain involves moderate tearing of the ligaments while a grade III is the complete rupture of a ligament [6]. Of the number of ankle sprains, approximately 85% are lateral or inversion ankle sprains [7, 11], 10% are syndesmotic ankle sprains, and 5% are medial or eversion ankle sprains [11]. Inversion ankle sprains occur when the foot becomes hyper-inverted while eversion ankle sprains occur when the foot becomes hyper-everted. Syndesmotic ankle sprains involve either a forced dorsiflexion or a forced external rotation of the foot. The focus of the present paper will be on inversion ankle sprains because they are the most prevalent.

## **1.3 Characteristics of the Ankle**

### *1.3.1 Ankle Anatomy*

There are two main groups of ligaments that can be injured by an ankle sprain. The lateral stabilizing ligaments are the most often injured ligaments in the ankle [6] and include the anterior talofibular ligament (ATF), the calcaneofibular ligament, and the posterior talofibular ligament (PTF). Inversion ankle sprains are responsible for injuries to the lateral ligaments. Due to its orientation across the joint, the ATF is the most easily injured ligament while the PTF is very difficult to injure [6]. The medial stabilizing ligaments include the deltoid ligament and the anterior tibiofibular ligament; these ligaments are injured during eversion ankle sprains [6].

In addition to the ligaments that cross the ankle, there are thirteen muscles that cross the ankle. These muscles are organized into three main compartments. The anterior compartment is comprised of the tibialis anterior, the extensor digitorum longus, the extensor hallucis longus, and the peroneus tertius. The lateral compartment is comprised of the peroneus longus muscle (PL) and the peroneus brevis muscle (PB). In the posterior compartment, the three superficial muscles are the gastrocnemius, the soleus, and the plantaris. The deep muscles contained in the posterior compartment include the popliteus, the flexor hallucis longus, the flexor digitorum longus, and the tibialis posterior. The tibialis anterior and tibialis posterior are responsible for ankle inversion. The two muscles contained in the lateral compartment, the PB and PL muscles, are two muscles responsible for ankle eversion [12]. During an inversion ankle sprain, the peroneal muscles are stretched and a reflex is activated which acts to counter the inversion movement of the ankle. As a result, these muscles may have a role in the prevention of ankle sprains.

### *1.3.2 Joint Stability*

From a functional point of view, an ankle sprain can be considered a loss of joint stability. Joint stability describes the ability of a joint to maintain or regain its position following an external disturbance [13]. All the structures in a joint – ligaments, tendons, muscles, bones – contribute to joint stability; however, during functional activities the

predominate mechanisms for maintaining joint stability are active muscle stiffness and active muscle reflexes [13-15].

### *1.3.3 Joint Stability - Joint Stiffness*

One contributor to joint stability is joint stiffness and is defined as the resistance of a joint to stretch or deformation in response to external forces [16]. Joint stiffness promotes stability by helping to prevent joints from moving outside the normal range of motion [16]. The active muscle tissue provides the largest contribution to overall joint stiffness and is therefore the dominant contributor to functional joint stability. Contraction of the agonist muscles is important in controlling joint stiffness; however, the simultaneous contraction of both agonist and antagonist muscles is also important. Increases in this coincident contraction, termed co-contraction or co-activation, can increase joint stiffness [17] and in turn increase joint stability.

### *1.3.4 Joint Stability – Muscular Stretch Reflex*

The second important mechanism that contributes to joint stability is active muscle reflex. Muscle spindles are sensory receptors within the muscle that detect muscle length and/or rate of change of muscle length [18]. If the spindles detect a change, a signal is sent to the nervous system which signals the muscle to activate. The initial muscle response is called the stretch reflex and is due to sudden changes in muscle length. Common parameters used to describe the stretch reflex are reflex delay and reflex amplitude.

In the ankle, sudden inversion causes the PB and PL muscles to stretch causing the activation of the peroneal stretch reflex. This activation of the peroneal reflexes in response to sudden inversion was shown by Grunebeg et al. [19] who found that peroneal reflex amplitude increased when landing on a tilted surface that caused inversion compared with a similar landing on a flat surface. Because of this increased reflex activation, it is possible that peroneal reflexes have a role in controlling ankle stability with inversion stress and thus have a role in stabilizing and protecting the ankle from inversion ankle sprains. This possible connection between peroneal reflexes and ankle sprains has led many researchers to investigate peroneal reflex response after sudden

ankle inversion [19-27]. Some of these studies have found increased peroneal reflex delay in individuals who exhibit functional instability from recurrent ankle sprains [22, 23]. Although it is difficult to determine if this increase in delay was present before and potentially contributed to the recurrent sprains, or if it resulted from the sprains, there remains an association between reflex delay and ankle sprains.

## **1.4 Risk Factors for Inversion Ankle Injury**

### *1.4.1 Intrinsic Risk Factors*

There are a number of factors that have been shown to increase the risk of an inversion ankle sprain. Perhaps the most frequently studied intrinsic risk factor is a previous history of ankle sprains [28, 29]. As stated previously, joint stability is closely linked to the occurrence of injury. With a previous ankle sprain, there is the possibility of ligament damage (increased joint laxity) and nerve damage, which could lead to decreased ankle stability and thus an increased risk of an ankle sprain [28]. Next are anthropometric factors like height and weight which may predispose an individual to a sprain [30, 31]. The greater an individual's height or weight, the greater the inversion torque that the ankle must endure, which may increase the risk for an ankle sprain [28]. Joint laxity (e.g. mechanical instability), another intrinsic risk factor, refers to the looseness of the ankle due to structural ligament or soft tissue damage. Joint laxity has long been associated with an increased risk for ankle sprains by medical personnel due to decreased ankle stability [28]. However, researchers who have investigated joint laxity and the increased risk of an ankle sprain have come to different conclusions depending on the joint laxity assessment technique used [28]. Barrett et al [32] found that joint laxity did not predict ankle sprains when using both anterior drawer and talar tilt measurements of joint laxity. Baumhauer et al [33] found that using the anterior drawer test showed a connection to the occurrence of ankle sprains but that the talar tilt test did not. In a later study, results from the talar tilt were associated with the occurrence of ankle sprains in men but not women [31]. A fourth intrinsic risk factor is functional instability. Functional instability unlike joint laxity is associated with a disruption of the sensory receptors at the ankle and could lead to decreases in ankle proprioception [34]. A decrease in ankle proprioception could lead to a decrease in ankle stability and thus an increased risk for

ankle sprains. Lastly, increased postural sway has been linked to an increased risk for ankle sprains by several studies [35-37]. A possible explanation is the increase in functional instability that has been found with increased postural sway [38].

#### *1.4.2 Extrinsic Risk Factors*

Unlike the intrinsic factors described above, extrinsic factors like bracing and taping have been associated with a decreased risk for ankle sprains [30, 39-41]. Most of the risk factors for inversion ankle sprains are connected to either a loss of ankle stability or a decrease in ankle proprioception. Ankle braces have been suggested to improve both of these conditions. Several studies hypothesized that the reason for the decrease in occurrence of ankle sprains was due to an increase in mechanical stability of the ankle [40] and/or an increase in ankle proprioception [39]. The decrease in ankle sprain risk with bracing, however, does not suggest that sprains do not occur when bracing or taping is used. According to a study of English soccer players, 32% of all injuries occurred while players were wearing some form of external support [8]. So although there may be a decreased risk, there is still some risk of incurring an ankle sprain.

#### *1.4.3 Fatigue as a Risk Factor*

Many recent epidemiological studies have suggested neuromuscular fatigue as a potential risk factor for athletic injuries [8, 42-45]. Reports have found that 71% of rugby injuries occurred in the second half of matches [42], 48% of soccer injuries occurred in the last third of the first and second halves of matches [8], and 47% of ice hockey injuries occurred in the last 5 min of a period [44]. Moreover, a study of telemark skiers found that the most likely time for an injury was in the afternoon between 2 p.m. and 4 p.m. [46]. These findings have lead researchers to hypothesize that neuromuscular fatigue may contribute to the occurrence of injury [42, 47].

#### *1.4.4 Gender as a Risk Factor*

There have also been reports that suggest gender as a risk factor for some sports injuries. It is well documented that females have an increased risk of anterior cruciate ligament (ACL) injury when compared with males [48-50]. Per hour of play, females

have been estimated to have a four to eight times greater risk for ACL injury than males [48-50]. With respect to ankle injuries, there is evidence of increased ankle sprains in females compared to males. The most compelling study by Hosea et al. [51] found that females were 25% more likely than males to sustain a grade I ankle sprain during basketball. The mechanism behind this increased risk is unknown.

## **1.5 Effects of Fatigue and Gender on Joint Stability**

Ankle stability is an important factor in determining whether an ankle sprain will occur. Many of the risk factors associated with inversion ankle sprains have been tied to decreases in joint stability; however, the mechanisms behind fatigue and gender as risk factors are relatively unknown. The importance of joint stability to injury occurrence has led researchers to investigate fatigue and gender with respect to joint stiffness and muscular reflex.

### *1.5.1 Effects of Fatigue*

Several studies have investigated the effects of fatigue on joint stiffness and found very different results. One study found that fatigue had no effect on ankle stiffness [52] but this study used only four subjects. Another study found a decrease in stiffness at the knee and a similar trend at the ankle due to stretch-shortening cycle exercises [53]. Increases in co-contraction, and coincidentally joint stiffness, have been found with fatigue of the trunk muscles [54] and the soleus and tibialis anterior muscles [55]. To our knowledge, there have been no studies specifically looking at the effects of fatigue on ankle co-contraction.

Studies of the muscular stretch reflex, the second main component of joint stability, have considered fatigue with respect to both reflex delay and reflex amplitude. Many studies have confirmed that neuromuscular fatigue has no effect on reflex delay for the vastus lateralis muscle [56], the knee extensors [57, 58], and the lateral gastrocnemius and soleus [16]. Conversely for reflex amplitude, studies have found both increases and decreases in reflex amplitude with fatigue. Reflex amplitude has been shown to increase in the knee extensors [57, 58] and elbow flexors [59] and decrease in the soleus muscle [60], finger flexors [61], and the first dorsal interosseus muscle [62] with fatigue.

### *1.5.2 Effects of Gender*

The effect of gender on joint stiffness for multiple joints including the ankle has been investigated, although the results have been inconsistent. Several studies have found that females have a decreased stiffness when compared to males in the knee flexors [63, 64], the knee extensors [64], the ankle invertors and evertors [16], and in the lower extremity [65]. An increased stiffness in females compared to males was also found for the plantar flexion/dorsiflexion (PD) stiffness of the ankle [16]. Moreover, larger amounts of co-contraction were found in females compared to males in the leg [65], which supports the idea that females have greater stiffness in the lower extremity. Some of the differences in stiffness with gender were attributed to anthropometric differences between males and females [63, 65].

Investigations of reflex with gender have found no differences with respect to reflex delay of the vastus lateralis muscle [56]. To our knowledge, no studies have investigated reflex amplitude with gender or peroneal reflex delay and amplitude with gender.

### *1.5.3 Effects of Fatigue and Gender*

We were able to find only one study considering the effects of both fatigue and gender on ankle stiffness. Massimini et al. [16] showed that with fatigue, PD ankle stiffness increases in males and decreases in females even after accounting for size differences in joint structure between genders. The reason for the contradicting changes in stiffness with fatigue was not discussed. Our literature search revealed no studies looking at co-contraction at the ankle with regards to fatigue and gender.

The effects of fatigue and gender have been investigated with respect to both EMG amplitude of voluntary contractions and reflex delay and amplitude. Several studies looking at voluntary contractions with fatigue and gender have found increases in EMG amplitude for the trunk muscles [66] and decreases for the plantar flexor muscles [67] following fatigue, but no differences were found with gender and reflexes were not investigated. The behavior of voluntary contractions, however, may be different than the muscular reflex response. There has been one study considering the effects of both

fatigue and gender on muscular reflex. Moore et al. investigated the vastus lateralis muscle and found no change in reflex delay for both males and females or a change in reflex amplitude for females [56]. An increase in reflex amplitude was found for males. The gender difference in reflex amplitude changes with fatigue were attributed to differences in how males and females respond to isokinetic fatigue. These suggested differences in how males and females fatigue have been investigated extensively [68-71]. Results show that males and females respond differently to fatigue with respect to parameters like metabolic response [70], endurance time [68, 71], and median frequency shifts [68]. Many physiological and anatomical explanations have been offered to explain these fatigue differences including muscle mass, metabolic byproducts, and muscle type distribution.

### **1.6 Goals of the Present Study**

Fatigue and gender have recently been realized as potential risk factors for ankle sprains because of the growing number of supporting epidemiological studies. Considering the prevalence and impact that inversion ankle sprains have on athletes, there is a growing need to investigate fatigue and gender as risk factors and to determine how they affect ankle sprains. The occurrence of ankle sprains is closely tied to changes in joint stability; however, studies looking at the effects of fatigue and gender on joint stability at the ankle are limited especially in the inversion/eversion (IE) direction. To our knowledge, there are no studies investigating the effects of fatigue and gender on IE ankle stiffness, co-contraction, or peroneal muscle reflexes. Therefore, to begin the investigation of how ankle stability in the IE direction is affected by fatigue and gender, a study was performed on the peroneal stretch reflexes. The goal of the present research was to investigate the effects of fatigue and gender on peroneal reflexes following sudden ankle inversion.

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## VITA

### ERIN L. WILSON

Erin L. Wilson was born in Newark, Delaware on May 8, 1982. She attended Rising Sun High School in North East, Maryland and graduated in 2000. She attended Virginia Polytechnic and State University where she received a Bachelor of Science in Engineering Science and Mechanics in 2004. She also completed a minor in mathematics and an option in biomechanics. Continuing in a 5 year BS/MS program, she completed her Master of Science at Virginia Polytechnic and State University in Biomedical Engineering. The focus of her research was on the biomechanical analysis of balance and sports injuries. Her main projects investigated the effects of fatigue and gender on ankle reflexes as well as how low back fatigue affected recovery from a perturbation. Erin has two loving parents, Richard and Nicolette, as well as a twin sister Lauren who unfortunately attended the University of Maryland. In her free time she enjoys reading, hanging out with all her Hokies, attending football games, grilling, hiking, and soaking up as much sun as possible.

