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# Effects of Neuromuscular Training on the Dynamic Restraint Characteristics of the Ankle

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# EFFECTS OF NEUROMUSCULAR TRAINING ON DYNAMIC RESTRAINT CHARACTERISTICS OF THE ANKLE

by

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A thesis submitted to the faculty of

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in partial fulfillment of the requirements for the degree of

Master of Science

Department of Exercise Sciences

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GRADUATE COMMITTEE APPROVAL

of a thesis submitted by

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This thesis has been read by each member of the following graduate committee and by majority vote has been found to be satisfactory.

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As chair of the candidate's graduate committee, I have read the thesis of Christena W. Linford in its final form and have found that (1) its format, citations, and bibliographical style are consistent and acceptable and fulfill university and department style requirements; (2) its illustrative materials including figures, tables, and charts are in place; and (3) the final manuscript is satisfactory to the graduate committee and is ready for submission to the university library.

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# ABSTRACT

## EFFECTS OF NEUROMUSCULAR TRAINING ON DYNAMIC RESTRAINT CHARACTERISTICS OF THE ANKLE



Christena W. Linford

Department of Exercise Sciences

Master of Science


**Objective:** To examine the influence of a 6-week training program on the electromechanical delay (EMD) and reaction time of the peroneus longus muscle.

**Design and Setting:** The study was guided by a 2 x 2 factorial design with repeated measures on the time factor. The independent variables for this study were group (training and control) and time (pre- and post-training). Dependent variables for this study were muscle reaction time and electromechanical delay of the peroneus longus muscle.

**Subjects:** Thirty-six healthy, physically active, college-age (21.8 ± 2.3 yr) male and female (M = 14, F = 28, height = 173.7 ± 11.2 cm, weight = 69.1 ± 18.4 kg) subjects were recruited for this study. Subjects had experienced no more than one ankle sprain to either ankle in their life, and had not sprained either ankle in the last year. Subjects were not currently experiencing any lower extremity pathology and had no history of serious injury to either lower extremity.

**Measurements:** The EMD of the peroneus longus was determined by the onset of force contribution after a percutaneous electrical stimulation was administered, as measured by EMG and force plate data. Reaction time was measured after a perturbation during walking. Data was analyzed using two 2 X 2 X 2 ANOVAs. Group (treatment and control) and gender were between treatments factors, and time was a within treatments factor.

**Results:** Upon initial examination, there was a trend in the EMD measurements to show an increase in EMD in the treatment group. However, this lacked statistical significance ($F = 2.96$, $p = 0.0983$). Reaction time demonstrated a trend towards a decrease in reaction time in the treatment group, but again, this lacked statistical significance ($F = 2.88$, $p = 0.1025$). Effect size for this reaction time was 1.2.

**Conclusions:** The 6-week training program used in this study did not have a significant effect on the reaction time and electromechanical delay of the peroneus longus muscle.

**Key Words:** electromechanical delay (EMD), reaction time, peroneus longus, training program

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**ABSTRACT**

**Effects of neuromuscular training on the dynamic restraint characteristics of the ankle.**

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**Results:** The training program had a marginally significant effect (F = 4.227, $p = 0.052$ two-sided) on the difference between pre- and post-test scores of EMD after controlling for pre-test EMD scores—the average EMD for a training subject being longer than that of the control group. The training program significantly decreased (F = 4.030, $p = 0.029$ one-tailed) the reaction time of subjects after controlling for the effects of the pre-test reaction time. For both reaction time and EMD, there was not a significant difference between genders or the interaction of gender and treatment.

**Conclusions:** The 6-week training program used in this study significantly reduced reaction while marginally increases the electromechanical delay of the peroneus longus muscle in healthy subjects.

**Key Words:** electromechanical delay (EMD), reaction time, peroneus longus, training program

## INTRODUCTION

Ankle sprains are a common injury not only in sports, but also in activities of daily living. The most common type of sprain is an inversion sprain, and it is estimated that 1 in every 10,000 people sustains this injury every day.[1] In addition, 7%-10% of hospital emergency department visits are people with ankle sprains.[1] It is estimated that 40% of all people will have chronic symptoms after a single lateral ankle sprain.[2]

One possible explanation for chronic symptoms and subsequent sprains is that the initial sprain creates an unstable joint. This instability may be related to loss of either passive and/or active restraints. Passive restraint is provided by the bones, ligaments, and capsule. Active, or dynamic, restraint is provided by the neuromuscular system. The peroneal muscles are of particular interest at the ankle because they are the primary muscles responsible for everting the foot against an inversion moment.

Researchers have examined several different methods of neuromuscular training in decreasing the frequency of ankle sprains.[3-7] In order for a neuromuscular rehabilitation program to be effective, two possible mechanisms for improvement are through a decrease in the reaction time or an increase in the magnitude of the muscular contraction. Many[8-12] question, however, if the active restraints can react fast enough to reduce injury and if the neuromuscular system can be changed by training. How fast a muscle reacts is dependent upon the reaction time and the electromechanical delay of that muscle. The reaction time is the time between perturbation and electrical activity of the muscle.[13] The electromechanical delay (EMD) is a measurement of the time lag between muscle activation and the muscle's contraction or force production.[14] Together these numbers constitute the response time of a muscle.

Previous researchers[8-12, 15] fell short of adequately testing response time for two reasons. First, researchers[8-12, 15] have used an ankle inversion mechanism that examines dynamic restraint characteristics while the subject is standing. Most people do not sprain their ankles while standing. In order to more closely mimic the dynamic mechanism of an ankle sprain injury, a runway with built in trapdoors has been developed. This has allowed researchers to measure the reaction time of the ankle evertors while walking. Second, in the past, electromechanical delay was determined in a partial or non-weight bearing position.[9-11, 15] Recently, however, Mora et al[14] tested electromechanical delay by having subjects stand on a force plate and electrically stimulating the common peroneal nerve. This technique resulted in electromechanical delay measurements recorded in a more functional weight-bearing position that were significantly shorter than those previously recorded.

These two new techniques, dynamic testing of the ankle evertors on the runway and weight-bearing electromechanical delay measurements, may allow for a more functional assessment of the active restraint involved during an inversion moment. Using the response time measurements, neuromuscular training programs can be examined to determine their influence on active restraint provided by the peroneal muscles.

The purpose of this study was to examine if there were any differences in the dynamic restraint characteristics, as measured by reaction time and EMD, in a simulated injury model following a neuromuscular training program.

# METHODS

## Design

The study was guided by a 2 x 2 pre-post factorial design. The independent variables for this study were group (training and control) and gender (male and female). Dependent variables for this study were the average of measurements of the difference in pre-test and post-test muscle reaction times and electromechanical delay of the peroneus longus muscle. The control variable was ankle range of motion during the inversion moment.

## Subjects

Thirty-six healthy, physically active, college-age (21.8 ± 2.3 yr) male and female (M = 14, F = 28, height = 173.7 ± 11.2 cm, weight = 69.1 ± 18.4 kg) subjects were recruited for this study. Six subjects were dropped after initial testing because an adequate response from peroneus longus muscle to direct stimulation of the common peroneal nerve could not be attained. The remaining subjects were randomly assigned to a treatment (n = 15) or a control group (n = 15). One subject was dropped from the treatment group after an undisclosed ACL injury was discovered. A subject was dropped from both the treatment and control group before data analysis due to equipment error in measurement. Another subject in the treatment group experienced discomfort with the testing methods and did not wish to return. Therefore, data analysis was performed on 13 treatment subjects and 13 control subjects.

Groups were gender matched through separate randomization of males and females into the treatment or control group. Participants had not experienced an ankle sprain in the last year, and no more than one sprain to either ankle in their life. In addition, subjects were not currently suffering from a lower extremity injury and had no history of major injury that resulted in severe ligamentous damage, fracture, or the need for surgery to either lower extremity. Each subject was asked to read and sign an informed consent form approved by the Institutional Review Board after the study had been described and all questions answered. Subjects were free to drop out of the study at any time.

**Instruments**

A runway (Figure 1) consisting of trap doors was utilized for the study. The runway (8.5 m x .076 m x .025 m) consisted of 7 separate 1.22 m segments. A bilateral trap door mechanism was present in the center four segments, allowing for an ankle injury mechanism to occur on either side of the runway. An adhesive, non-slip material covered the surface of the runway and the trap door in order to prevent the foot from slipping when the trap door was released. The trapdoor mechanisms inverted 30° to the selected side when triggered. An electric switch controlled an electric solenoid that triggered the release of the trap door supports. Once released, the trap door rested on a spring plunger that held the door in place until the foot struck the trap, causing it to fall to 30°. The fall of the trap door was marked by the release of an electromagnetic switch.

Electromyography (EMG) measurements were collected using surface electromyography (MP150, BIOPAC Systems Inc., Santa Barbara, CA). Signals were amplified (DA100B, BIOPAC Systems Inc., Santa Barbara, CA) from disposable, pre-gelled Ag-AgCl electrodes.

Ankle motion was measured using an electric goniometer (TSD130A, BIOPAC Systems Inc., Santa Barbara, CA), which was secured to the outside of the foot and lower leg to measure inversion range of motion. The goniometer was placed over the lateral malleolus and secured to the shoe and lower leg with tape.

**Procedures**

All subjects reported to the lab approximately one week prior to testing for an orientation session. During this session, subjects practiced walking to a cadence of a metronome set to 100 steps/min. After the subjects became comfortable walking on the runway at the set cadence, we were able to establish each subject's stride length. This was necessary to determine a starting point from which the subject would consistently step with each foot on each of the eight trap door mechanisms located in the runway.

After the orientation session, any questions subjects had were answered and an Institutional Review Board approved informed consent was signed by those who participated in the study. Subjects were then randomized into either the treatment or control group.

On the test day, the dominant leg was determined as the leg with which the subject would drop kick a ball. Each was then prepared before application of the electrodes by shaving the area of the dominant leg. That area was then lightly abraded and cleaned with isopropyl alcohol. The surface electrodes were placed 2 cm center to center, parallel to the peroneus longus muscle fibers 4-6 cm distal to the fibular head. Placement was confirmed by visual inspection of the EMG signal during active eversion and walking.

Each subject began a testing session by warming up on an exercise bike for 5 minutes at a moderate intensity. All subsequent data was collected from the subject's dominant leg.

To assess the EMD, a supramaximal percutaneous electrical stimulus of the common peroneal nerve was used. The stimulation electrode (Figure 2) was placed over the common peroneal nerve as it passed behind the fibular head. Lateral ground reaction force was represented by the mechanical contribution induced by stimulation.[14] Subjects stood with the test leg on the force plate over a marked spot with the non-test leg off the force plate and were able to grasp a hand railing in front of them. This provided support and prevented sway. Subjects were instructed to hold this position, looking straight ahead. The common peroneal nerve was then stimulated ten times, with a 15 second rest period between stimulations. The onset times of the processed EMG response and lateral ground force were defined as the point where the signal was 2 standard deviations higher than the mean resting activity. The EMD was then defined as the time interval between the onset of the peroneous longus EMG activity and the onset of lateral ground reaction force deviation.[14] An example of the computer EMG output for EMD is shown in Figure 3.

Subjects were then prepared for reaction testing on the runway. Each subject wore blinders that obstructed the field of vision below eye level and headphones connected to an electric metronome that blocked any sound of the triggering of the trapdoor mechanism and gave them the cadence to which they were to step. Each subject then practiced walking the length of the runway several times to recheck the previously determined starting point. Modifications to the starting point were made as necessary.

The subject was instructed to walk to a sign placed at the end of the runway. The sign was a reference to allow the subject to walk straight, and to notify the subject as to the end of the runway. An assistant walked behind the subject and off the runway to ensure that the subject did not step off the runway or lose balance. The subject walked this length 30 times.

Each ankle was randomly tested during a session, but only data from the dominant leg was measured and recorded. This was done in order to reduce a learning effect from repetitive testing of the dominant leg and to try to keep the subject from guessing when or where the trap door would fall. The trap door was triggered six times for each leg according to one of two random sequences.

The EMG data was collected for 5.0-7.0 seconds, depending how long it took the subject to walk the length of the runway. This allowed for inspection of muscle activity throughout the entire trial. The peroneus longus muscle was considered active when it exceeded 2 standard deviations of the peak baseline (standing) activty.[13] The reaction time was considered the time from the onset of the trap door release to the time the peroneous longus became active. Figure 4 illustrates the EMG signal during the reaction time measurement.

Subjects in the control group were instructed to maintain their current activity level and to return for further testing in 6-weeks.

Subjects in the treatment group were given a schedule for the neuromuscular training program. (Table 1.) The protocol consisted of warm-up, sensorimotor, strength, and power components. Each session lasted approximately 40 minutes and was repeated 3 days/week. At least one-day rest was observed between sessions, and subjects observed approximately 1 min rest between sets and exercises. Both dominant and non-dominant legs completed the rehabilitation exercises. All training sessions were monitored by trained assistants to encourage the subjects' compliance and maximum effort. No subject missed more than one training session, so all subjects were able to complete follow-up testing.

Measurements were repeated within two days of completion of the training program. Subjects in the gender matched control group also repeated the measurements within the same time frame.

Data collected from both EMD and reaction time measurements were analyzed in separate custom designed computer software programs. The software programs mathematically determine the EMD or reaction times. If the computer could not determine the EMD or reaction time, that trial was dropped. No more than 3 EMD or reaction time trials were dropped from any subject.

**Data Analysis**

Averaged muscle reaction time means from the six trials and averaged EMD means were used in data analysis. Data was analyzed using two 2 x 2 ANCOVAs (covariate pre-test score). Group (treatment and control) and gender (male and female) were between subject factors. The significance level was set at $p \leq 0.05$.

## RESULTS

The training program had a marginally significant effect (F = 4.227, $p = 0.052$ two-sided) on the difference between pre- and post-test scores of EMD after controlling for pre-test EMD scores—the average EMD for a training subject being longer than that of the control group. The training program significantly decreased (F = 4.030, $p = 0.029$ one-tailed) the reaction time of subjects after controlling for the effects of the pre-test reaction time. For both reaction time and EMD, there was not a significant difference between genders or the interaction of gender and treatment. Means and standard deviations are shown in Table 2.

## DISCUSSION

Treatment and prevention of ankle sprains consumes a large amount of time in athletic training settings. Traditional rehabilitation exercises include strength, power, and neuromuscular control or proprioception exercises of the leg muscles. Direct measurement of the efficacy of these exercises in terms of neuromuscular adaptation is limited. More popular indirect measurements such as balance and postural sway have dominated the research.[16-22] This study focused on direct measurement through reaction time and EMD of the peroneus longus muscle after a 6-week training program.

The EMD measurements in this study were longer than both the control and functionally unstable ankle groups found by Mora et al.[14] This may be due to the magnitude of the stimulus. Our study did not standardize the magnitude of the stimulus, but rather based it on visual inspection of the response and subject comfort. The magnitude of the stimulus may vary directly with the EMD of a subject.

The average reaction time before treatment in both groups was 62.46 ± 7.35 msec. This is faster than some previous studies[7, 10, 15] and slower than others.[11, 23, 24] Variability in measurements between the studies may be due to methodological differences as well as varying definitions of when the peroneal musculature is active. None of the studies cited above examined reaction time during walking, and only two studies[15, 24] examined the reaction time during one hundred percent weight bearing, which is closer to a dynamic setting. It is probable that the amount of inversion placed on the ankle influences reaction time as well. Only one study[15] with a reaction time slower than those in our study inverted to 30º, while all the studies[11, 23, 24] with faster reaction times than our study inverted to 30º our greater. It is probable that the amount of inversion stimulus used in testing influences reaction time.

Nieuwenhuijzen et al[25] is the only study we found that examined the reaction time of the peroneus longus during walking. Subjects walked on a treadmill equipped with a box that fell to 25º when stepped on, causing the ankle to invert. The average reaction time when walking at 4 mph was 42 msec. While our study controlled for the cadence of gait, it did not control for the speed. This likely introduced variability into our study because the faster speeds of walking have been associated with faster reaction times.[25] Nieuwenhuijzen et al[25] caused their ankles to invert at 403º/sec while our subjects inverted at approximately 350º/sec. This could support the idea that the faster the inversion speed, the shorter the reaction time.[25, 26]

Unlike several other studies using training protocols,[7, 27] our study did cause significant changes in EMD and reaction time. There are several explanations for why our study demonstrated significance. First, we controlled for the pre-test score. This was done on the assumption that subjects who demonstrated a higher pre-test reaction time would have more room for improvement than those with a lower pre-test reaction time.

Other research[7, 27, 28] using ankle disk training, examined the efficacy of one single rehabilitation tool in changing the reaction time of the peroneus longus. Neither study reported enhanced reaction times of the peroneals. However, Tropp et al[28] followed soccer players with previous ankle sprains who trained with an ankle disk and found that training decreased their sprain incidence to be the same as those with no history of ankle injury. Rozzi et al[19] and Hoffman[17] looked at the effect of ankle disk training on postural sway and found that sway decreased after training. This is an indirect measurement of neuromuscular characteristics. While our study did use an ankle disk, it also used many other exercises, which may explain why it is significant.

The EMD showed a marginally significant increase after training while the reaction time showed a significant decrease. If all measurement variables were held constant, any change in peroneus longus EMD would likely be a result of a change muscle preactivation or gamma motoneuron drive. Our testing protocol differed from all other studies [7, 17, 19, 27] because we tested reaction time in a dynamic setting yet EMD was induced electrically in a static stance position (bilateral stance). This would change the amount of weight on the test limb, which could influence preactivation and gamma drive. This may also explain why we found an improvement in reaction time, but not EMD.

The clinical significance of this study hinges on the time necessary to generate a protective response given a sudden inversion perturbation. By combining the EMD and reaction time measurement collected in this study, we can develop a theoretical response time of approximately 78.5 msec, that decreased by 5 msec after training.

It is arguable that a change of 5 msec would not be enough to influence the prevention of all ankle sprains. However, given that ankle injuries occur at varying inversion rates, it is possible that a 5 msec decrease in response time could play a role in ankle injury prevention under certain loading circumstances. Neuromuscular training may be able to influence ankle injury and/or severity of ankle injury occurring at slower inversion rates, but likely not those that occur at faster rates.

Our study focused on the training of healthy ankles. However, previous research has shown that patients with chronic ankle instability also have slower peroneal reaction times.[9, 10] Our research shows that those with slower pre-test reaction times showed greater improvement following training. Therefore, it seems likely that if this training program were used on that population, the subjects would demonstrate an improvement in their reaction time.

## CONCLUSION

The 6-week training program used in this study significantly reduced reaction while marginally increases the electromechanical delay of the peroneus longus muscle in healthy subjects. Further studies are needed to examine the influence of this training program on functionally unstable ankles.

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| Exercise | Weeks 1 & 2 | Weeks 3 &4 | Progressions | Weeks 5 & 6 |
|---|---|---|---|---|
| **Warm-up** | | | | |
| Jump Rope | 3 min | 3 min | | 3 min |
| **Stretching** | | | | |
| BAPS | 2 x 20 sec | 2 x 20 sec | | 2 x 20 sec |
| **Balance** | | | | |
| Single Leg | 60 sec | 90 sec | Pivot Balance | 90 sec |
| Dynadisk | 60 sec | 90 sec | | 120 sec |
| BAPS | 60 sec | 90 sec | | 120 sec |
| **Kicks (3 Directions)** | | | | |
| Forward | 2 x 30 | 3 x 30 | | 3 x 45 |
| Backward | 2 x 30 | 3 x 30 | | 3 x 45 |
| Step-downs | 3 x 20 | 3 x 30 | | 3 x 45 |
| Lateral Hops | 2 x 30 sec | 3 x 30 sec | Zig-zag Hops | 3 x 30 sec |
| **Cool Down** | | | | |
| Jump Rope | 3 min | 3 min | | 3 min |

**Table 1. Exercise protocol**

| | Treatment | | Control | |
|---|---|---|---|---|
| | Pre | Post | Pre | Post |
| EMD (msec) | 16.6±1.3 | 17.6±1.1 | 16.8±1.4 | 16.7±1.1 |
| Reaction Time (msec) | 61.9±6.5 | 57.1±7.7 | 63.0±8.3 | 63.5±6.8 |

**Table 2. Mean changes and standard deviations**

**Figure 1.  Runway setup**

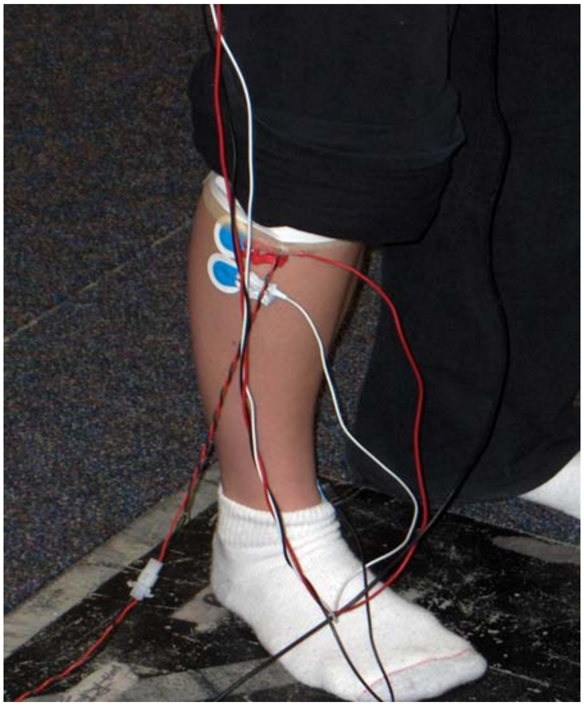

**Figure 2. EMD setup**

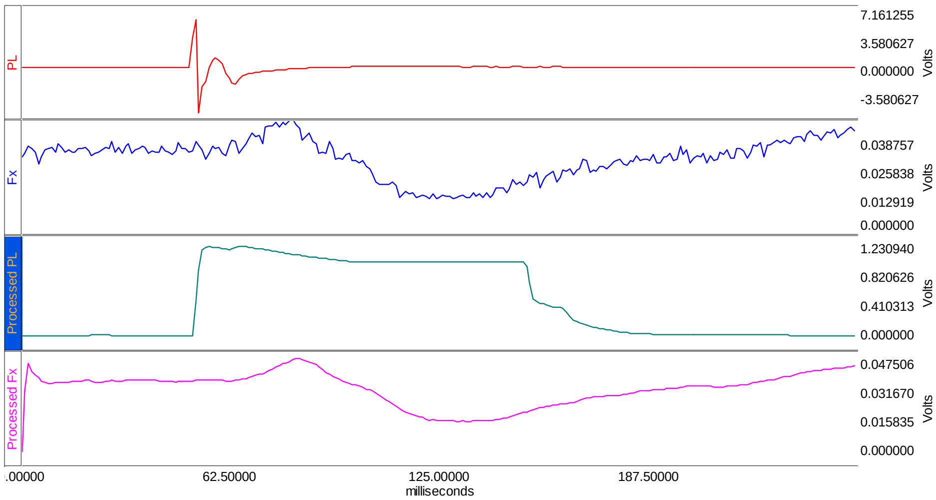


**Figure 3. EMG signals for EMD measurement**

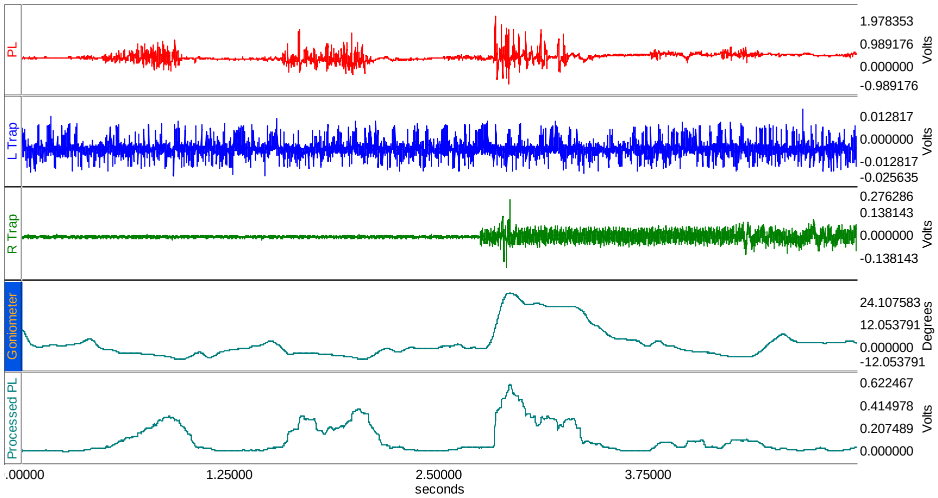


**Figure 4. EMG signal for reaction time measurement**

Appendix A

Prospectus

# Chapter 1

## Introduction

Ankle sprains are a common injury not only in sports, but also in activities of daily living. The most common type of sprain is an inversion sprain, and it is estimated that 1 in every 10,000 people sustains this injury every day.[1] In addition, 7-10% of hospital emergency department visits are people with ankle sprains.[1] It is estimated that 40% of all people will have chronic symptoms after a single lateral ankle sprain.[2] One possible explanation for chronic symptoms and subsequent sprains is that the initial sprain creates an unstable joint. This instability may be related to a mechanical or anatomical abnormality.

The ankle does have some protection from sprains in the form of passive and active restraints. Passive restraint is provided by the bones, ligaments, and capsule. Active, or dynamic, restraints are provided by the neuromuscular system. The peroneal muscles are of particular interest at the ankle because they are the primary muscles responsible for everting the foot against an inversion moment. Many[3-7] question if the active restraints can react fast enough to reduce injury and if the neuromuscular system can be changed through training. How fast a muscle reacts is dependent upon the reaction time and the electromechanical delay of that muscle. The reaction time is the time between perturbation and electrical activity of the muscle.[8] The electromechanical delay (EMD) is a measurement of the time lag between muscle activation and the muscle's contraction or force production.[9] Together these numbers constitute the response time of a muscle.

Previous researchers[3-7, 10] fell short of adequately testing response time for two reasons. First, researchers[3-7, 10] have used a standing platform. Most people do not sprain their ankles while standing. In order to more closely mimic the dynamic mechanism of an ankle sprain injury, a runway with built in trapdoors has been developed. This will allow us to measure the reaction time of the neuromuscular system of the ankle evertors while walking. Second, in the past, electromechanical delay was determined using a standing inversion platform.[4-6, 10] An inversion platform tests the ankle in a static situation in partial weight bearing. Recently, however, Mora et al.[9] tested electromechanical delay by having subjects stand on a force plate and electrically stimulating the common peroneal nerve. This technique resulted in electromechanical delays that were significantly shorter than those previously recorded. These two new techniques, dynamic testing of the ankle evertors on the runway and electromechanical delay, have been combined in this study. Together they may provide us with more sensitive measures for testing the response time of the peroneus longus to ankle inversion perturbations.

Researchers have examined several different methods of neuromuscular training in decreasing the frequency of ankle sprains.[11-15] In order for a neuromuscular rehabilitation program to be effective, it must influence one of two factors that can offset the injury. These two factors are the timing and magnitude of the muscular contraction. Dynamic stability is dependent upon the musculature being able to react fast enough and strong enough to decrease or even prevent the injury. This study will focus on the response time of the peroneous longus muscle.

If a training program could decrease the response time of the dynamic stabilizers of the ankle and thereby decrease the incidence of ankle sprains, money, time, as well as the pain and problems associated with injury would be diminished.

*Problem Statement*

The purpose of this project is to examine if there are any differences in the dynamic restraint characteristics, as measured by reaction time and electromechanical delay, in a simulated injury model following a neuromuscular training program. Specific objectives include:

1. Determine if muscle reaction time of the peroneus longus during an injury-like situation differs following an 6 week neuromuscular training program
2. Determine if the electromechanical delay (EMD) of the peroneus longus muscle differs following an 6 week neuromuscular training program

*Null Hypotheses*

1. The designed 6-week neuromuscular training program will not decrease the reaction time of the peroneus longus muscle during an injury-like situation.
2. The designed 6-week neuromuscular training program will not decrease the electromechanical delay of the peroneus longus muscle.

*Alternative Hypotheses*

1. The designed 6-week neuromuscular control program will decrease the reaction time of the peroneus longus muscle during an injury-like situation.
2. The designed 6-week neuromuscular control program will decrease the electromechanical delay of the peroneus longus muscle.

*Delimitations*

The delimitations of this study are as follows:

1. Subjects will be active college-age students that have not experienced an ankle sprain in the last year, and no more than one sprain to either ankle in their life. Individuals with a previously diagnosed third-degree sprain are excluded.
2. Subjects who have a history of major injury, which results in severe ligamentous damage, fracture, or the need for surgery to either lower extremity are excluded.

*Limitations*

Subjects will be a non-random sample of convenience.

*Definition of Terms*

Electromechanical delay (EMD)-the lag time between peroneal muscle activation and their contraction/force production.

Response time-reaction time plus the electromechanical delay.

Dominant leg-leg with which a subject drop kicks a ball.

Proprioception-afferent information arising from internal peripheral areas of the body that contribute to postural control, joint stability, and several conscious sensations.[16]

Reaction time-period of time between perturbation and activity of the muscle, peroneal muscles will be considered active when they exceed 2 standard deviations of baseline (standing) activity.[8]

Neuromuscular control-the unconscious activation of dynamic restraints occurring in preparation for and in response to joint motion and loading for the purpose of maintaining and restoring functional joint stability.[16]

Dynamic stability-also known as active stability, stiffness and support provided to a joint complex by contractile elements such as muscles and musculotendinous units.

Passive stability-support provided by noncontractile elements such as the bones, ligaments, and capsule.

Neuromuscular training-techniques used to alter either the speed or magnitude of a muscle contraction by influencing the neural input to the muscle and thereby the output of that muscle.

Functional instability-a condition of recurrent sprains and/or feeling of giving way.[4,17]

Chronic ankle instability-the occurrence of repetitive bouts of lateral ankle instability, resulting in numerous ankle sprains.[18]

Mechanical instability-an anatomic abnormality resulting in excessive laxity and/or recurrent sprains.

# Chapter 2

# Review of Literature

Ankle instability following injury can lead to subsequent sprains in an individual. Two types of instability exist and may occur singly or together. Mechanical instability is an anatomic abnormality resulting in excessive laxity and/or recurrent sprains. In contrast, functional instability is a condition of recurrent sprains and/or feelings of giving way.[4, 17] Before discussing mechanical and functional instability, anatomy and range of motion will first be reviewed. Dynamic stability, biomechanics, mechanism of injury, and grades of ankle sprains will be discussed.

## *Bony Structure*

The bony structure of the ankle is composed of three articulations: the talocrural joint, the subtalar joint, and the distal tibiofibular syndesmosis.[18, 19] The tibia is the primary weight bearing bone of the lower leg and forms the roof of the ankle mortise as well as the medial border.[19] The talocrural joint is a hinge joint that transmits torque from the lower leg to the foot during weight bearing.[18, 20] The talocalcaneal, or subtala joint is a composite joint formed by three separate articulations between the talus superiorly and the calcaneus inferiorly.[21] Together, the three surfaces provide the triplanar movements of pronation and supination around a single joint axis.[18] The distal tibiofibular syndesmosis allows only limited movement between the bones, but gliding at this joint is critical to normal mechanics.

*Ligaments*

The contribution of the medial and lateral ligaments to the stability of the ankle joint is critical. The talocrural joint receives support from the joint capsule and several ligaments, including the anterior talofibular ligament, posterior talofibular ligament, calcaneofibular ligament laterally and the deltoid ligament medially.[18] The primary purposes of the anterior talofibular and posterior talofibular ligaments are to restrain anterior displacement of the talus and posterior displacement of the talus, respectively.[20] The calcaneofibular ligament restrains inversion of the calcaneus. In end range dorsiflexion, the posterior talofibular ligament is maximally stressed and the calcaneofibular ligament is taut, whereas the anterior talofibular ligament is loose.[22] The reverse is true in end range plantarflexion. In addition, the anterior talofibular ligament prevents internal rotation of the talus.

Because the majority of sprains occur in inversion and plantar flexion, the resultant damage of these movements needs to be examined. With the inversion force, tensile forces affect the lateral structures of the ankle: the anterior talofibular ligament, the calcaneofibular ligament, the posterior talofibular ligament, the lateral capsule, and the peroneal tendons. The compressive forces of an inversion sprain result in damage to the medial structures: the medial malleolus, deltoid ligament, and medial neurovascular bundle.[19] The plantarflexion component of the injury causes tensile forces to the anterior structures: anterior capsule, long toe extensors, and extensor retinaculum, and compressive forces to the posterior structures: posterior capsule and the retrocalcaneal bursa.[19]

*Range of Motion*

The range of motion necessary for normal gait patterns may be less than the ranges needed for athletic activities.[23] Range of motion should be about equal bilaterally.[23] Significant asymmetry is abnormal and probably indicates a pre-existing or existing pathology.[23]

Average range of motion for the ankle in plantar flexion and dorsiflexion are 50 degrees and 20 degrees, respectively, and 20 degrees and 5 degrees for inversion and eversion, respectively.[19] Minimum plantarflexion needed is 20 degrees.[23] Normal walking requires an average minimum of 4-6 degrees of inversion with supination and 4-6 degrees of eversion with pronation.[23] A total range of 8-12 degrees of frontal plane motion at the subtalar joint is considered normal for walking.[23] Range of motion decreases as a person ages.

*Chronic Ankle Instability*

Lateral ankle instability refers to the existence of an unstable ankle due to lateral ligamentous damage caused by excessive supination of the rearfoot.[18] Chronic ankle instability (CAI) denotes the occurrence of repetitive bouts of lateral ankle instability, resulting in numerous ankle sprains.[18] Mechanical and functional instability can both contribute to lateral ankle instability and will both be reviewed.

Care must be taken to distinguish between laxity and instability. For the purpose of this paper, laxity will refer to the looseness of a joint as determined by the clinician. Instability will refer to the looseness described by the patient.

*Mechanical Instability*

Mechanical instability of the ankle complex occurs as a result of anatomic changes after the initial ankle sprain, which leads to insufficiencies in several areas that predispose the ankle to further episodes of instability.[18] These areas are pathological laxity, arthrokinematic impairments, and synovial and degenerative changes.

*Pathological Laxity.* Ligamentous damage often results in pathologic laxity of injured joints, thus causing these joints to be mechanically unstable. Laxity may be assessed by stress radiographs or physical examination. Pathological laxity can result in joint instability when the ankle is put in vulnerable positions during functional activities, resulting in subsequent injury to joint structures.[18]

*Arthrokinematic Impairments.* Hypermobility is often associated with mechanical instability because of the tearing or lengthening of the ligaments supporting a joint. Hypermobility affects the arthrokinematic, or accessory, movements of a joint.[24] Hypomobility may also be thought of as a mechanical insufficiency.[18, 24] Hypomobility at any joint in the lower extremity kinetic chain can challenge the motor-control mechanisms of an individual and lead to joint instability.[24]

*Functional Instability*

Functional instability is a condition of recurrent sprains and/or feeling of giving way.[4, 17] It is important when discussing instability to distinguish between mechanical and functional instability. Mechanical instability involves an anatomic abnormality such as disruption of one or more lateral collateral ligaments of the ankle.[25]

Mechanical instability can cause functional instability,[26] but not all functional instability is caused by mechanical instability. Tropp et al.[27] found in a study of 444 soccer players that 128 players had functional instability of one or both ankle joints. Of the 159 unstable ankles, only 66 or 42% were found to be mechanically unstable as well.[27]

Several theories have been developed to explain why functional instability occurs without mechanical instablity. In general, there are three areas of focus in looking at functional ankle instability: impaired proprioception and postural control, impaired neuromuscular-firing patterns, and strength deficits.

*Impaired Proprioception and Postural Control.* Impairment of ankle proprioception has been suggested frequently in the literature as one of the causes of ankle instability. In measurement of kinesthesia, or being able to identify where the body is in space, in subjects with chronic ankle sprains, several researchers found deficits in this component of proprioception.[28, 29] Deficits were also demonstrated in replication of joint angles in injured subjects,[30, 31] but not in all studies.[32]

Refshauge et al.[33] found that a proprioceptive deficit exists in individuals with a history of recurrent ankle sprains. Specifically, they found the perception of inversion and eversion movements are impaired. The authors, however, recognize that their findings relate only to perception of movement and should not be generalized to active or passive position matching.[33] Deficits seen in injured ankles may be due to damage of the mechanoreceptors located in the lateral ligaments of the ankle.[17, 33]

The reflex mechanism of the body as a whole attempts to fulfill one primary requirement: to maintain the body's center of mass over the feet.[25] Impaired postural control is seen in subjects with a history of repetitive ankle sprains.[27, 34, 35] Hertel[18] hypothesized that the deficits are likely due to a combination of impaired proprioception and neuromuscular control. When balancing in a single-leg stance, the healthy foot pronates and supinates in an effort to keep the body's center of gravity over the base of support in what is referred to as the "ankle strategy" of postural control. Injured subjects use a less efficient method correcting body position at the hip.[18]

*Impaired Neuromuscular Control.* Controversy continues on whether a lack of neuromuscular control contributes to functional ankle instability and an unstable joint. Studies using reaction times have been done to study neuromuscular control. The results of these studies contribute to the confusion. Several researchers[4-6, 36] examining peroneal reaction time in injured and uninjured ankles reported increases in reaction time for functionally unstable ankles. However, other researchers contradict these findings showing no difference in reaction time of the peroneal muscles between healthy and injured subjects.[7, 10, 26, 37]

Contradiction in results may be due to the methods used. Most studies were conducted on a standing inversion platform, but the degree and speed of inversion varies from study to study. In addition, the definition of injury for each study was varied. In one study[38] subjects self reported instability, while in another study,[26] objective radiographs were used. The time of testing after injury is not consistent between studies either. Some injured subjects were tested a few weeks after an injury[26] while others were not tested until months,[6, 38] and even years[7] after an ankle sprain. It remains likely that immediately following an ankle injury there is a delay in the reaction time in the peroneal musculature, but this deficit is rectified during the healing and rehabilitation of the sprain.

*Strength Deficits.* Following acute injury to the lateral ligament complex of the ankle, there are immediate strength deficits. It is speculated that these strength deficits are long term and thus contribute to chronic ankle instability. Concentric and eccentric strength is important for the prevention of lateral ankle sprains. The literature does not support the idea that a strength deficit is highly correlated with chronic ankle instability.[39] However, clinically practitioners commonly use strengthening programs as they think it will limit chronic ankle sprains.

*Effects of Neuromuscular Training.* Research done by Sheth et al[15] and Osborne et al[40] examined the influence of ankle disk training on the reaction times of muscles in the lower leg. Both studies showed a significant delay in the reaction time of the anterior tibialis muscle, but there was no training effect on the peroneus longus reaction time.[15, 40]

Hoffman and Payne[41] used ankle disk training with a healthy population, but instead of measuring reaction time of the muscles, they measured postural sway. They found that after 10 weeks of training, postural sway decreased in both the medial-lateral and anterior-posterior directions.

Many rehabilitation protocols utilize balance exercises as part of their regimes. The theory behind these exercises is that balance training treats existing proprioceptive deficits and restores ankle joint stability to the injured ankle.[34] In a study using healthy and self-reported unstable ankles, Rozzi et al[34] found that 4 weeks of balance training improved joint proprioception for both groups.

Chong et al,[42] designed a study to try to determine what aspect of ankle disk training improves balance. Subjects were restrained at the hips and trunk with a custom-made thoracolumbosacral brace while they performed a single-leg balance test with their head tilted back and eyes closed. Subjects showed improvement in tasks on the board during the 4 weeks, but their single-leg test failed to show improvements in sway velocity, number of touchdowns, or falls relative to pretest scores.[42] The authors concluded that the improvements resulted from enhanced proprioception in other body segments such as the knees, hips, spine, and upper extremities, but that the ankle disc did not improve balance by specifically targeting ankle proprioception.[42]

Research could not be found that examined the effects of plyometric training on muscle reaction times. Possible theories exist regarding why it might be beneficial. It is possible that plyometric training could produce results similar to those found from strength training. Strength training has been shown to cause an increase in motor neuronal output.[43] These adaptations may involve increased firing rates, increased motoneuron excitability and decreased presynaptic inhibition, downregulation of inhibitory neural pathways, and possible increased levels of central descending motor drive.[43] Regarding plyometric training, muscle spindle sensitivity might also be influenced by training. Almeida-Silveira et al[44] performed plyometric training tests on rats and suggested that the muscle spindle sensitivity is decreased with training. This means it takes less of a stimulus to cause a reaction of the spindle.

*Dynamic Stability*

Muscles, when contracted, generate stiffness, which leads to dynamic protection of the joint. Many muscles cross the ankle complex and may be considered dynamic stabilizers. The peroneous longus and brevis muscles are key to the control of supination of the rearfoot and protection against lateral ankle sprains.[45] Select muscles of the anterior compartment, the extensor digitorum longus, and peroneus tertius may also contribute to the dynamic stability of the lateral ankle by contracting eccentrically during forced supination of the rearfoot.[18]

Two factors that must be taken into consideration when a muscle fires to offset an injury moment are the timing and magnitude of the contraction. In other words, the muscle must react fast enough and strong enough in order to offset the injury. Gamma motoneuron drive has a direct influence on both aspects because it sets the sensitivity of the muscle spindle.[46] For example, if a muscle spindle has a lower threshold, it will react sooner to a stimulus. It is theorized that increased activity of the gamma motoneuron before activity also decreases the electromechanical delay (EMD), or time between when muscle stimulation and mechanical contribution, because the nerves innervating the muscles are brought closer to threshold before a stimulus requiring contraction of the muscles is required. Gamma motoneuron drive is influenced by periphery information from proprioceptors, descending information from the central nervous system, the brainstem, and possibly cold.[16, 46] The following figure (Figure 6) illustrates how gamma motoneuron drive has the potential to affect the speed of the contraction.

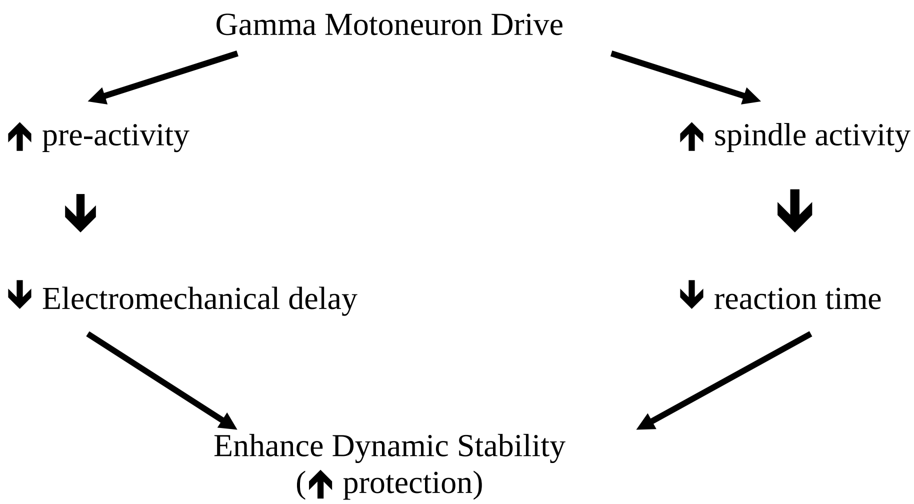


Figure 1. Potential influences of gamma motoneuron drive on dynamic stability

Applying this diagram to the ankle and lateral ankle instability, the EMD would relate to the time between activation of the peroneal muscles and their mechanical contribution. Research done by Mora et al[9] indicates that peroneus longus EMDs are sensitive to musculo-tendinous stiffness in an indirect relationship. This means that if the pre-activity of the peroneus longus is increased prior to the injury mechanism, the EMD will be decreased, and perhaps the injury minimized, or even prevented.

*Measurement Technique*

In addition to being strong enough, the reaction must be fast enough to overcome the injury mechanism. This is commonly examined by measuring the latency period of the peroneal muscles. Research[3-7, 10, 26, 36, 38, 47] using standing inversion platforms have traditionally been used to measure the latency of these muscles. The range for reaction times in unstable ankles is 58[26] to 84[4] msec. In healthy ankles the range is 47.7[36] to 69[5] msec. If training could decrease the reaction time, perhaps inversion injuries could be decreased or even prevented.

The actual time it takes to sprain an ankle can only be hypothesized for several reasons. First, an EMG study has never been done during an actual injury. All estimated made about this time have been made with the data collected from a standing inversion platform. The standing platforms rely on the subject completing relaxing before the trapdoor is dropped and the subject must roll into the inversion mechanism with the trapdoor. The trapdoors also only fall a fraction of the distance it actually takes to sprain an ankle. All these factors are unrealistic to expect in a real injury response. Finally, there are some ankle sprains that are already being prevented by the body. Every time a person rolls their ankle, they do not sprain their ankle. Something is catching the ankle and preventing it from spraining.

The range of reaction times for the peroneal musculature is due to several variables. First, a standard definition of reaction time is not used in the research. Each author uses their own definition for a reaction time, and this makes comparison to other studies difficult. Next, the tilting angle of the inversion platform in previously mentioned studies ranged from $20^{o}$[10] to $50^{o}$[36] which has the potential to influence the reaction time and make comparisons between studies difficult. Finally, the inversion moment speed varied across the studies. This has the potential to introduce the greatest variation because the reaction of the musculature is dependent upon velocity.

Inadequate conclusions have been drawn from previous research.[3-7, 10, 26, 36, 38, 47] These conclusions have been based on ankle testing done when subjects are standing. Ankle sprains rarely occur while one stands, therefore, standing does not mimic the mechanics of an ankle sprain. This study, using a walkway instead of a trap door to simulate inversion, is needed to examine the electromechanical delay and muscle reaction times in a more injury like situation.

*Biomechanics*

Rearfoot motion, or motion of the talus and calcaneous, does not occur strictly in any of the cardinal planes. Instead, it is a coordinated movement of the talocrural, subtalar, and distal tibiofibular joints that allows the rearfoot to move as a single unit about an axis of rotation oblique to the long axis of the lower leg.[18] Because of the wedge shape of the talus being wider at the anterior aspect, the most stable position of the ankle is in end range dorsiflexion. As the ankle moves into plantar flexion, the wider aspect of the tibia articulates with the more narrow talus, thus reducing stability.[20] There is a consensus among investigators that the primary ankle motion of dorsiflexion and plantarflexion occurs around an oblique axis that causes the foot to move across all three planes.[21] This is significant because injury will cause a decrease in range of motion in all three planes. Therefore, when considering rehabilitation activities, triplanar exercises need to be used to regain normal arthrokinematics.

Although the subtalar joint is composed of three articulations, the alternating convex-concave facets limit the potential mobility of the joint.[21] Movement of the talus differs in weight bearing and non-weight bearing situations. In open chain supination, the subtalar joint inverts, adducts, and plantarflexes. The opposite motions occur in open chain pronation.[23] During closed chain supination and pronation, the talus abducts and adducts, respectively.[23] In normal range of motion, the three articulations of the subtalar joint move in unison about a common axis of motion.[23] Closed chain subtalar pronation internally rotates the lower leg while supination causes external rotation of the leg.[23]

*Mechanism of Injury*

Most inversion ankle sprains are a combination of sudden, unexpected inversion, plantar flexion, and internal rotation of the tibia. The uncontrolled movement produces unexpected torque to the ankle joint.[12] The ankle ligaments can be damaged when this unexpected torque is applied at a rate that exceeds the minimum time necessary for the neuromuscular system to respond.[13]

Common situations where an individual may sprain an ankle include landing from a fall, landing on another person's foot, or stepping on an uneven surface. In these situations, the forefoot contact precedes rearfoot contact, and the forefoot through a gearing mechanism and movement coupling sequence would transmit a supination moment to the talus and calcaneous.[25]

The sequence of ligament tears in an inversion injury begins with the anterior talofibular ligament.[48] As the inversion mechanism continues, the calcaneofibular ligament is then injured.[48] The posterior talofibular ligament is the strongest of the lateral ankle complex, and is therefore, injured the least.[48] The differing strengths of the lateral ligaments is likely due to both physiological and positional differences.

*Grades*

Ankle sprains are usually graded on a three degree scale with Grade I sprains being mild, Grade II sprains moderate, and Grade III sprains severe. However, authors acknowledge that grading ankle sprains is largely a subjective interpretation of the abnormal laxity and symptoms observed in the ankle.[1] Table 1 illustrates the subjective nature of the diagnosis by listing several criteria for assigning a grade of injury. As is shown, signs and symptoms often overlap in the categories.

Table 1. Signs and Symptoms Associated with Grades of Lateral Ankle Sprains

| Grades | Signs and Symptoms |
|---|---|
| Grade I (mild) | Mild pain[20]<br>Mild disability[20] minimal or no functional loss[1]<br>Weight bearing minimally impaired[20]<br>Point tenderness over ligament[20]<br>Little swelling over ligament[1, 20] that might become more generalized with time[1]<br>No joint laxity[1, 20]<br>Non-operative management[1]<br>Ligament stretch without macroscopic tearing[1] |
| Grade II (moderate) | Complains of a pop or snap on lateral side of ankle[20]<br>Moderate pain[1, 20]<br>Moderate disability[20]<br>Weight bearing is difficult[20]<br>Tenderness and edema with blood in the joint[1, 20]<br>Mild to moderate joint instability[1]<br>Positive talar tilt test[20]<br>Positive anterior drawer test between 4 and 14 mm[20]<br>Non-operative management[1]<br>Partial macroscopic tear[1]<br>Swelling and tenderness over the involved structures[1]<br>Some loss of joint motion[1] |
| Grade III (severe) | Severe pain[1, 20]<br>Weight bearing not possible[20]<br>Great amount of swelling[1, 20]<br>Hemarthrosis[20]<br>Positive talar tilt test[20]<br>Positive anterior drawer test[20]<br>Possible surgical intervention[1]<br>Complete ligament rupture[1] |

# Chapter 3

# Methods

*Research Design*

The study will be guided by a 2 x 2 factorial design with repeated measures on the time factor. The independent variables for this study are the neuromuscular training program and time.

Dependent variables for this study are muscle reaction time and electromechanical delay of the peroneus longus.

Control variables will be gender and ankle range of motion during the inversion moment.

*Subjects*

Thirty healthy, physically active, college-age (18–25 yrs) male and female students will be recruited as subjects for this study. Subjects will be randomly assigned to a treatment (n = 15) or a control group (n = 15). Groups will be gender matched through separate randomization of males and females into the treatment or control group. Participants will not have experienced an ankle sprain in the last year, and no more than one sprain to either ankle in their life. In addition, subjects will not currently be suffering from a lower extremity injury and have no history of major injury that resulted in severe ligamentous damage, fracture, or the need for surgery to either lower extremity. Each subject will be asked to read and sign an informed consent form approved by the Institutional Review Board after the study has been described and all questions answered.

*Instruments*

Runway (8.5 m x 0.76 m x 0.25 m)

Surface electromyography (MP150, BIOPAC Systems Inc., Santa Barbara, CA).

Amplifier (DA100B, BIOPAC Systems Inc., Santa Barbara, CA)

Disposable, pre-gelled Ag-AgCl electrodes (Type Blue Sensor P00S, Medicotest, Ølstykke, Denmark)

Percutaneous electric muscle stimulator (BIOPAC Systems Inc., Santa Barbara, CA)

Electric goniometer (TSD130A, BIOPAC Systems Inc., Santa Barbara, CA)

Biomechanical ankle platform system (BAPS board) (Spectrum Therapy Products, Jasper, MI)

Custom made slant board with non-stick surface and 15 degree lateral decline

Balance Disc (Power Systems Sports, Knoxville, TN)

Thera-Band Exercise Tubing (Medco Sports Medicine, Tonawanda, NY)

*Description of Instruments*

A runway consisting of trap doors will be utilized for the study. The runway (8.5 m x .076 m x .025 m) consists of 7 separate 1.22 m segments, which may be linked together in any order. A bilateral trap door mechanism is present in the center four segments, allowing for an ankle injury mechanism to occur on either side of the runway. An adhesive, non-slip material covers the surface of the runway and the trap door in order to prevent the foot from slipping when the trap door is released. Trap door mechanisms (1.22 m x 0.76 m x 0.25 m) will be used to mimic an ankle inversion injury mechanism. The trapdoor mechanisms will fall 30° to the selected side. A mechanical lever controls an electric solenoid that triggers the fall of the trap door, which in turn triggers measurements through a signal recorded on the computer. The trapdoor falls as soon as a few pounds of pressure are placed on it.

Electromyography (EMG) measurements will be collected using surface electromyography (MP150, BIOPAC Systems Inc., Santa Barbara, CA). Signals will be amplified (DA100B, BIOPAC Systems Inc., Santa Barbara, CA) from disposable, pre-gelled Ag-AgCl electrodes.

Ankle motion will be measured using an electric goniometer (TSD130A, BIOPAC Systems Inc., Santa Barbara, CA), which will be secured to the outside of the foot and lower leg to measure inversion. The goniometer will be placed behind the lateral malleolus and secured to the shoe and lower leg with tape. Measurements taken during inversion on the runway will be used to make sure each subject reaches $30^{o}$ during testing.

*Procedures*

All subjects will report to the lab approximately one week prior to testing for an orientation session. During this time subjects will be oriented to where adhesive surface electrodes will be placed, the supramaximal percutaneous electrical stimulation, and the function of the trap door runway. Their dominant leg will also be determined and recorded as the leg with which they drop kick a ball. Subjects will also practice walking on the runway and establishing an isometric reference position.

During the practice session, subjects will practice walking to a cadence of a metronome set to 100 steps/min. After the subjects become comfortable walking on the runway at the set cadence, we will be able to establish each subjects; stride length. This is necessary to determine a starting point from which the subject will consistently step with each foot on each of the eight trap door mechanisms located in the runway.

Subjects will also establish an isometric reference position. To do this, subjects will side lie on a table on the non-dominant side with the dominant leg hanging off the end of the table. The non-dominant leg will be flexed at the knee and hip and remain on the table. A 5 lb weight will be attached to the lateral aspect of the ankle. After having the neutral position of the ankle described, the subjects will then be asked to hold the ankle in that position for 8 seconds. During actual testing, EMG activity will be collected in this position. This measurement will allow for normalization of data and will be performed before and after each subsequent testing session.

After the orientation session, any questions subjects may have will be answered and an Institutional Review Board approved informed consent will be signed by those who will participate in the study. Subjects will then be randomized into either the treatment or control group.

On the test day, subjects will be prepared before application of the electrodes by shaving the area. That area will then be abraded with sand paper and cleaned with alcohol. The surface electrodes will be placed parallel to the peroneus longus muscle fibers 4-6 cm distal to the fibular head. Placement will be assessed by visual inspection of the EMG signal during resisted eversion.

Subjects will begin a testing session by warming up on an exercise bike for 5 min at a moderate intensity. All subsequent data will be collected from the subject's dominant leg.

To assess the EMD, a supramaximal percutaneous electrical stimulation of the common peroneal nerve will be used, as described by Mora et al.[9] The stimulation electrode will be placed over the common peroneal nerve as it passes behind the fibular head. Lateral ground reaction force will represent the mechanical contribution induced by stimulation.[9] Subjects will stand with the test leg on the force plate and the non-test leg off the force plate and be able to grasp a hand railing in front of them. This will provide support and decrease sway. The common peroneal nerve will then be stimulated ten times. The onset times of the EMG response and lateral ground force reaction deviation will be defined as the point where the signal becomes higher than the baseline plus two standard deviations of the mean resting activity. The EMD will then be defined as the time interval between the onset of the peroneous longus EMG activity and the onset of lateral ground reaction force deviation.[9]

Subjects will then be prepared for reaction testing on the runway. Each subject will wear blinders that obstruct the field of vision below eye level and headphones connected the electric goniometer that block the sound of the triggering of the trapdoor mechanism and give them the cadence to which they are to step. The subject will then practice walking the length of the runway several times to recheck the previously determined starting point. Modifications to the starting point can then be made as necessary. Testing will then begin.

While the subject is standing at the beginning of the runway, a baseline EMG measurement will be recorded for use in determining the initiation of joint muscle activity following the release of the trap door. The subject will then be instructed to walk to a sign placed at the end of the runway. The sign is a reference to allow the subject to walk straight, and to notify the subject as to the end of the runway. An assistant will walk behind the subject and off the runway to ensure that the subject does not step off the runway or lose balance. The subject will walk this length 30 times.

Each ankle will randomly be tested during a session, but only data from the dominant leg will be measured and recorded. This will be done in order to reduce a learning effect from repetitive testing of the dominant leg and to try to keep the subject from guessing when or where the trap door will fall. The trap door will be triggered six times for each leg when the heel strikes any of the triggered traps in the runway according to one of two random sequences. The subject will not know whether the trap door will fall, where in the runway it will fall, or which side will fall.

The EMG data will be collected for 5.0 sec, which allows for inspection of muscle activity while the subject walks the entire length of the runway. The peroneus longus muscle will be considered active when it exceeds 2 standard deviations of the peak baseline (standing) activty.[8] The reaction time will be considered the time from the onset of the trap door release to the time the peroneals become active. Baseline measurements will be recorded on each subject.

Subjects in the control group will be instructed to maintain their current activity level and to return for further testing in eight weeks.

Subjects in the treatment group will be given a schedule for the neuromuscular training program. The protocol will consist of warm-up, sensorimotor, strength, and power components. Each session will last approximately 30 minutes and be repeated 3 days/week. At least one-day rest will be observed between sessions, and subjects will observe approximately 1 min rest between sets and exercises. Both dominant and non-dominant legs will complete the rehabilitation exercises. All training sessions will monitored to encourage the subject's compliance and maximum effort.

Each training session for weeks 1 and 2 will consist of the following exercises:

1. Jump rope warm-up at moderate intensity for 3 minutes.
2. Static stretching on BAPS board, while sitting with the knee at 90 degrees, in the frontal and sagittal planes (inversion/eversion and plantarflexion/dorsiflexion). Two sets will be done in each direction and each stretch will be held for 20 seconds.
3. Maintenance of a single-leg stance with hand on hips for 60 seconds.
4. Maintenance of a single-leg stance on a Dynadisk with hands on hips for 60 seconds. (If the non-stance leg is lowered to prevent a fall, it should be immediately raised after balance is restored.)
5. Maintenance of a single-leg stance on a BAPS board with hands on hips for 60 seconds. (If the non-stance leg is lowered to prevent a fall or any edge of the board touches, it should be immediately raised after balance is restored.)
6. Three-direction forward tubing kicks. Subjects will face away from the anchored elastic tubing with the affected knee and hip slightly flexed. The

tubing will be placed on the non-affected leg and subjects will be instructed to kick straight ahead and diagonally to the left and right. During the kicks the affected leg should remain in the same position. Two sets of 30 total kicks will be performed.

7. Three-direction backward tubing kicks. Subjects will face toward the anchored elastic tubing with the affected knee and hip slightly flexed. The tubing will be placed on non-affected leg, and subjects will be instructed to kick straight back and diagonally to the left and right. During the kicks the affected leg should remain in the same position. Two sets of 30 total kicks.
8. Lateral step-downs onto a step with a 15° lateral decline. This places the ankle in slight inversion during the step. Three sets of 20 step-ups.
9. Lateral hops. Two marks will be placed on the floor with a line separating the marks. Subjects will hop (single leg) over the line to the marks. Two sets of hops with each set lasting 30 seconds.
10. A jump rope cool down at low intensity for 3 minutes.

Week 3 and 4 progressions:

1. The single-leg stance exercises will be progressed and subjects will be required to maintain the position 90 seconds rather than 60 seconds (Exercise 3-5).
2. Additionally, a set will be added to tubing, step-up, and hopping exercises (Exercises 6, 7, 8, and 9).

Week 5 and 6 progressions:

1. Static single-leg stance exercises will be performed by standing on the ball/pivot of the foot (Exercise 3) for 90 seconds.
2. Dynadisk and ankle disk exercises will be performed for 120 seconds rather than 60 seconds (Exercises 4 and 5).
3. Tubing exercises will be increased to 3 sets of 45 total kicks (Exercises 6 and 7).
4. Step-ups will be increased to 3 sets of 30 (Exercise 8).
5. Hops will then be performed by following a marked zig-zag pattern (3 sets of 30 sec) instead of lateral hops (Exercise 9).

Subjects will be dropped if they miss more than two training sessions without making them up. Make-up training sessions must be completed within one day of the missed training session.

Measurements will be repeated within two days of completion of the training program. Subjects in the gender matched control group will also repeat the measurements within the same time frame.

*Data Analysis*

Averaged muscle reaction time means from the six trials will be and averaged EMD means will be used in data analysis. Two 2 x 2 ANOVAs with repeated measures on time will be computed to detect differences between groups over time for both dependent variables. The significance level will be accepted at $P \leq 0.05$ for all tests.

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Appendix A-1

Informed Consent

Consent to be a Research Subject

**Introduction**

This research is being conducted by Dr. Ty Hopkins at Brigham Young University to determine how the muscles around the ankle work to protect the joint and if they can be trained to work differently. You were selected to participate because you have a history of ankle sprains to one ankle or because you fit the following criteria: (1) no history of injury to either ankle, (2) no known neurological disorders, (3) no lower extremity injury within the past 6 months, and (4) no previous lower extremity surgery.

**Procedures**

You will be randomly assigned to one of four groups. Depending on your group, you will report to the biomechanics lab (124 RB) three to twenty-one times for orientation, testing, and potentially exercise training. During the orientation we will explain the study and all of its procedures. You will also be asked to practice on some of the equipment in order to become familiar with it. During testing we will place several adhesive electrodes on the lower leg for measurement of muscle activity. We will then place a different kind of electrode behind your knee to stimulate the nerve that causes muscle contraction of the lower leg muscles. This is done to measure reflexes. These measurements will be recorded while you lay quietly on a padded table, sit quietly in a chair, stand on one leg, walk, and jog. We will than apply an instrument used to measure ankle movement to your ankle with adhesive tape. You will then walk the length of a 28 foot runway 25 times. Twelve times one of the parts of the runway will tilt approximately 30º when you step on it. This allows us to measure muscle activity when the ankle is tilted. A testing session will last approximately 60-90 minutes, and it will be repeated 2 times over 6 weeks. If you are assigned to an exercise training group, you will report to the biomechanics lab 3 times per week for 6 weeks beginning after the first testing session. Each training session will last approximately 45-60 minutes. During the training exercises you will perform a series of balance and simple strength exercises. It will include a warm-up and cool-down period.

**Risks/Discomforts**

There are minimal risks for participation in this study. However, while walking down the runway, one of the segments will suddenly tilt to 30º. Ankle injury does not typically occur until 40-45º. It is possible that you could lose your balance when the segment tilts. A research assistant will be behind you to help you regain your balance. The stimulus used to elicit a reflex could be uncomfortable. The shocks in this study feel similar to a shock of static electricity, like when you are walking across a carpet and then touch a door knob, except the voltage is much lower. (A shock of static electricity can provide up to thousands of volts of electricity). You could also feel discomfort or muscle soreness following the 1$^{st}$ or 2$^{nd}$ day of exercise training. However, this should be minimal and it should go away within a couple of days.

**Benefits**

Subjects who participate in the exercise training program may experience improved ankle stability following the study, which could reduce the future incidence of ankle injury. It is hoped that through your participation we will learn how to more effectively rehabilitate and prevent ankle injuries.

**Confidentiality**

All information provided will remain confidential and will only be reported as group data with no identifying information. All data will be kept in a locked storage cabinet and only those directly involved with the research will have access to them. After the research is completed, all original data will be destroyed.

**Compensation**

Participants may receive extra credit points from instructors who chose to participate in this study. For those who do not wish to participate in the research, and equal number of extra credit point can be earned by completing an assignment of equal time commitment.

**Participation**

Participation in this research study is voluntary. You have the right to withdraw at anytime or refuse to participate entirely without jeopardy to your class status, grade, or standing with the university.

**Questions about the Research**

If you have any questions regarding this study, you may contact Dr. Ty Hopkins at 422-1573, tyhopkins@byu.edu.

**Questions about your Rights as Research Participants**

If you have questions you do not feel comfortable asking the researcher, you make contact Dr. Shane Schulthies, IRB Chair, 422-5490, 120B RB, shane_schulthies@byu.edu.

I have read, understood, and received a copy of the above consent and desire of my own free will and volition to participate in this study.

Signature: ____________________________________________ Date: ______________

Appendix A-2

Subject Information Form

**Subject Information Form**

Name: ________________________________________Phone Number: ________________

Gender: _______ Date of Birth: _________ Height: ________ Weight: _____

**TREATMENT OR CONTROL** (circle one) Subject Number: ________________

Pre-treatment data collection: ____________________________________________________

Post-treatment data collection: ____________________________________________________

**Treatment Only:**

Begin rehabilitation on: __________________________________________________________

Progress rehabilitation on: _______________________________________________________

Progress rehabilitation on: _______________________________________________________

Complete rehabilitation on: ______________________________________________________

**Notes:**

Appendix A-3

Rehabilitation Record

# Rehabilitation Record

Name: ________________________________________ Phone Number: _______________

Weeks 1 and 2:

| Exercise: | Date: | Date: | Date: | Date: | Date: | Date: |
|---|---|---|---|---|---|---|
| Warm-up | | | | | | |
| Stretch: BAPS | | | | | | |
| Balance: Floor | | | | | | |
| Balance: Dynadisk | | | | | | |
| Balance: BAPS | | | | | | |
| Kicks: Forward | | | | | | |
| Kicks: Backward | | | | | | |
| Step-downs | | | | | | |
| Lateral Hops | | | | | | |
| Cool down | | | | | | |
| Supervisor Signature | | | | | | |

Name: ____________________________________Phone Number: ______________

Weeks 3 and 4:

| Exercise: | Date: | Date: | Date: | Date: | Date: | Date: |
|---|---|---|---|---|---|---|
| Warm-up | | | | | | |
| Stretch: BAPS | | | | | | |
| Balance: Floor | | | | | | |
| Balance: Dynadisk | | | | | | |
| Balance: BAPS | | | | | | |
| Kicks: Forward | | | | | | |
| Kicks: Backward | | | | | | |
| Step-downs | | | | | | |
| Lateral Hops | | | | | | |
| Cool down | | | | | | |
| Supervisor Signature | | | | | | |

Name: ________________________________________Phone Number: ______________

Weeks 5 and 6:

| Exercise: | Date: | Date: | Date: | Date: | Date: | Date: |
|---|---|---|---|---|---|---|
| Warm-up | | | | | | |
| Stretch: BAPS | | | | | | |
| Balance: Floor | | | | | | |
| Balance: Dynadisk | | | | | | |
| Balance: BAPS | | | | | | |
| Kicks: Forward | | | | | | |
| Kicks: Backward | | | | | | |
| Step-downs | | | | | | |
| Zig-zag Hops | | | | | | |
| Cool down | | | | | | |
| Supervisor Signature | | | | | | |

Appendix B
Raw Data

**EMD Data**

| Subject | Group | Gender | Trial | Pre | Post |
|---|---|---|---|---|---|
| 1 | Tx | M | 1 | 16 | 14 |
| 1 | Tx | M | 2 | 20 | 14 |
| 1 | Tx | M | 3 | 21 | 18 |
| 1 | Tx | M | 4 | 18 | 21 |
| 1 | Tx | M | 5 | 21 | 19 |
| 1 | Tx | M | 6 | 19 | 21 |
| 1 | Tx | M | 7 | 19 | 17 |
| 1 | Tx | M | 8 | 20 | 19 |
| 1 | Tx | M | 9 | 18 | **drop** |
| 1 | Tx | M | 10 | 20 | **drop** |
| 2 | Tx | F | 1 | 16 | 17 |
| 2 | Tx | F | 2 | 16 | 16 |
| 2 | Tx | F | 3 | 17 | 16 |
| 2 | Tx | F | 4 | 17 | 18 |
| 2 | Tx | F | 5 | 16 | 15 |
| 2 | Tx | F | 6 | 18 | 16 |
| 2 | Tx | F | 7 | 17 | 16 |
| 2 | Tx | F | 8 | 16 | 17 |
| 2 | Tx | F | 9 | 16 | 14 |
| 2 | Tx | F | 10 | 17 | 17 |
| 3 | Tx | M | 1 | 17 | 19 |
| 3 | Tx | M | 2 | 18 | 21 |
| 3 | Tx | M | 3 | 19 | 20 |
| 3 | Tx | M | 4 | 17 | 19 |
| 3 | Tx | M | 5 | 17 | 18 |
| 3 | Tx | M | 6 | 16 | 17 |
| 3 | Tx | M | 7 | 19 | 19 |
| 3 | Tx | M | 8 | 17 | 20 |
| 3 | Tx | M | 9 | 18 | 21 |
| 3 | Tx | M | 10 | 19 | 20 |
| 4 | Tx | F | 1 | 16 | 19 |
| 4 | Tx | F | 2 | 17 | **drop** |
| 4 | Tx | F | 3 | 17 | 19 |
| 4 | Tx | F | 4 | 16 | 18 |
| 4 | Tx | F | 5 | 16 | 16 |
| 4 | Tx | F | 6 | 16 | 16 |
| 4 | Tx | F | 7 | 17 | 17 |
| 4 | Tx | F | 8 | 17 | 18 |
| 4 | Tx | F | 9 | 15 | **drop** |
| 4 | Tx | F | 10 | 18 | 19 |
| 5 | Tx | F | 1 | 15 | 17 |
| 5 | Tx | F | 2 | 15 | 18 |
| 5 | Tx | F | 3 | 15 | 19 |

| Subject | Group | Gender | Trial | Pre | Post |
|---|---|---|---|---|---|
| 5 | Tx | F | 4 | 14 | 17 |
| 5 | Tx | F | 5 | 16 | 17 |
| 5 | Tx | F | 6 | 17 | 18 |
| 5 | Tx | F | 7 | 15 | 16 |
| 5 | Tx | F | 8 | 15 | 17 |
| 5 | Tx | F | 9 | 14 | 19 |
| 5 | Tx | F | 10 | 15 | 18 |
| 6 | Tx | M | 1 | **drop** | **drop** |
| 6 | Tx | M | 2 | **drop** | **drop** |
| 6 | Tx | M | 3 | **drop** | **drop** |
| 6 | Tx | M | 4 | **drop** | **drop** |
| 6 | Tx | M | 5 | **drop** | **drop** |
| 6 | Tx | M | 6 | **drop** | **drop** |
| 6 | Tx | M | 7 | **drop** | **drop** |
| 6 | Tx | M | 8 | **drop** | **drop** |
| 6 | Tx | M | 9 | **drop** | **drop** |
| 6 | Tx | M | 10 | **drop** | **drop** |
| 7 | Tx | M | 1 | 19 | 22 |
| 7 | Tx | M | 2 | 20 | 22 |
| 7 | Tx | M | 3 | 19 | **drop** |
| 7 | Tx | M | 4 | 20 | 19 |
| 7 | Tx | M | 5 | 19 | 19 |
| 7 | Tx | M | 6 | 19 | 19 |
| 7 | Tx | M | 7 | 17 | 17 |
| 7 | Tx | M | 8 | 16 | 21 |
| 7 | Tx | M | 9 | 20 | 21 |
| 7 | Tx | M | 10 | 18 | 16 |
| 8 | Tx | M | 1 | 15 | 15 |
| 8 | Tx | M | 2 | 15 | 17 |
| 8 | Tx | M | 3 | 16 | 19 |
| 8 | Tx | M | 4 | 17 | 16 |
| 8 | Tx | M | 5 | 16 | 19 |
| 8 | Tx | M | 6 | 17 | 16 |
| 8 | Tx | M | 7 | 16 | 19 |
| 8 | Tx | M | 8 | 17 | 18 |
| 8 | Tx | M | 9 | 17 | 18 |
| 8 | Tx | M | 10 | 15 | 18 |
| 9 | Tx | F | 1 | 19 | 19 |
| 9 | Tx | F | 2 | 19 | 15 |
| 9 | Tx | F | 3 | 16 | 17 |
| 9 | Tx | F | 4 | 19 | 17 |
| 9 | Tx | F | 5 | 17 | 18 |
| 9 | Tx | F | 6 | 19 | 18 |
| 9 | Tx | F | 7 | 15 | 15 |
| 9 | Tx | F | 8 | 18 | 20 |
| 9 | Tx | F | 9 | 17 | 19 |

| Subject | Group | Gender | Trial | Pre | Post |
|---|---|---|---|---|---|
| 9 | Tx | F | 10 | 17 | 18 |
| 10 | Tx | F | 1 | 17 | 19 |
| 10 | Tx | F | 2 | 16 | 19 |
| 10 | Tx | F | 3 | 15 | 20 |
| 10 | Tx | F | 4 | 14 | 18 |
| 10 | Tx | F | 5 | 16 | 16 |
| 10 | Tx | F | 6 | 15 | 18 |
| 10 | Tx | F | 7 | 15 | 21 |
| 10 | Tx | F | 8 | 16 | 17 |
| 10 | Tx | F | 9 | 14 | 19 |
| 10 | Tx | F | 10 | 15 | 19 |
| 11 | Tx | F | 1 | 15 | 15 |
| 11 | Tx | F | 2 | 15 | 18 |
| 11 | Tx | F | 3 | 14 | 13 |
| 11 | Tx | F | 4 | 17 | 15 |
| 11 | Tx | F | 5 | 15 | 15 |
| 11 | Tx | F | 6 | 15 | 14 |
| 11 | Tx | F | 7 | 15 | 19 |
| 11 | Tx | F | 8 | 15 | 17 |
| 11 | Tx | F | 9 | 14 | 16 |
| 11 | Tx | F | 10 | 17 | 15 |
| 12 | Tx | F | 1 | 15 | 18 |
| 12 | Tx | F | 2 | 17 | 19 |
| 12 | Tx | F | 3 | 15 | 18 |
| 12 | Tx | F | 4 | 17 | 18 |
| 12 | Tx | F | 5 | 14 | 18 |
| 12 | Tx | F | 6 | 15 | 16 |
| 12 | Tx | F | 7 | 18 | 17 |
| 12 | Tx | F | 8 | 17 | 18 |
| 12 | Tx | F | 9 | 18 | 20 |
| 12 | Tx | F | 10 | 15 | 17 |
| 13 | Tx | F | 1 | 19 | 15 |
| 13 | Tx | F | 2 | 16 | 20 |
| 13 | Tx | F | 3 | 17 | 16 |
| 13 | Tx | F | 4 | 18 | 13 |
| 13 | Tx | F | 5 | 18 | 18 |
| 13 | Tx | F | 6 | 18 | 17 |
| 13 | Tx | F | 7 | 17 | 17 |
| 13 | Tx | F | 8 | 16 | 16 |
| 13 | Tx | F | 9 | 15 | 16 |
| 13 | Tx | F | 10 | 17 | 17 |
| 14 | Tx | M | 1 | 16 | 17 |
| 14 | Tx | M | 2 | 17 | 17 |
| 14 | Tx | M | 3 | 17 | 18 |
| 14 | Tx | M | 4 | 16 | 16 |
| 14 | Tx | M | 5 | 16 | 17 |

| Subject | Group | Gender | Trial | Pre | Post |
|---|---|---|---|---|---|
| 14 | Tx | M | 6 | 17 | 14 |
| 14 | Tx | M | 7 | 18 | 17 |
| 14 | Tx | M | 8 | 15 | 16 |
| 14 | Tx | M | 9 | 15 | 16 |
| 14 | Tx | M | 10 | 15 | 14 |
| 15 | Tx | F | 1 | 13 | 19 |
| 15 | Tx | F | 2 | 17 | 17 |
| 15 | Tx | F | 3 | 15 | 17 |
| 15 | Tx | F | 4 | 16 | 17 |
| 15 | Tx | F | 5 | 14 | 20 |
| 15 | Tx | F | 6 | 16 | 16 |
| 15 | Tx | F | 7 | 15 | 17 |
| 15 | Tx | F | 8 | 15 | 17 |
| 15 | Tx | F | 9 | 17 | 18 |
| 15 | Tx | F | 10 | 16 | 18 |
| 16 | C | M | 1 | 18 | 19 |
| 16 | C | M | 2 | 18 | 17 |
| 16 | C | M | 3 | 16 | 18 |
| 16 | C | M | 4 | 17 | 17 |
| 16 | C | M | 5 | 15 | 18 |
| 16 | C | M | 6 | 17 | 19 |
| 16 | C | M | 7 | 19 | 17 |
| 16 | C | M | 8 | 17 | 17 |
| 16 | C | M | 9 | 16 | 14 |
| 16 | C | M | 10 | 16 | 17 |
| 17 | C | F | 1 | 17 | 17 |
| 17 | C | F | 2 | 16 | 12 |
| 17 | C | F | 3 | 15 | 13 |
| 17 | C | F | 4 | 14 | 19 |
| 17 | C | F | 5 | 16 | 15 |
| 17 | C | F | 6 | 16 | 19 |
| 17 | C | F | 7 | 15 | 16 |
| 17 | C | F | 8 | 18 | 19 |
| 17 | C | F | 9 | 18 | 18 |
| 17 | C | F | 10 | 17 | 17 |
| 18 | C | F | 1 | 15 | 17 |
| 18 | C | F | 2 | 16 | 19 |
| 18 | C | F | 3 | 17 | 18 |
| 18 | C | F | 4 | 15 | 17 |
| 18 | C | F | 5 | 15 | 18 |
| 18 | C | F | 6 | 16 | 21 |
| 18 | C | F | 7 | 16 | 18 |
| 18 | C | F | 8 | 17 | **drop** |
| 18 | C | F | 9 | 15 | 18 |
| 18 | C | F | 10 | 18 | 19 |
| 19 | C | F | 1 | 18 | **drop** |

| Subject | Group | Gender | Trial | Pre | Post |
|---|---|---|---|---|---|
| 19 | C | F | 2 | 19 | 19 |
| 19 | C | F | 3 | 21 | 17 |
| 19 | C | F | 4 | 18 | **drop** |
| 19 | C | F | 5 | 19 | 20 |
| 19 | C | F | 6 | 17 | **drop** |
| 19 | C | F | 7 | 19 | 17 |
| 19 | C | F | 8 | 19 | 20 |
| 19 | C | F | 9 | 16 | 21 |
| 19 | C | F | 10 | 18 | 21 |
| 20 | C | M | 1 | 17 | 17 |
| 20 | C | M | 2 | 15 | 17 |
| 20 | C | M | 3 | 14 | 17 |
| 20 | C | M | 4 | 15 | 18 |
| 20 | C | M | 5 | 16 | 18 |
| 20 | C | M | 6 | 16 | **drop** |
| 20 | C | M | 7 | 15 | 19 |
| 20 | C | M | 8 | 14 | 17 |
| 20 | C | M | 9 | 16 | **drop** |
| 20 | C | M | 10 | 15 | 15 |
| 21 | C | F | 1 | **drop** | **drop** |
| 21 | C | F | 2 | **drop** | **drop** |
| 21 | C | F | 3 | **drop** | **drop** |
| 21 | C | F | 4 | **drop** | **drop** |
| 21 | C | F | 5 | **drop** | **drop** |
| 21 | C | F | 6 | **drop** | **drop** |
| 21 | C | F | 7 | **drop** | **drop** |
| 21 | C | F | 8 | **drop** | **drop** |
| 21 | C | F | 9 | **drop** | **drop** |
| 21 | C | F | 10 | **drop** | **drop** |
| 22 | C | F | 1 | 15 | 17 |
| 22 | C | F | 2 | 18 | 17 |
| 22 | C | F | 3 | 18 | 19 |
| 22 | C | F | 4 | 15 | 13 |
| 22 | C | F | 5 | 15 | 16 |
| 22 | C | F | 6 | 15 | 14 |
| 22 | C | F | 7 | 20 | 16 |
| 22 | C | F | 8 | 17 | 18 |
| 22 | C | F | 9 | 17 | 15 |
| 22 | C | F | 10 | 15 | 17 |
| 23 | C | F | 1 | 17 | **drop** |
| 23 | C | F | 2 | 20 | 18 |
| 23 | C | F | 3 | 17 | 16 |
| 23 | C | F | 4 | 15 | 16 |
| 23 | C | F | 5 | 20 | **drop** |
| 23 | C | F | 6 | **drop** | 16 |
| 23 | C | F | 7 | **drop** | 17 |

| Subject | Group | Gender | Trial | Pre | Post |
|---|---|---|---|---|---|
| 23 | C | F | 8 | 18 | 16 |
| 23 | C | F | 9 | 17 | 17 |
| 23 | C | F | 10 | 16 | 15 |
| 24 | C | F | 1 | 17 | 17 |
| 24 | C | F | 2 | 17 | 17 |
| 24 | C | F | 3 | 17 | 15 |
| 24 | C | F | 4 | 15 | 14 |
| 24 | C | F | 5 | 16 | 15 |
| 24 | C | F | 6 | 16 | 15 |
| 24 | C | F | 7 | 14 | 17 |
| 24 | C | F | 8 | 18 | 16 |
| 24 | C | F | 9 | 16 | 15 |
| 24 | C | F | 10 | 19 | 16 |
| 25 | C | F | 1 | 17 | 17 |
| 25 | C | F | 2 | 15 | 15 |
| 25 | C | F | 3 | 15 | 19 |
| 25 | C | F | 4 | 17 | 16 |
| 25 | C | F | 5 | 15 | 15 |
| 25 | C | F | 6 | 16 | 18 |
| 25 | C | F | 7 | 17 | 14 |
| 25 | C | F | 8 | 15 | 18 |
| 25 | C | F | 9 | 14 | 15 |
| 25 | C | F | 10 | 18 | 17 |
| 26 | C | M | 1 | 14 | 14 |
| 26 | C | M | 2 | 16 | 16 |
| 26 | C | M | 3 | 17 | 16 |
| 26 | C | M | 4 | 15 | 16 |
| 26 | C | M | 5 | 17 | 14 |
| 26 | C | M | 6 | 15 | 14 |
| 26 | C | M | 7 | 13 | 13 |
| 26 | C | M | 8 | 15 | 15 |
| 26 | C | M | 9 | 15 | 14 |
| 26 | C | M | 10 | 15 | **drop** |
| 27 | C | M | 1 | 16 | 18 |
| 27 | C | M | 2 | 16 | 15 |
| 27 | C | M | 3 | 16 | 15 |
| 27 | C | M | 4 | 14 | 18 |
| 27 | C | M | 5 | 16 | 16 |
| 27 | C | M | 6 | 15 | 15 |
| 27 | C | M | 7 | 15 | 15 |
| 27 | C | M | 8 | 15 | 15 |
| 27 | C | M | 9 | 16 | 17 |
| 27 | C | M | 10 | 15 | 17 |
| 28 | C | M | 1 | 18 | 16 |
| 28 | C | M | 2 | 18 | 18 |
| 28 | C | M | 3 | 16 | 16 |

| Subject | Group | Gender | Trial | Pre | Post |
|---|---|---|---|---|---|
| 28 | C | M | 4 | 17 | 16 |
| 28 | C | M | 5 | 19 | 16 |
| 28 | C | M | 6 | 18 | 17 |
| 28 | C | M | 7 | 19 | 17 |
| 28 | C | M | 8 | 18 | 18 |
| 28 | C | M | 9 | 19 | 16 |
| 28 | C | M | 10 | 18 | 18 |
| 29 | C | M | 1 | 19 | 17 |
| 29 | C | M | 2 | 20 | 18 |
| 29 | C | M | 3 | 20 | 17 |
| 29 | C | M | 4 | 19 | 17 |
| 29 | C | M | 5 | **drop** | 15 |
| 29 | C | M | 6 | 20 | 16 |
| 29 | C | M | 7 | **drop** | 16 |
| 29 | C | M | 8 | 21 | **drop** |
| 29 | C | M | 9 | 22 | **drop** |
| 29 | C | M | 10 | 20 | 15 |
| 30 | C | M | 1 | 18 | 17 |
| 30 | C | M | 2 | 17 | 17 |
| 30 | C | M | 3 | 19 | 15 |
| 30 | C | M | 4 | 17 | 17 |
| 30 | C | M | 5 | 16 | 17 |
| 30 | C | M | 6 | 17 | 17 |
| 30 | C | M | 7 | 18 | 16 |
| 30 | C | M | 8 | 16 | 16 |
| 30 | C | M | 9 | 17 | 17 |
| 30 | C | M | 10 | 19 | 17 |

**Reaction Time Data**

| Subject | Group | Gender | Trial | Pre | Post |
|---|---|---|---|---|---|
| 1 | Tx | M | 1 | **drop** | 30 |
| 1 | Tx | M | 2 | 65 | 65 |
| 1 | Tx | M | 3 | 48 | 55 |
| 1 | Tx | M | 4 | **drop** | 52 |
| 1 | Tx | M | 5 | **drop** | **drop** |
| 1 | Tx | M | 6 | 43 | **drop** |
| 2 | Tx | F | 1 | 76 | 43 |
| 2 | Tx | F | 2 | 67 | **drop** |
| 2 | Tx | F | 3 | 51 | 52 |
| 2 | Tx | F | 4 | 67 | **drop** |
| 2 | Tx | F | 5 | 58 | 39 |
| 2 | Tx | F | 6 | 72 | 65 |
| 3 | Tx | M | 1 | **drop** | 76 |
| 3 | Tx | M | 2 | 79 | **drop** |
| 3 | Tx | M | 3 | 49 | 52 |
| 3 | Tx | M | 4 | **drop** | **drop** |
| 3 | Tx | M | 5 | 95 | **drop** |
| 3 | Tx | M | 6 | **drop** | 90 |
| 4 | Tx | F | 1 | 40 | 58 |
| 4 | Tx | F | 2 | 60 | **drop** |
| 4 | Tx | F | 3 | **drop** | 43 |
| 4 | Tx | F | 4 | **drop** | **drop** |
| 4 | Tx | F | 5 | 66 | 65 |
| 4 | Tx | F | 6 | 39 | **drop** |
| 5 | Tx | F | 1 | 89 | 38 |
| 5 | Tx | F | 2 | 30 | 49 |
| 5 | Tx | F | 3 | 68 | **drop** |
| 5 | Tx | F | 4 | 59 | **drop** |
| 5 | Tx | F | 5 | 61 | 52 |
| 5 | Tx | F | 6 | 69 | 71 |
| 6 | Tx | M | 1 | **drop** | **drop** |
| 6 | Tx | M | 2 | **drop** | **drop** |
| 6 | Tx | M | 3 | **drop** | **drop** |
| 6 | Tx | M | 4 | **drop** | **drop** |
| 6 | Tx | M | 5 | **drop** | **drop** |
| 6 | Tx | M | 6 | **drop** | **drop** |
| 7 | Tx | M | 1 | **drop** | 64 |
| 7 | Tx | M | 2 | 55 | **drop** |
| 7 | Tx | M | 3 | 41 | 68 |
| 7 | Tx | M | 4 | **drop** | **drop** |
| 7 | Tx | M | 5 | **drop** | 72 |
| 7 | Tx | M | 6 | 82 | 45 |
| 8 | Tx | M | 1 | **drop** | **drop** |
| 8 | Tx | M | 2 | 51 | 72 |

| Subject | Group | Gender | Trial | Pre | Post |
|---|---|---|---|---|---|
| 8 | Tx | M | 3 | 75 | 73 |
| 8 | Tx | M | 4 | 46 | 70 |
| 8 | Tx | M | 5 | 73 | 40 |
| 8 | Tx | M | 6 | 55 | **drop** |
| 9 | Tx | F | 1 | 45 | **drop** |
| 9 | Tx | F | 2 | 63 | 50 |
| 9 | Tx | F | 3 | 53 | **drop** |
| 9 | Tx | F | 4 | 64 | 35 |
| 9 | Tx | F | 5 | 57 | **drop** |
| 9 | Tx | F | 6 | 57 | 73 |
| 10 | Tx | F | 1 | 54 | **drop** |
| 10 | Tx | F | 2 | **drop** | 79 |
| 10 | Tx | F | 3 | **drop** | 41 |
| 10 | Tx | F | 4 | 45 | **drop** |
| 10 | Tx | F | 5 | **drop** | 77 |
| 10 | Tx | F | 6 | 48 | 75 |
| 11 | Tx | F | 1 | 58 | **drop** |
| 11 | Tx | F | 2 | 85 | 46 |
| 11 | Tx | F | 3 | 70 | 77 |
| 11 | Tx | F | 4 | 61 | 37 |
| 11 | Tx | F | 5 | **drop** | 39 |
| 11 | Tx | F | 6 | 54 | **drop** |
| 12 | Tx | F | 1 | **drop** | 59 |
| 12 | Tx | F | 2 | 50 | **drop** |
| 12 | Tx | F | 3 | 79 | **drop** |
| 12 | Tx | F | 4 | **drop** | 59 |
| 12 | Tx | F | 5 | 40 | 55 |
| 12 | Tx | F | 6 | 77 | 35 |
| 13 | Tx | F | 1 | 71 | **drop** |
| 13 | Tx | F | 2 | 40 | **drop** |
| 13 | Tx | F | 3 | 66 | 39 |
| 13 | Tx | F | 4 | **drop** | 60 |
| 13 | Tx | F | 5 | **drop** | **drop** |
| 13 | Tx | F | 6 | 77 | 93 |
| 14 | Tx | M | 1 | 37 | 41 |
| 14 | Tx | M | 2 | 68 | **drop** |
| 14 | Tx | M | 3 | 71 | 60 |
| 14 | Tx | M | 4 | 66 | 36 |
| 14 | Tx | M | 5 | **drop** | 67 |
| 14 | Tx | M | 6 | 69 | **drop** |
| 15 | Tx | F | 1 | 80 | 79 |
| 15 | Tx | F | 2 | **drop** | 63 |
| 15 | Tx | F | 3 | **drop** | 62 |
| 15 | Tx | F | 4 | 58 | 75 |
| 15 | Tx | F | 5 | 74 | 53 |
| 15 | Tx | F | 6 | **drop** | 66 |

| Subject | Group | Gender | Trial | Pre | Post |
|---|---|---|---|---|---|
| 16 | C | M | 1 | 43 | 56 |
| 16 | C | M | 2 | 64 | **drop** |
| 16 | C | M | 3 | **drop** | 82 |
| 16 | C | M | 4 | 67 | 42 |
| 16 | C | M | 5 | 68 | 70 |
| 16 | C | M | 6 | **drop** | **drop** |
| 17 | C | F | 1 | 73 | 39 |
| 17 | C | F | 2 | 87 | **drop** |
| 17 | C | F | 3 | **drop** | 67 |
| 17 | C | F | 4 | 45 | 77 |
| 17 | C | F | 5 | 43 | 62 |
| 17 | C | F | 6 | 74 | **drop** |
| 18 | C | F | 1 | 54 | 60 |
| 18 | C | F | 2 | **drop** | 62 |
| 18 | C | F | 3 | 45 | **drop** |
| 18 | C | F | 4 | **drop** | **drop** |
| 18 | C | F | 5 | 70 | 78 |
| 18 | C | F | 6 | **drop** | **drop** |
| 19 | C | F | 1 | 61 | 69 |
| 19 | C | F | 2 | **drop** | 34 |
| 19 | C | F | 3 | 70 | 69 |
| 19 | C | F | 4 | **drop** | 69 |
| 19 | C | F | 5 | **drop** | 89 |
| 19 | C | F | 6 | 86 | 38 |
| 20 | C | M | 1 | **drop** | 99 |
| 20 | C | M | 2 | 45 | **drop** |
| 20 | C | M | 3 | 35 | 29 |
| 20 | C | M | 4 | 44 | **drop** |
| 20 | C | M | 5 | 100 | **drop** |
| 20 | C | M | 6 | **drop** | 33 |
| 21 | C | F | 1 | **drop** | **drop** |
| 21 | C | F | 2 | **drop** | **drop** |
| 21 | C | F | 3 | **drop** | **drop** |
| 21 | C | F | 4 | **drop** | **drop** |
| 21 | C | F | 5 | **drop** | **drop** |
| 21 | C | F | 6 | **drop** | **drop** |
| 22 | C | F | 1 | 66 | 69 |
| 22 | C | F | 2 | 53 | 64 |
| 22 | C | F | 3 | **drop** | 70 |
| 22 | C | F | 4 | 50 | 62 |
| 22 | C | F | 5 | 45 | 60 |
| 22 | C | F | 6 | **drop** | 42 |
| 23 | C | F | 1 | 58 | 97 |
| 23 | C | F | 2 | 65 | 78 |
| 23 | C | F | 3 | 69 | 66 |
| 23 | C | F | 4 | 85 | 72 |

| Subject | Group | Gender | Trial | Pre | Post |
|---|---|---|---|---|---|
| 23 | C | F | 5 | 86 | 45 |
| 23 | C | F | 6 | 81 | 62 |
| 24 | C | F | 1 | 79 | 85 |
| 24 | C | F | 2 | **drop** | 86 |
| 24 | C | F | 3 | 54 | 72 |
| 24 | C | F | 4 | **drop** | **drop** |
| 24 | C | F | 5 | 54 | 72 |
| 24 | C | F | 6 | **drop** | 58 |
| 25 | C | F | 1 | 71 | 74 |
| 25 | C | F | 2 | 58 | 83 |
| 25 | C | F | 3 | 80 | **drop** |
| 25 | C | F | 4 | 83 | **drop** |
| 25 | C | F | 5 | **drop** | 74 |
| 25 | C | F | 6 | **drop** | 40 |
| 26 | C | M | 1 | **drop** | **drop** |
| 26 | C | M | 2 | **drop** | 75 |
| 26 | C | M | 3 | 57 | 84 |
| 26 | C | M | 4 | **drop** | **drop** |
| 26 | C | M | 5 | 81 | 47 |
| 26 | C | M | 6 | 91 | **drop** |
| 27 | C | M | 1 | 64 | **drop** |
| 27 | C | M | 2 | **drop** | **drop** |
| 27 | C | M | 3 | 71 | 50 |
| 27 | C | M | 4 | 83 | 47 |
| 27 | C | M | 5 | 79 | 34 |
| 27 | C | M | 6 | 81 | **drop** |
| 28 | C | M | 1 | 35 | 72 |
| 28 | C | M | 2 | 52 | 50 |
| 28 | C | M | 3 | 57 | 81 |
| 28 | C | M | 4 | **drop** | 41 |
| 28 | C | M | 5 | 73 | 82 |
| 28 | C | M | 6 | 50 | 46 |
| 29 | C | M | 1 | **drop** | 29 |
| 29 | C | M | 2 | 52 | **drop** |
| 29 | C | M | 3 | 55 | **drop** |
| 29 | C | M | 4 | **drop** | 74 |
| 29 | C | M | 5 | 68 | 83 |
| 29 | C | M | 6 | 46 | 82 |
| 30 | C | M | 1 | **drop** | 40 |
| 30 | C | M | 2 | **drop** | 57 |
| 30 | C | M | 3 | 68 | **drop** |
| 30 | C | M | 4 | 42 | **drop** |
| 30 | C | M | 5 | **drop** | **drop** |
| 30 | C | M | 6 | 76 | 51 |