THE INFLUENCE OF VESTIBULAR-OCULAR REFLEX TRAINING ON STATIC AND DYNAMIC POSTURAL STABILITY IN SUBJECTS WITH CHRONIC ANKLE INSTABILITY

THESIS

Presented to the Graduate Council of
Texas State University-San Marcos
in Partial Fulfillment
of the Requirements

for the Degree

Master of SCIENCE

by

Jessica R. Hilgendorf, B.S.

San Marcos, Texas
August 2011

THE INFLUENCE OF VESTIBULAR-OCULAR REFLEX TRAINING ON STATIC AND DYNAMIC POSTURAL STABILITY IN SUBJECTS WITH CHRONIC ANKLE INSTABILITY

Committee Members Approved:

Rod A. Harter, Chair

Luzita Vela

Denise Gobert

Approved:

J. Michael Willoughby
Dean of the Graduate College

FAIR USE AND AUTHOR'S PERMISSION STATEMENT

Fair Use

Duplication Permission

ACKNOWLEDGMENTS

I would like to thank my committee members for all of their hard work in helping me accomplish this thesis. They have all been instrumental in pushing me to do my best, and for supporting me through the entire process. I would also like to thank my parents, Blaine and Kay Hilgendorf, for their continued support throughout my entire education. Without their support I would not have had many of the opportunities that I have had the privilege to experience.

This manuscript was submitted on April 18th, 2011.

TABLE OF CONTENTS

Page

ACKNOWLEDGEMENTS iv

LIST OF TABLES vi

LIST OF FIGURES vii

CHAPTER

I. INTRODUCTION 1

II. THE INFLUENCE OF VESTIBULAR-OCULAR REFLEX TRAINING ON POSTURAL STABILITY, DYNAMIC VISUAL ACUITY AND GAZE STABILIZATION IN PATIENTS WITH CHRONIC ANKLE INSTABILITY 10

III. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE STUDY 39

APPENDIX A – IRB Application 45

APPENDIX B – Approved Consent Form 48

APPENDIX C – Participant Screening Questionnaire 53

APPENDIX D – Review of Literature 55

VITA 69

LIST OF TABLES

Table **Page**

2.1. CONSORT Flow Chart....29

2.2. Subject's Demographics....30

2.3. Outcome Measures....30

2.4. TRADITIONAL Balance Group Protocol....31

2.5. VOR Balance Group Protocol....32

2.6. Error Criteria....33

2.7. ANOVA Results....33

LIST OF FIGURES

Figure **Page**

1.1 Vestibular-Ocular Reflex (VOR) Function..4

2.1 Vestibular-Ocular Reflex (VOR) Function 15

2.2 Directions in Single Limb Hop to Stabilization Exercise..34

2.3 Nine Number Grid 34

CHAPTER 1

INTRODUCTION

Ankle sprains are extremely common in sports, comprising 25% of all injuries in athletics, with 85% of these injuries involving the lateral ankle[1]. According to Hale and Hertel, lateral ankle sprains account for up to 45% of all injuries in sports[2].

Chronic ankle instability (CAI) is defined as repetitive occurrences of lateral ankle instability that lead to numerous ankle sprains[3]. Balance training has been shown to help patients who suffer from chronic ankle instability[4]. CAI is commonly attributed to functional instability, joint instability caused by proprioceptive and neuromuscular deficits[3]. Chronic ankle instability is extremely common, and according to Hertel, 70% of patients who have had an ankle sprain have at least one recurrence[3]. Arnold et al, reported more conservative findings, with only 30 to 40 percent of patients reported recurrent sprains or residual symptoms[5]. Ross et al, stated that 30 to 78 percent of people reported recurrent episodes of ankle sprains[1]. While a wide range of incidence of CAI exists in the literature, it is apparent that once a person sustains a lateral ankle sprain, it is quite likely that she/he will develop CAI.

There are many components that make up a comprehensive ankle sprain rehabilitation program. Flexibility, strengthening, and agility exercises are all incorporated in the neuromuscular training during balance rehabilitation[6]. In their 2010 systematic review, Webster and Gribble evaluated the evidence related to functional rehabilitation interventions and chronic ankle instability. These authors found strong evidence that the functional interventions used, agility testing, multidirectional hopping, and jump landing education improved functional ability and decreased the risk of further ankle injury[7]. Of the 3,952 studies that Webster and Gribble initially identified with the search parameters chosen for their systematic review, only six studies met all of their inclusion criteria; all six reported significant reductions in the relative risk ratio, i.e., all ratio values were less than 1, indicating that there was a decrease in risk of ankle injury after functional rehabilitation was used.

Horak et al,[8] identified six postural systems that contribute to balance and need to be functioning in order for an individual to control his or her balance. These components are: biomechanical constraints, stability limits/verticality, anticipatory postural adjustments, postural responses, sensory orientation, and stability in gait[8]. Ideally, all six of these systems are working together when an athlete is participating in sport activities. When these six systems are not functioning properly an athlete will be unable to perform to the best of his or her ability. If not, an athlete may experience delayed reaction time, have the inability to balance or recover from a change in direction, or even experience dizziness if the sensory and equilibrium information is not accurate[8].

There are three types of postural stability: static, dynamic, and functional stability. For the purposes of this study, static postural stability was operationally defined as the ability to limit the movement of the center of gravity when the base of support remains fixed[9]. Dynamic postural stability is the ability to shift and control the center of gravity within a fixed base of support, while functional postural stability is the ability to move and control the center of gravity within a changing base of support[9].

One important component currently missing from many ankle rehabilitation protocols is the training and/or re-training of the vestibular-ocular reflex (VOR). Most of the research involving the vestibular-ocular reflex and rehabilitation looks at patients with vestibular disorders, the elderly, or the development of the system in newborns and children. The VOR is a reflexive eye movement that centers images on the retina during head movement[10, 11, 12, 13, 14, 15]. The VOR is considered a low latency reflex that allows the eyes to compensate for the head rotation to stabilize gaze during movement[16]. The VOR is important because it is initiated every time the head starts to move and it is what allows the eyes to move in the opposite direction of the head movement so that the image can be centered on the fovea of the eye[4, 8, 10, 11, 17]. Figure 1.1 illustrates how the VOR works.

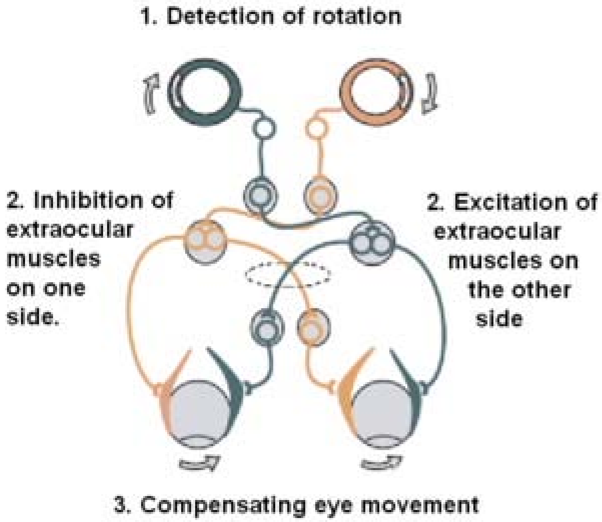


Figure 1.1: Vestibular-Ocular Reflex (VOR) Function

When athletes are participating in their respective sports, they need to be able to coordinate their head movement with whole body movement. The fovea of the eye has a high volume of cones which allows for visual acuity to occur[12]. Cohen et al, conducted one of the earliest studies to employ vestibular rehabilitation, using balance retraining along with repetitive head exercises in patients who ranged in age from 28-82 years old and had been diagnosed with disorders in the vestibular systems that resulted in greater improvements in balance in both treatment groups[18]. Their results suggested that utilizing gradual increases of head movement, number of repetitions, visual and vestibular interaction, and the use of the greatest range of motion resulted in significant improvements in static and dynamic balance[18].

The purpose of the present study was to employ a randomized controlled trial to compare the ability of traditional and VOR- enhanced rehabilitation protocols to improve postural stability, dynamic visual acuity and gaze stabilization among chronic ankle instability (CAI) patients.

They hypotheses for this study are:

1. The VOR rehabilitation protocol will result in a statistically significant improvements on latency time as measured by the Motor Control Test ($p < 0.05$) compared to the TRADITIONAL balance training group.

2. Overall Stability Index (OSI) and modified Overall Stability Index (mOSI) values obtained from the Athlete Single Leg Stability Test will be significantly better for the VOR group than the traditional balance training group ($p<.05$).

3. The Dynamic Visual Acuity (DVA) test will show that visual acuity loss will improve significantly in the VOR rehabilitation group than in the traditional balance training group at the conclusion of the four-week intervention ($p<.05$).

4. The Gaze Stabilization Test (GST) will show that average maximum head velocity achieved will be significantly greater in the VOR rehabilitation group than in the TRADITIONAL rehabilitation balance training group at the conclusion of the four-week intervention ($p<.05$).

A scientific abstract of the results of this study was submitted on November 15, 2010 for peer-review and presentation at the 62nd Annual Meeting of the National Athletic Trainers' Association, to be held in New Orleans, Louisiana, June 19-22, 2011.

The primary manuscript from this study, found in Chapter 2, will be submitted for review of publication in the *Journal of Athletic Training* in May 2011.

References

1. Ross SE, Guskiewicz KM, Gross MT, Yu B. Balance measures for discriminating between functionally unstable and stable ankles. *Med. Sci. Sports Exerc.* 2009; 41 (2): 399-407.
2. Hale SA, Hertel J. Reliability and sensitivity of the foot and ankle disability index in subjects with chronic ankle instability. *J Athl Train.* 2005; 40 (1): 35-40.
3. Hertel J. Functional anatomy, pathomechanics, and pathophysiology of lateral ankle instability. *J Athletic Train*. 2002;3 7(4): 364-375.
4. McKeon PO, Paolini G, Ingersoll CD, et al. Effects of balance training on gait parameters in patients with chronic ankle instability: a randomized controlled trial. *Clin Rehabil*. 2009; 23: 609-621.
5. Arnold BL, De La Motte S, Linens S, Ross SE. Ankle instability is associated with balance impairments: a meta-analysis. *Med. Sci. Sports Exerc.* 2009; 41 (5): 1048-1062.
6. Batson G. Update on Proprioception: Considerations for dance education. *J Dance Med Sci*. 2009; 13(2): 35-41.
7. Webster KA, Gribble PA. Functional rehabilitation interventions for chronic ankle instability: a systematic review. *J Sport Rehabil.* 2010; 19: 98-114.
8. Horak FB, Wrisley DM, Frank J. The balance evaluation systems test (BESTest) to differentiate balance deficits. *Phys Ther*. 2009; 89(5): 484-498.
9. Nashner LM, McCollum G. The organization of human postural movements: a formal basis and experimental synthesis. *Behav Brain Sci.* 1985; 8: 135-172.

10. Badaracco C, Labini F, Meli A, Angelis E, Tufarelli D. Vestibular rehabilitation outcomes in chronic vertiginous patients through computerized dynamic visual acuity and gaze stabilization test. *Otology & Neurology*. 2007; 28: 809-813.
11. Hasegawa T, Yamashita M, Suzuki T, Hisa Y, Wada Y. Active linear head motion improves dynamic visual acuity in pursuing a high-speed moving object. *Exp Brain Res*. 2009; 194(4): 505-516.
12. Juhola M, Aalto H, Hirvonen T. A signal analysis technique of vestibulo-ocular reflex stimulated with impulsive head movements. *Ann Biomed Eng*. 2006; 34(7): 1213-1225.
13. Laurutis VP, Robinson DA. The vestibulo-ocular reflex during human saccadic eye movements. *J Physiol*. 1986; 373: 209-233.
14. Schubert MC, Migliaccio AA, Clendaniel RA, Allak A, Carey JP. Mechanism of dynamic visual acuity recovery with vestibular rehabilitation. *Arch Phys Med Rehabil*. 2008; 89(3): 500-507.
15. Nandi R, Luxon LM. Development and assessment of the vestibular system. *Int J Audiol.* 2008; 47: 566-577.
16. Di Girolamo S, Picciotti P, Sergi B, Di Nardo W, Paludetti G, Ottaviani F. Vestibulo-ocular reflex modification after virtual environment exposure. *Acta Otolaryngol*. 2001; 121: 211-215.
17. Scherer M, Migliaccio AA, Schubert MC. Effect of vestibular rehabilitation on passive dynamic visual acuity. *J Vestib Res*. 2008; 18(2-3): 147-157.

18. Cohen H, Kane-Wineland M, Miller LV, Hatfield CL. Occupation and visual/vestibular interaction in vestibular rehabilitation. *Otolaryngo Head Neck Surg*. 1995; 112: 526-532.
19. [Untitled image of vestibular ocular reflex function]. Retrieved October 4, 2010, from: http://www.thefullwiki.org/Oculocephalic_reflex.

CHAPTER 2

ABSTRACT

The Influence of Vestibular-Ocular Reflex Training on Postural Stability, Dynamic Visual Acuity and Gaze Stabilization in Patients with Chronic Ankle Instability

Hilgendorf JR, Vela LI, Gobert DV[‡], Harter RA: Department of Health and Human Performance and [‡]Department of Physical Therapy, Texas State University, San Marcos, TX.

Context: The vestibular-ocular reflex (VOR) is a low latency, reflexive eye movement that allows the eyes to compensate for head rotation in order to stabilize gaze during the movement. The VOR is important during physical activity because it is initiated each time the head starts to move, and causes the eyes to move in the opposite direction of the head so that the intended image can be centered on the fovea of the eye. **Objectives:** To compare the ability of traditional and VOR-enhanced rehabilitation protocols to improve postural stability, dynamic visual acuity and gaze stabilization among chronic ankle instability (CAI) patients. **Design:** Randomized controlled trial. **Setting:** Research laboratory setting. **Participants:** 16 physically-active women and men (age, 22.2±1.5 yrs; hgt, 171.1±7.0 cm; mass, 73.5±18.3 kg) with unilateral CAI, defined as a history of at least two ankle sprains on the same ankle and self-reported feelings of giving way. Participants were free of any neurological or vestibular impairments. **Interventions:** Subjects were randomly assigned to 1 of 2 treatments: Traditional rehabilitation group (N = 8) (TRADITIONAL) utilized a CAI ankle rehabilitation protocol modified from

McKeon et al. (2009), or a VOR rehabilitation group (N = 8) utilized a modified McKeon CAI protocol with the addition of side-to-side head movements incorporated into all exercises. Each patient participated in 3 rehabilitation sessions/week for 4 weeks. The 2 experimental groups were tested on 2 occasions: a pretest (Week 0) and posttest (Week 4); we used a Group (2) x Time (2) mixed factorial ANOVA (p=0.05). **Main Outcome Measures:** Motor control tests (MCT) obtained with the NeuroCom EquiTest™; overall stability indices obtained bilaterally from standard (OSI) and modified (mOSI) Athlete Single Leg Stability Tests with a Biodex BalanceMaster™; dynamic visual acuity (DVA) and gaze stabilization test (GST) using the NeuroCom inVision™. **Results:** Vertical GST scores were significantly better in the VOR group 150.5±19.3 deg/sec compared to the TRADITIONAL group, 122.8±21.7 deg/sec (F (1, 14) = 11.02, p=0.005). Significant positive group differences were also observed for the VOR group on the horizontal DVA test (p=0.038). Six of the 9 outcome measures evaluating postural stability, gaze stabilization and dynamic visual acuity significantly improved from pretest to posttest (p=0.001). Of particular interest were the OSI and more challenging mOSI dynamic postural stability tests that improved for both right and left limbs over the 4-week intervention: OSI pretest (8.4±3.4) to posttest (3.1±1.8), p=0.001; mOSI pretest (11.7±2.4) to posttest (5.5±1.8), p=0.001). **Conclusions:** As hypothesized, subjects in the VOR group demonstrated significantly better scores on the vertical GST and horizontal DVA tests. Both the TRADITIONAL and VOR rehabilitative protocols produced significant positive changes from pretest to posttest, suggesting that both are effective in improving postural stability, gaze stabilization and dynamic visual acuity in CAI patients.

Word Count: 452

INTRODUCTION

Ankle sprains are extremely common in sports, comprising 25% of all injuries in athletics, with 85% of these injuries involving the lateral ankle[1]. According to Hale and Hertel, lateral ankle sprains account for up to 45% of all injuries in sports[2].

Chronic ankle instability (CAI) is defined as repetitive occurrences of lateral ankle instability that lead to numerous ankle sprains[3]. Balance training has been shown to help patients who suffer from chronic ankle instability[4]. CAI is commonly attributed to functional instability, joint instability caused by proprioceptive and neuromuscular deficits[3]. Chronic ankle instability is extremely common, and according to Hertel, 70% of patients who have had an ankle sprain have at least one recurrence[3]. Arnold et al reported more conservative findings, with only 30% to 40 % of patients reported recurrent sprains or residual symptoms[5]. Ross et al stated that 30% to 78 % of people reported recurrent episodes of ankle sprains[1]. While a wide range of incidence of CAI exists in the literature, it is apparent that once a person sustains a lateral ankle sprain, it is quite likely that she/he will develop CAI.

There are many components that make up a comprehensive ankle sprain rehabilitation program. Flexibility, strengthening, and agility exercises are incorporated in the neuromuscular training during balance rehabilitation[6]. A recent systematic review by Webster and Gribble evaluated the evidence related to functional rehabilitation interventions and chronic ankle instability. These authors found strong evidence that the functional interventions used, agility testing, multidirectional hopping, and jump landing education improved functional ability and decreased the risk of further ankle injury[7]. Of the nearly 4,000 studies that Webster and Gribble initially identified with the search parameters chosen for their systematic review, only 6 met all of their inclusion criteria; all 6 reported significant reductions in the relative risk ratio, indicative of significantly decreased risks of lateral ankle injury following participation in functional rehabilitation programs.[7]

There are six postural systems that contribute to balance and all need to be functioning for a person to control his or her balance[8]. These six components are: biomechanical constraints, stability limits/verticality, anticipatory postural adjustments, postural responses, sensory orientation, and stability in gait[8]. Ideally, all of these systems are working together when an athlete is participating in sport activities. When theses six systems are not functioning properly an athlete will be unable to perform to the best of his or her abilities. An athlete may experience delayed reaction time, have the inability to balance or recover from a change in direction, or even experience dizziness if the sensory and equilibrium information is not accurate[8].

There are three types of postural stability: static, dynamic, and functional stability. For the purposes of this study, static postural stability was operationally defined as the ability to limit the movement of the center of gravity when the base of support remains fixed[9]. Dynamic postural stability is the ability to shift and control the center of gravity within a fixed base of support, while functional postural stability is the ability to move and control the center of gravity within a changing base of support[9].

One important component currently missing from many ankle rehabilitation protocols is the training and/or re-training of the vestibular-ocular reflex (VOR). Most of the research involving the vestibular-ocular reflex and rehabilitation looks at patients with vestibular disorders, the elderly, or the development of the system in newborns and children. The VOR is a reflexive eye movement that centers images on the retina during head movement[10-15]. The VOR is considered a low-latency reflex and allows the eyes to compensate for the head rotation to stabilize gaze during movement[16]. The VOR is important because it is initiated every time the head starts to move and it is what allows the eyes to move in the opposite direction of the head movement so that the image can be centered on the fovea of the eye[4, 8, 10, 11, 17]. Figure 2.1 demonstrates how the VOR works.

When athletes are participating in their respective sports, they need to be able to coordinate their head movement with whole body movement. The fovea of the eye has a high volume of cones which allows for visual acuity to occur[12]. Cohen et al used vestibular rehabilitation exercises during balance retraining in their protocol along with repetitive head exercises and subjects had greater improvements in balance at the end of the intervention[18]**.** Their results suggested that utilizing gradual increases of head movement, repetition, visual and vestibular interaction, and the use of the greatest range of motion resulted in the best outcomes with improvements in dynamic balance[18].

The purpose of this study was to employ a randomized controlled trial to compare the ability of traditional and VOR- enhanced rehabilitation protocols to improve postural stability, dynamic visual acuity and gaze stabilization among chronic ankle instability (CAI) patients.

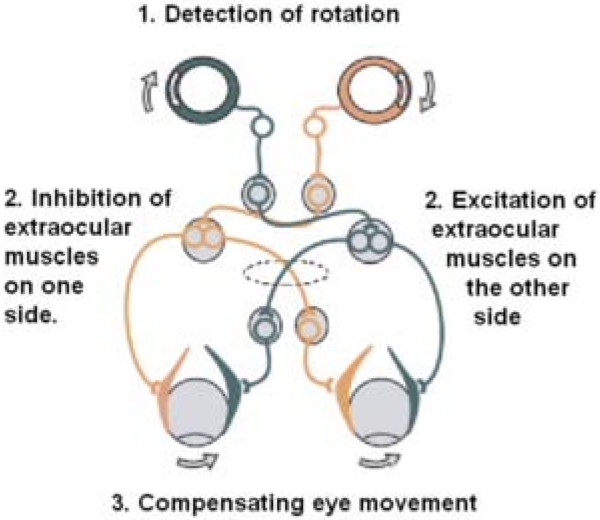


Figure 2.1: Explanation of the Vestibular-Ocular Reflex (VOR) Function

METHODS

Subjects

A total of 18 volunteers, 9 men and 9 women between the ages of 18 and 35, were recruited to this study by responding to any of the following: posted flyers that sought people who have chronic ankle instability at the Student Recreation Center, posted flyers in the athletic training rooms, and through announcements made to students enrolled in university Physical Fitness and Wellness activity courses. Volunteers were screened for participation eligibility through the use of a brief questionnaire to determine their general health status. Each volunteer also completed the Foot and Ankle Ability Measure (FAAM) questionnaire as a screening tool to help determine the functional limitations of a subject's ankle[20]. The FAAM was administered before and after the intervention, but the results were not analyzed as part of this study.

To qualify for inclusion into the study, volunteers had to physically active and free from any neurological conditions, specifically, vestibular cochlear and inner ear dysfunctions. For the purposes of this study, "physically active" was operationally defined as performing exercise at moderate and/or vigorous intensity for at least 30 minutes per day, 3 to 4 days a week, and the exercise bouts must last at least 10 minutes[16].

The inclusion criteria for participation in this study required that the volunteer have chronic ankle instability (CAI), operationally defined as having at least two lateral sprains to the same ankle in the past, episodes of "giving way" that had occurred within the past 6 months, the presence of residual symptoms during functional activities, and had to be symptom free from any other previous injury to the lower extremity. In addition, to qualify for participation, each volunteer was required to possess a contralateral normal limb (no history of significant ankle, knee or hip injuries) to serve as a control limb. Volunteers were required to be free from any symptoms associated with concussion or traumatic brain injury that may have occurred in the past.

Once a volunteer had qualified for participation in the study, the experimental protocol and risks associated with the study were explained and consent was obtained prior to participation in the study. Participants were randomly assigned to 1 of 2 experimental groups: a traditional balance protocol group and a vestibular-ocular protocol group. When subjects were randomly assigned to the treatment groups, equal numbers were assigned to each group. An individual was assigned by opening an envelope that either stated VOR or TRADITIONAL on the inside. The envelopes had equal numbers of VOR and TRADITIONAL options for both males and females. The order of testing was randomly assigned to each individual by counterbalancing the administration of the tests. The CONSORT flow chart is shown in Table 2.1, and participant demographic information is summarized in Table 2.2.

Instrumentation

The NeuroCom SmartEquiTest™ computerized posturography system has been widely used to diagnose specific postural stability and functional impairments in clinical populations across all age groups[21]. Using the clinical software, static, dynamic, and functional stability tests can be administered. The Motor Control Test (MCT) was selected to assess the participant's ability for the autonomic system (motor system to recover from unexpected disturbances)[22]. The manufacturer's standard protocol for the MCT was used for both pretesting and posttesting.

A second device manufactured by NeuroCom International, the inVision™ package, allowed us to quantify a subject's ability to maintain visual acuity and stable gaze while actively moving his or her head. The outcome measures possible with the inVision™ instrumentation include the Dynamic Visual Acuity (DVA) test that quantifies the impact of VOR system impairment on a patient's ability to perceive objects accurately while moving the head at a given velocity on a given axis, and the Gaze Stabilization Test (GST) that permits quantification of the range of movement velocities on a given axis over which a subject is able to maintain an acceptable level of visual acuity[21]. The subject's head movements are measured in the yaw and pitch planes. By GST convention, yaw is the right to left head movement, while pitch is defined as up and down head movement.

A Biodex Balance System SD™ was utilized in this study to administer the Athlete Single Leg Stability test[23]. This test assessed single leg postural stability, and facilitated bilateral comparisons of the subject's dynamic postural stability in the CAI ankle and the normal contralateral ankle[23]. This test was administered according to the manufacturer's published protocol, but was repeated for both limbs while the subject's laterally rotated his or her head at a cadence of 2 Hz, where 1 Hz (cycle) was defined as a total excursion of 120 degrees of right side-to-left side head movement (or the opposite pattern) completed in 1 second. A 2 Hz rate of side-to-side head movement is sufficient to activate the VOR[22].

Procedures

By completing a screening questionnaire containing orthopedic medical history questions and signing the consent form, the subjects agreed to participate in the study. The Neurocom EquiTest™, NeuroCom inVision™, and the Biodex Balance System SD™ were used to measure the changes that occurred over the 4-week intervention.

The 16 subjects who met the inclusion criteria were randomized into one of two equal treatment groups (n =8): a traditional CAI rehabilitation group (TRADITIONAL) or a vestibular-ocular reflex (VOR) CAI rehabilitation group. Each subject was required to participate in 3 rehabilitation sessions per week for 4 weeks. The specific activities performed during each session were recorded and individual patient progress through the assigned rehabilitation protocol was documented. During each session, the senior author (JRH) recorded the number of successful and unsuccessful attempts for each repetition on each leg for all exercises. After each session, the primary author used this information to determine whether a subject should be progressed to the next level of difficulty at the next rehabilitation session.

At the beginning of the study, each participant performed a total of 5 baseline tests on 3 different measurement systems: the MCT using the NeuroCom Smart EquiTest™ system; the GST and DVA tests available with the NeuroCom inVision™ system; and the Athlete Single Leg Stability Test and a modified Athlete Single Leg Stability Test on the Biodex Balance SD™ system. The order of the administration of these tests was counterbalanced for each subject. A minimum of 5 minutes of rest was imposed between each test in order to reduce the risk of participant fatigue.

The MCT assessed latency response, amplitude response, and symmetry response. These parameters were measured through small, medium, and large forward or backward horizontal translations of the device's force plate during bipedal stance[21].

The DVA test assessed impairments in identifying visual targets accurately while head movement occurred. There was a series of trials where the letter "E" appeared in a variety of sizes once the subject reached a velocity of 85 deg/sec of lateral head movement[21]. The monitor that the "E" appears on was placed 10 feet away from the subject's face[21]. This test gave information about the differences between static and dynamic visual acuity, and whether there were any right-to-left differences. For this evaluative parameter, the lower the score, representing the percentage loss of dynamic visual acuity, the better the patient performed.

The ASLST was administered using the Biodex Balance SD™ system. Each test lasted 20 seconds, was set on Level 4 (of 12 possible stability settings), and consisted of 3 trials for both the right and left limbs. Each ASLST was performed initially without head movement, and the repeated with the addition of side-to-side head movement at a controlled rate of 2 Hz, a test we named the modified Athlete Single Leg Stability Test. A metronome was set to help the subject keep head movement at that pace. There are 3 outcome measures from this test: anterior-posterior instability index (APSI), mediolateral stability index (MLSI) and overall stability index (OSI) score[23]. With the incorporation of lateral head movement during this test, a new outcome measure termed "modified overall stability index" score (mOSI) was created to go along with the OSI score that is associated with the ASLST. Table 2.3 contains a summary of all of the outcome measures.

The TRADITIONAL balance protocol group and the VOR balance protocol group completed all baseline tests, and then both groups performed specific exercises outline in the protocols listed in Table 2.4 and Table 2.5 over a four week period. The protocols were performed 3 times a week and required between 20 to 30 minutes to complete. Every exercise session was supervised by the primary author. Attendance at the rehabilitation sessions was excellent, and no subject was dropped from the study for exceeding the limit of having 2 or more missed sessions. Each participant wore a pair of his or her own athletic shoes, and dressed in clothing in which they could comfortably move. The TRADITIONAL exercise protocol used for this study was adapted from the recent paper by McKeon et al, and the VOR protocol was a modified McKeon et al, protocol that had head movements incorporated into each exercise. Each exercise was progressed based on the subject's ability to complete exercises error free, and each limb was progressed individually. See Table 2.6 for a summary of the error free criteria[4]. This progression helped protect all of our participants from sustaining a recurrence of their ankle injury for the duration of this study.

Statistical Methods

A series of 2 x 2 (Group x Time) ANOVAs were used to determine the presence of significant main effects and interactions for each of the 9 outcome measures. A critical value of $p \leq 0.05$ was used to define statistical significance. Levene's Test of Equality of Error Variances was used to evaluate the presence of homogeneity of variance between the randomly-assigned treatment groups. The software package PASW Statistics 18.0.3 was used to perform all statistical analyses.

RESULTS

We found significant differences between the experimental groups on the vertical GST, with the VOR group (mean ± standard error, 150.5 ± 5.9 deg/sec) demonstrating significantly better scores than the TRADITIONAL group (122.7 ± 5.9 deg/sec); [F (1,14) = 11.02, p=0.005, 1 – β = 0.87]. In addition, vertical GST in the VOR group improved significantly from pretest to posttest, from 136.0 ± 27.1 deg/sec to 165.0 ± 11.5 deg/sec compared with the TRADITIONAL group, 122.2 ± 27.3 deg/sec to 123.3 ± 16.0 deg/sec, respectively [F (1,14) = 4.60, p=0.05, 1 – β = 0.52].

Significant group differences were also observed for the horizontal dynamic visual acuity (DVA) test [(F 1, 14) = 5.23, p=0.038, 1 – β = 0.57], with the

TRADITIONAL group’s horizontal DVA being significantly poorer (mean ± standard error, 25.6% ± 3.1%) than the VOR group’s DVA (15.7% ± 3.1%).

Six of the 9 outcome measures evaluating postural stability, gaze stabilization and dynamic visual acuity significantly improved from pretest to posttest (p=0.001). Of particular interest were the OSI and more challenging mOSI dynamic postural stability tests that improved for both right and left limbs over the 4-week intervention: OSI pretest (8.4 ± 3.4) to posttest (3.1 ± 1.8), p=0.001; mOSI pretest (11.7 ± 2.4) to posttest (5.5 ± 1.8), p=0.001). Please refer to Table 2.7 for a summary of the ANOVA results.

DISCUSSION

The Gaze Stabilization Test measures the speed at which a patient’s head is voluntarily moved while visual acuity levels are still acceptable[21]. Normal visual acuity is 20/20 vision. This clinical test provides information on where the impairment is occurring, such as in what direction and in what axis. Ward et al[24] found that the GST test-retest reliability was good (ICC = 0.75 in the yaw plane, 0.69 in pitch plane) in a same day testing for both the young group and the older group of subjects, and test-retest reliability at the 7 to 10 day (NOTE: This change reflects the required AMA style) mark was fair to good (ICC = 0.59 in the yaw plane, 0.54 in pitch plane).

The 21% improvement in the GST observed in the VOR group was most likely due to the inclusion of head movements during their CAI rehabilitation exercise protocol. There are no similar studies that allow for direct comparisons with our findings, but Badracco et al,[10] evaluated 32 patients who suffered from chronic dizziness (mean age, 60.7 yrs). Their 12 two-hour rehabilitation intervention sessions included vestibular rehabilitation exercises in a static position while on a stability platform, and on a moving footpath. They found that GST scores significantly improved in the patients and they attributed those improvements on the vestibular rehabilitation exercises. The patients had an average of a 32% improvement in their GST scores after the intervention[10].

The Dynamic Visual Acuity test is used to identify deficiencies in a person's ability to see objects clearly while their head is in motion, and this is functionally important to active individuals because the head is going to be constantly moving while performing a specific sport or physical activity. In our study, the VOR group scored significantly better on the horizontal DVA test than did the TRADITIONAL group. This finding makes sense, given that the subjects in the VOR group moved their heads rapidly from side-to-side during every rehabilitation exercise that was performed 3 times per week for 4 weeks.

We could find only one previous study with which to compare our results on this outcome measure. Schubert et al,[14] performed a study with 9 subjects, 5 with vestibular hypofunction and 4 control subjects, where they incorporated vestibular rehabilitation exercises that included head movement over a 2 to 3 month time period, and found that the DVA scores improved in all 9 patients, suggesting that the vestibular-ocular reflex can be affected by a training regimen Post-intervention DVA testing by Schubert and associates revealed that significant improvements occurred in all of their patients ($p<0.05$) [14].

As noted previously, 6 of the 9 outcome measures used to evaluate the functional abilities of the CAI patients in the present study were significantly improved in both experimental groups between the pretest and posttest (p=0.001). Thus, both 4-week CAI rehabilitation protocols were statistically equivocal, each producing significant, positive improvements in the functional abilities of the participants in both groups.

The results of the OSI and mOSI tests were particularly of interest because they required each CAI patient to balance on a single leg, and compared the CAI limb with each patient's contralateral normal limb. Participants in both treatment groups went through the same Athlete Single Leg Stability test protocol on the Biodex Stability System except that the mOSI was introduced to induce the VOR. The mOSI test required single leg balance with 120 deg/sec side-to-side head movement. The modification of the OSI test and its inclusion in our study was necessary because all the other tests we employed were static balance tests.

The creation of the mOSI outcome measure allowed us to compare the postural stability in CAI patients performing the same single limb balance task with and without lateral head movement. The mOSI test was quite difficult for all of our patients; however, with the VOR group patients, the improvements from pretest and posttest were very clear when just watching them perform the test. The OSI and mOSI values are best obtained from a Biodex Stability System, but similar, less expensive (and less precise) single limb balance testing can be performed with a BAPS board, BOSU ball, or Airex Balance Pad. If the ASLST and modified ASLST are performed on a generic wobble board at a high school athletic training facility, computerized test results would obviously not be available. However, the clinician can keep track of opposite foot or wobble board floor touches over a 20-second period in order to objectively quantify patient progress in rehabilitation.

Webster and Gribble[7] provided a systematic review of articles that researched interventions with patients with chronic ankle instability. The results of three of these studies have particular relevance to our study. Rozzi et al,[25] recruited 13 healthy and 13 CAI patients and trained them on a Biodex Stability System 3 times a week for 4 weeks. These authors found similar results as our study in that both groups improved over the four week intervention. Balance scores on the Biodex improved for both groups on the impaired leg pretests and posttests on both levels used on the Biodex (Impaired Subjects posttest Level 2: 2.63 ± 1.92, Control Subjects posttest Level 2: 2.69 ± 2.32, Impaired Subjects posttest Level 6: 1.27 ± 0.66, Control Subjects posttest Level 6: 1.37 ± 0.66). Hale et al, [26] conducted a study that was very similar to ours in terms of clinical populations used (CAI patients) and duration (4 weeks). Instead of utilizing only balance training, they also used stretching, strengthening, jumping and running. Their participants included 16 with CAI in the CAI rehabilitation group, 13 with CAI in the control rehabilitation group, and 19 healthy subjects. The participants also met an average of 3.5 times per week for 4 weeks. The rehabilitation group improved in many of their measures, including, the star excursion balance test and their self-reported functional level measured with the Foot and Ankle Disability Index (FADI). Finally, Ross and Guskiewicz[27] employed a 6-week intervention with both 30 CAI subjects and 30 healthy subjects and found that the coordination training improved both anteroposterior and mediolateral dynamic stability in the CAI patients.

Each of these 3 studies produced similar results, suggesting that CAI rehabilitation protocols of 4 to 6 week duration should include at least one form of balance and/or strengthening exercises. Each study reported improvements in their CAI participants balance abilities.

Given the dearth of research on the incorporation of vestibular-ocular reflex training into orthopedic rehabilitation protocols, it is difficult to compare and contrast with results of our study with others. The traditional protocol used in our study was similar to the protocol previously used by McKeon et al,[4] in a study of balance among CAI patients. McKeon et al,[4] also observed improvements in static postural control and self-reported function, a finding that is supported by the positive changes in OSI and mOSI scores in our study improved in both limbs of both groups after participating in the 4-week CAI rehabilitation protocols.

Our VOR group incorporated head movement into each of their exercises during the 4 week protocol that were designed to activate the vestibular-ocular reflex and thus may partially explain the significant improvements observed for the GST and DVA scores. The data shown with the greater improvements in the scores for the VOR group along with the improved balance scores (OSI and mOSI) for the VOR group indicate that incorporating head movement into traditional balance exercises elicited greater improvements than the standard protocol. It is likely that training effects influenced the results in the dynamic visual acuity tests, gaze stabilization, and mOSI tests for the VOR group. The degree of difficulty, especially of the mOSI, could not have just been learned in one pretest session. The incorporation of the head movement into the CAI rehabilitation exercises was most likely responsible for the better overall balance scores observed. The only unstable surface used in both of our CAI rehabilitation protocols was a foam pad (during single limb stance exercises), but that would not be considered nearly as unstable as the Biodex's platform that can tilt to 25 degrees from any position[23].

A protocol longer than 4 weeks would have been helpful in determining if the improvements would be of greater magnitude than those observed. Although, if a 4 week CAI rehabilitation protocol is just as effective a 6 week protocol it would be preferable to utilize the 4 week protocol. This would allow for quicker recovery for injured patients, and those patients would be able to return to their activities more effectively in a shorter period of time. If a patient needed to perform CAI rehabilitation in a clinical setting, reimbursement would be more likely be approved for an effective 4-week rehabilitation program in deference to an effective 6-week program, decreasing the costs of rehabilitation to both the third party payer and the patient. This protocol can be replicated in almost any setting. All that is needed is adequate space where the movement patterns can be laid out, a foam pad or some other unstable surface, e.g., DynaDisk®, mini-trampoline.

One of the limitations that we acknowledge is the sample size associated with this study. The recruitment of additional CAI patients to our randomized controlled trial would likely have increased statistical power, and concomitantly reduced the chances of making a Type II error. Low statistical power could lead to Type II error which would be giving a false negative finding, accepting the null hypothesis of no treatment effect when it is false. That being said, the observed statistical power for the GST horizontal outcome measure was excellent ($1-\beta = 0.87$), resulting in a significant main effect for TIME. There was a wide range of observed statistical power for our other 8 outcome measures, with the lower levels of power associated with higher risk of making a Type II error ($1-\beta = 0.10$ to 0.87).

CONCLUSION

As hypothesized, subjects in the VOR group demonstrated significantly greater improvement on the vertical GST and the horizontal DVA than the TRADITIONAL treatment group. Both the TRADITIONAL and VOR rehabilitative protocols produced significant beneficial changes from pretest to posttest after the 4-week intervention, suggesting that both were effective in improving postural stability, gaze stabilization and dynamic visual acuity in CAI patients.

Given the promising results of this randomized clinical trial with a relatively small sample size, more research with CAI patients needs to be performed with rehabilitation exercises that elicit the vestibular-ocular reflex. These future studies should also include subjects who intend to return to a specific sport or job activity to determine if the benefits of this or similar vestibular-ocular reflex rehabilitation exercise protocols are sport or activity specific.

Table 2.1: CONSORT Flow Chart

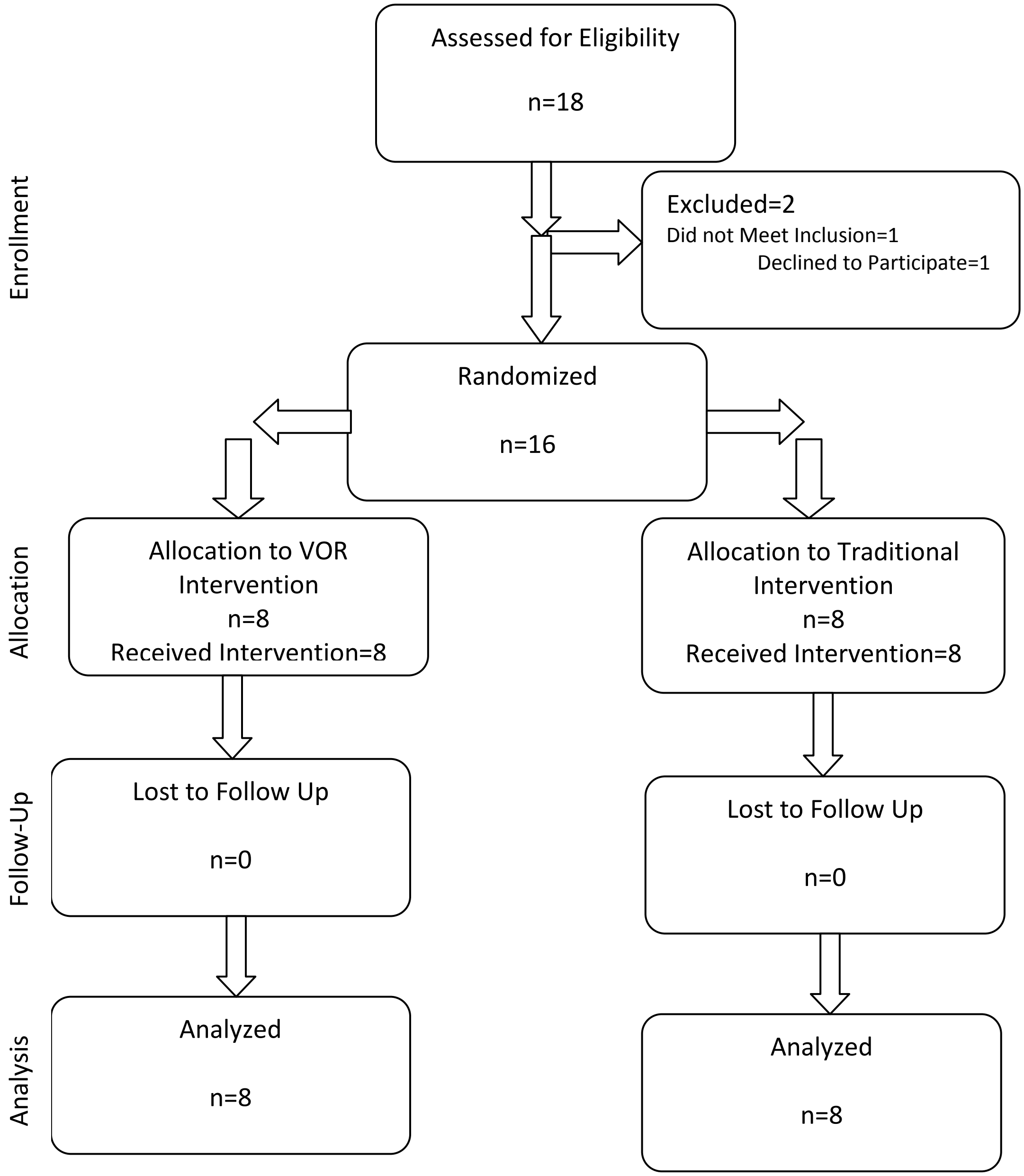


Table 2.2 Subject Demographics (N = 16)

Parameter	**Mean**	**Standard Deviation (+/-)**
Age (yrs)	22.1	1.5
Height (cm)	171.1	7.0
Mass (kg)	73.5	18.3

Table 2.3: Outcome Measures

PARAMETERS	**OUTCOME MEASURES**
Static Stability (NeuroCom EquiTest System)	Motor Control Test • Latency (msec)
Dynamic Stability (Biodex Stability System SD)	Athlete Single Leg Stability Test • Overall Stability Index Score • Modified Overall Stability Index Score
Vestibular-Ocular Reflex (NeuroCom inVision system)	Dynamic Visual Acuity Test • % of Dynamic Visual Acuity Loss (Horizontal and Vertical) Gaze Stabilization Test • Average maximum head velocity achieved (Horizontal and Vertical)

Table 2.4 Traditional Balance Group Protocol

Single Leg Stance: Three repetitions were performed with eyes open. Subjects were asked to focus on a specific point on the wall for the duration of the repetition. Progression only occurred if the subject performed two sets of three repetitions on a single limb error free in a row. Below is the progression.

1. Arms across chest on hard floor for 60 seconds
2. Arms across chest for 30 seconds on foam pad (Foam pad was 20cm x16.4cm x2.5 cm)
3. Arms across chest for 60 seconds on foam pad
4. Arms across chest for 90 seconds on foam pad
5. Ball Toss: 20 throws done in 30 seconds with a 2.7 kg medicine ball. The rehabilitation coordinator will catch the ball and throw it back to the subject. Subject is balancing on one foot on stable ground.

Single Limb Hop to Stabilization: Five repetitions were performed per direction for each limb. Subjects had to perform two sets of five repetitions in each direction error free before advancing to the next level for that limb and direction. These directions were: anterior/posterior, medial/lateral, anteromedial/posterolateral, and posteromedial/anterolateral. Subjects hopped one legged from the starting position to the target position, and once the subject stabilized they had to hop back to the starting position. The directional patterns were marked out on a drop cloth that was secured to a flat floor. See Figure 2.2 for image of directions used.

1. 45.7 cm hop. Allowed to use arms to aid in stabilizing after landing.
2. 45.7 cm hop with hands on hips while stabilizing balance after landing.
3. 68.6 cm hop. Allowed to use arms to aid in stabilizing after landing.
4. 68.6 cm hop with hands on hips while stabilizing balance after landing.
5. 91.4 cm hop. Allowed to use arms to aid in stabilizing balance after landing.
6. 91.4 cm hop with hands on hips while stabilizing balance after landing.

Unanticipated Hop to Stabilization: A 9 number grid with each number located 45.7cm apart was outlined on a drop cloth that was secured to a flat floor. Each square was 20.32cm x 20.32 cm. The grid lines were made of duct tape and measured using a fiberglass tape measure. In each session the subjects completed two sequences of hops on each leg. Each sequence included 9 numbers to which the subject was required to hop. The order of the numbers was randomly selected for each session using a random number sequencer. Subjects hopped one legged from the starting position to the target position. Once the subject was stabilized they hopped to the next number in the sequence. The subject used any sequence of hops to reach the next number. The subject was required to perform two sets of two sequences of numbers error free and in the time allowed in order to progress to the next level of difficulty.

1. 5 seconds allowed per move
2. 3 seconds allowed per move
3. 1 second allowed per move

Table 2.5: Vestibular-Ocular Reflex (VOR) Balance Group Protocol

Single Limb Stance: Three repetitions with eyes open were performed on each limb. Subjects were asked to focus on a specific point on the wall for the duration of the repetition. The subject turned his or her head to the right and left in time with the metronome pace. The starting metronome pace was 60 beats per minute and each week (every 3 sessions) the pace increased by 30 beats per minute with the final pace being 120 beats per minute. Each limb was progressed individually and was only progressed if the subject could perform two sets of three repetitions on a single limb error free to be progressed to the next level.

1. Arms across chest on hard floor for 60 seconds
2. Arms across chest for 30 seconds on foam pad (Foam pad was 20cm x16.4cm x2.5 cm)
3. Arms across chest for 60 seconds on foam pad
4. Arms across chest for 90 seconds on foam pad
5. Ball Toss: 20 throws done in 30 seconds with a 2.7 kg medicine ball. The rehabilitation coordinator will catch the ball and throw it back to the subject. Subject is balancing on one foot on stable ground.

Single Limb Hop to Stabilization: Five repetitions were performed in each direction for each limb. These directions were: anterior/posterior, medial/lateral, anteromedial/posterolateral, and posteromedial/anterolateral. Once a subject had hopped to the target and they were stabilized they performed 10 seconds of head movements to the metronome pace. The starting metronome pace was 60 beats per minute and each week (every 3 sessions) the pace increased by 30 beats per minute with the final pace being 120 beats per minute. After the 10 seconds of head movement the subject returned to the starting position and once stabilized they could hop back to the target until all 5 repetitions had been completed. Subjects must have performed two sets of 5 repetitions error free before advancing that limb and direction. See Figure 2.2 for directions used.

1. 45.7 cm hop. Allowed to use arms to aid in stabilizing after landing.
2. 45.7 cm hop with hands on hips while stabilizing balance after landing.
3. 68.6 cm hop. Allowed to use arms to aid in stabilizing after landing.
4. 68.6 cm hop with hands on hips while stabilizing balance after landing.
5. 91.4 cm hop. Allowed to use arms to aid in stabilizing balance after landing.
6. 91.4 cm hop with hands on hips while stabilizing balance after landing.

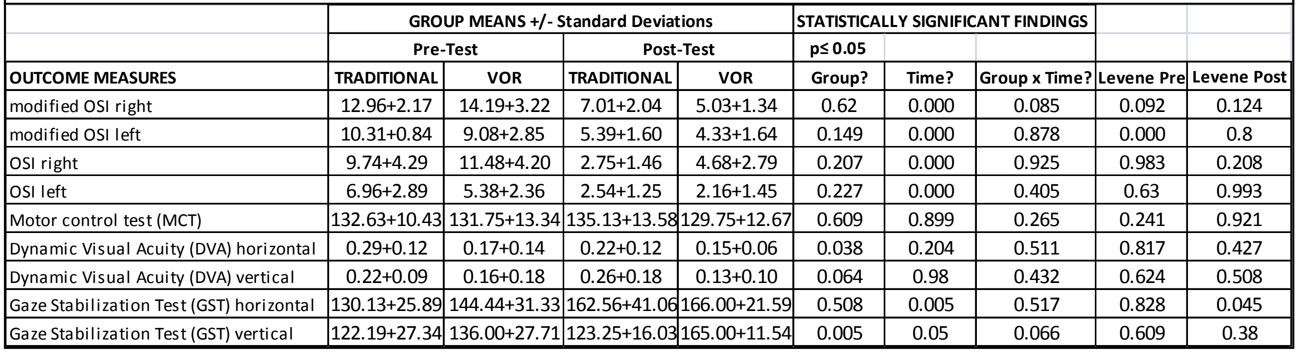
Unanticipated Hop to Stabilization: A 9 number grid with each number located 45.7cm apart was outlined on a drop cloth that was secured to a flat floor. Each square was 20.32cm x 20.32 cm. The grid lines were made of duct tape and measured using a fiberglass tape measure. In each session the subjects completed two sequences of hops on each leg. Each sequence included 9 numbers to which the subject was required to hop. The order of the numbers was randomly selected for each session using a random number sequencer. Subjects hopped one legged from the starting position to the target position. Once the subject was stabilized they moved their heads at the metronome pace for 10 seconds, and they hopped to the next number in the sequence. The starting metronome pace was 60 beats per minute and each week (every 3 sessions) the pace increased by 30 beats per minute with the final pace being 120 beats per minute. The subject used any sequence of hops to reach the next number. The subject was required to perform two sets of two sequences of numbers error free and in the time allowed in order to progress to the next level of difficulty.

1. 5 seconds allowed per move
2. 3 seconds allowed per move
3. 1 second allowed per move

Table 2.6 Error Criteria

1. Touching down with opposite limb
2. Excessive trunk motion (>30° lateral flexion)
3. Removal of hands from hips during hand-on-hips activities
4. Bracing the non-stance limb against the stance limb
5. Missing the target

Table 2.7: ANOVA Results



	GROUP MEANS +/- Standard Deviations				**STATISTICALLY SIGNIFICANT FINDINGS**				
	Pre-Test		**Post-Test**		**p≤ 0.05**				
OUTCOME MEASURES	**TRADITIONAL**	**VOR**	**TRADITIONAL**	**VOR**	**Group?**	**Time?**	**Group x Time?**	**Levene Pre**	**Levene Post**
modified OSI right	12.96+2.17	14.19+3.22	7.01+2.04	5.03+1.34	0.62	0.000	0.085	0.092	0.124
modified OSI left	10.31+0.84	9.08+2.85	5.39+1.60	4.33+1.64	0.149	0.000	0.878	0.000	0.8
OSI right	9.74+4.29	11.48+4.20	2.75+1.46	4.68+2.79	0.207	0.000	0.925	0.983	0.208
OSI left	6.96+2.89	5.38+2.36	2.54+1.25	2.16+1.45	0.227	0.000	0.405	0.63	0.993
Motor control test (MCT)	132.63+10.43	131.75+13.34	135.13+13.58	129.75+12.67	0.609	0.899	0.265	0.241	0.921
Dynamic Visual Acuity (DVA) horizontal	0.29+0.12	0.17+0.14	0.22+0.12	0.15+0.06	0.038	0.204	0.511	0.817	0.427
Dynamic Visual Acuity (DVA) vertical	0.22+0.09	0.16+0.18	0.26+0.18	0.13+0.10	0.064	0.98	0.432	0.624	0.508
Gaze Stabilization Test (GST) horizontal	130.13+25.89	144.44+31.33	162.56+41.06	166.00+21.59	0.508	0.005	0.517	0.828	0.045
Gaze Stabilization Test (GST) vertical	122.19+27.34	136.00+27.71	123.25+16.03	165.00+11.54	0.005	0.05	0.066	0.609	0.38

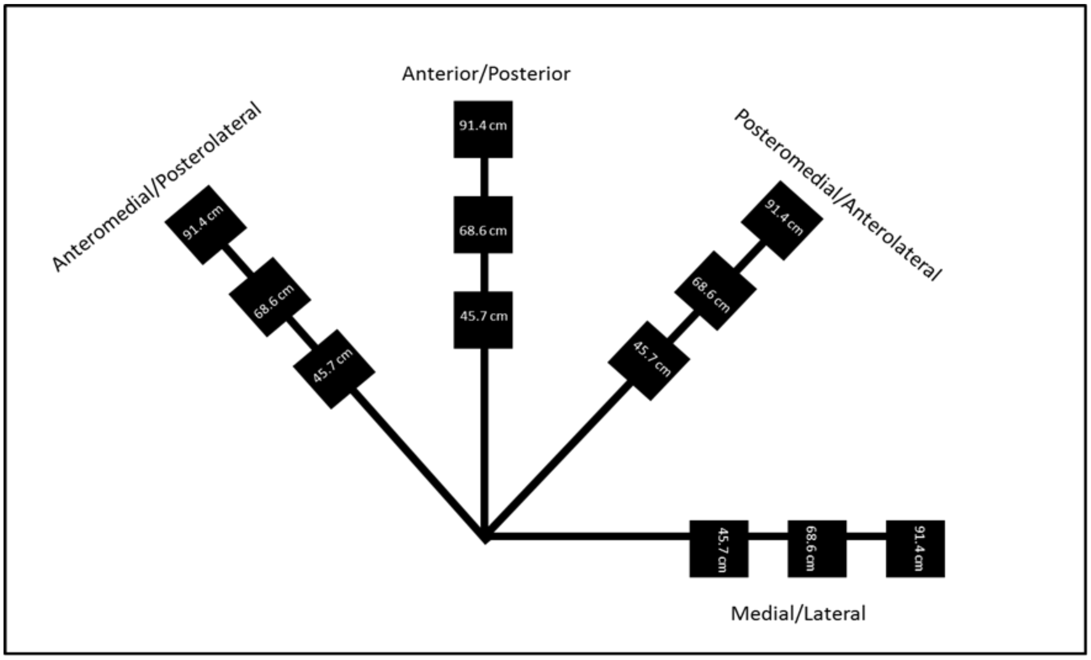


Figure 2.2: Directions in Single Limb Hop to Stabilization Exercise

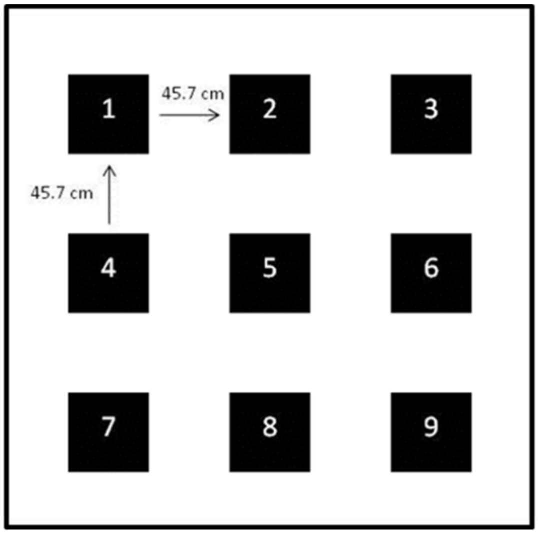


Figure 2.3: Nine Number Grid

References

1. Ross SE, Guskiewicz KM, Gross MT, Yu B. Balance measures for discriminating between functionally unstable and stable ankles. *Med. Sci. Sports Exerc.* 2009; 41 (2): 399-407.
2. Hale SA, Hertel J. Reliability and sensitivity of the foot and ankle disability index in subjects with chronic ankle instability. *J Athl Train.* 2005; 40 (1): 35-40.
3. Hertel J. Functional anatomy, pathomechanics, and pathophysiology of lateral ankle instability. *J Athletic Train*. 2002; 37(4): 364-375.
4. McKeon PO, Ingersoll CD, Kerrigan DC, Saliba E, Bennett BC & Hertel J. Balance training improves function and postural control in those with chronic ankle instability. *Med Sci Sports Ex*. 2008; 40: 1810-1819.
5. Arnold BL, De La Motte S, Linens S, Ross SE. Ankle instability is associated with balance impairments: a meta-analysis. *Med. Sci. Sports Exerc.* 2009; 41 (5): 1048-1062.
6. Batson G. Update on proprioception: Considerations for dance education. *J Dance Med Sci*. 2009; 13(2): 35-41.
7. Webster KA, Gribble PA. Functional rehabilitation interventions for chronic ankle instability: a systematic review. *J Sport Rehabil.* 2010; 19: 98-114.
8. Horak FB, Wrisley DM, Frank J. The balance evaluation systems test (BESTest) to differentiate balance deficits. *Phys Ther*. 2009; 89(5): 484-498.
9. Nashner LM, McCollum G. The organization of human postural movements: a formal basis and experimental synthesis. *Behav Brain Sci.* 1985; 8: 135-172.

10. Badaracco C, Labini F, Meli A, Angelis E, Tufarelli D. Vestibular rehabilitation outcomes in chronic vertiginous patients through computerized dynamic visual acuity and gaze stabilization test. *Otology & Neurology*. 2007; 28: 809-813.
11. Hasegawa T, Yamashita M, Suzuki T, Hisa Y, Wada Y. Active linear head motion improves dynamic visual acuity in pursuing a high-speed moving object. *Exp Brain Res*. 2009; 194(4): 505-516.
12. Juhola M, Aalto H, Hirvonen T. A signal analysis technique of vestibulo-ocular reflex stimulated with impulsive head movements. *Ann Biomed Eng*. 2006; 34(7): 1213-1225.
13. Laurutis VP, Robinson DA. The vestibulo-ocular reflex during human saccadic eye movements. *J Physiol*. 1986; 373: 209-233.
14. Schubert MC, Migliaccio AA, Clendaniel RA, Allak A, Carey JP. Mechanism of dynamic visual acuity recovery with vestibular rehabilitation. *Arch Phys Med Rehabil*. 2008; 89(3): 500-507.
15. Nandi R, Luxon LM. Development and assessment of the vestibular system. *Int J Audiol.* 2008; 47: 566-577.
16. Di Girolamo S, Picciotti P, Sergi B, Di Nardo W, Paludetti G, Ottaviani F. Vestibulo-ocular reflex modification after virtual environment exposure. *Acta Otolaryngol*. 2001; 121: 211-215.
17. Scherer M, Migliaccio AA, Schubert MC. Effect of vestibular rehabilitation on passive dynamic visual acuity. *J Vestib Res*. 2008; 18(2-3): 147-157.

18. Cohen H, Kane-Wineland M, Miller LV, Hatfield CL. Occupation and visual/vestibular interaction in vestibular rehabilitation. *Otolaryngo Head Neck Surg*. 1995; 112: 526-532.
19. [Untitled image of vestibular ocular reflex function]. Retrieved October 4, 2010, from: http://www.thefullwiki.org/Oculocephalic_reflex.
20. Carcia CR, Martin RL, Drouin JM. Validity of the foot and ankle ability measure in athletes with chronic ankle instability. *J Athl Train*. 2008; 43 (2): 179-183.
21. NeuroCom International, Inc. Clackamas, OR. 2007: 4.
22. Meli A, Zimatore G, Badaracco C, De Angelis E, Tufarelli D. Vestibular rehabilitation and 6-month follow-up using objective and subjective measures. *Acta Oto-Laryngologica*. 2006; 126: 259-266.
23. Biodex Medical Systems, Inc. Balance System. 2008. Balance system SD: Operation and Service Manual.
24. Ward BK, Mohammed MT, Whitney SL, Furman, JM. The reliability, stability, and concurrent validity of a test of gaze stabilization. *J Vestib Res.* 2010; 20: 363-372.
25. Rozzi SL, Lephart SM, Sterner R, Kuligowski L. Balance training for persons with functional unstable ankles. *J Orthop Sports Phys Ther.* 1999; 29 (8): 478-486.
26. Hale SA, Hertel J, Olmstead-Kramer LC. The effect of a 4-week comprehensive rehabilitation program on postural control and lower extremity function in individuals with chronic ankle instability. *J Orthop Sports Phys Ther.* 2007; 37(6): 303-311.

27. Ross SE, Guskiewicz K. Effect of coordination training with and without Stochastic Resonance Stimulation on dynamic postural stability of subjects with functional ankle instability and subjects with stable ankles. *Clin J Sport Med.* 2006; 16(4): 323-328.

Chapter 3

Recommendations for Future Research

This study was quite different from any studies that I found in the literature. Upon reflection after completing my master's thesis, there are several aspects of this study that could be improved, altered, and even omitted from future research studies of this nature. That being said, this relatively small, randomized controlled trial was a good starting point for the incorporation of vestibular-ocular reflex (VOR) exercises into the rehabilitation programs of active people with chronic ankle instability (CAI).

Subject recruitment went well overall, but without any financial incentives available to compensate the participants for their time and transportation costs, it was difficult to find people who were willing to meet 3 times per week for 4 weeks. I learned that it was easier to recruit female participants than male participants. It may have been easier to recruit female participants because I am also a female, or it may be that the females were more likely to dedicate to the 4-week protocol. It was good to have a near-equal number of males and females in the study (9 women, 7 men), but in the future it would be better to recruit sufficient numbers of each sex in order to add another independent variable to the experimental design to determine whether sex differences influence the results in both the traditional and VOR-enhanced rehabilitation programs for CAI patients. Focusing on athletes that are in a specific sport and comparing different sports may also be an interesting study to learn if the VOR exercises are more beneficial for some athletes than others, e.g., soccer versus basketball.

Since the CAI rehabilitation protocol that I utilized in this study was adapted from one that had already been shown to produce clinically-significant improvements, it was good to be able to evaluate the addition of rapid side-to-side head movements that activated the VOR and to learn if that factor added value to the McKeon et al. (2008) protocol. The rapid head movements did not seem to elicit nausea in any of the subjects in the VOR group; I instructed them to focus their vision on a point on the wall, and perhaps this was of benefit to them. I think the decision to gradually increase the metronome speed weekly also played a big role in reducing dizziness, as well as acclimating the participants to the head movement.

The doctor's office/meeting room in the Endzone Complex used to administer the rehabilitation protocol was sufficient in size and was good because the door could be shut to reduce outside noise in distracting the patients. Using the drop cloth with the movement patterns permanently outlined was convenient because it could easily be cleared away if the room needed to be used and it also made it portable if need be. One drawback was that after a few weeks of use, the drop cloth would sometimes get wrinkled more easily and it would take time to have to set it back up so that the surface was flat again. Ideally if one space could be designated for the patterns and they could be taped or painted directly on the floor it would reduce set up time and would eliminate the wrinkles. I feel that it is important to limit the amount of distractions during the VOR protocol in order for it to be successful. In specific, I would not recommend conducting these rehabilitation sessions during prime operating time in a collegiate or high school athletic training clinical facility.

In hindsight, the Motor Control Test (MCT) was probably not an appropriate outcome measure for this experiment. The MCT is a bipedal test, and CAI was present in only one ankle of each participant. None of the CAI rehabilitation exercises used in my study was bipedal, and the MCT didn’t give any information on individual limbs. The rest of the outcome measures used provided satisfactory information and produced important insights.

Increasing the sample size is one of the major recommendations that I have for future investigations of this type. Now that statistically significant effect sizes have been identified for most of the 9 outcome measures analyzed in this study, accurate *a priori* statistical power estimates can be performed, and sufficient numbers of CAI patients can be recruited in future studies so as to reach Cohen’s recommended minimum statistical power level of 0.80. This increase in statistical power will substantially reduce the chance of making a Type II error. On several of the ANOVA analyses performed in my study, the chances that I made a Type II error were relatively high, as the observed power in some cases was as low as 0.10, i.e., a 90% chance of accepting the null hypothesis of no difference when it was indeed false.

The 4-week CAI rehabilitation protocol that involved 3 sessions per patient per week was very time consuming for one clinical graduate assistant athletic trainer to accomplish. Future researchers should be prepared to spend a significant number of months collecting data. Recruiting of subjects was an ongoing process. As soon as I could include a subject I set up the time for them to come in and do their pretests. All subjects finished their rehabilitation sessions within the 4-week timeframe, and they would do their post testing within a week of finishing their sessions. I started recruiting in April 2010 and did not finish data collection on all subjects until July 2010. I would also recommend that 3 instead of 2 testing sessions be conducted in future interventions that are 4 weeks in length: a pretest at entry into the study, another testing session at the midpoint (2-week mark), and posttest at the conclusion of the study.

In order to evaluate the possibility of the existence of a significant learning effect, I suggest that future investigators include a separate control group of subjects with unilateral CAI. There is an ethical dilemma associated with this strategy, in not providing patient care to persons in known need, but the use of a crossover experimental design would eliminate this concern. For those CAI patients randomized to the true control group, they would be assigned to the either VOR or TRADITIONAL experimental group at the end of the initial 4-week "CONTROL" period. This approach would not work with intercollegiate or interscholastic athletes who have eligibility remaining, but for those who have endured multiple episodes of chronic ankle instability over a period of years, waiting an additional 4 weeks to participate in a clinically-effective intervention should not be problematic.

Lastly, before running the two-way ANOVAs (GROUP x TIME) on all of the outcome measures chosen for this study, I might have calculated a Pearson product moment correlation matrix using all 9 dependent variables in order to evaluate the redundancy of these measures. In this way I could have tested for multicollinearity among the variables and eliminated one of any pair of variables that had a Pearson "r" of $\geq$ 0.80 from the ANOVA calculations. This process would have lowered my chances of making a Type I error arising from conducting multiple statistical analyses. In my thesis, with 9 dependent variables analyzed at a per comparison alpha of 0.05 ($\alpha_{PC} = 0.05$), the experimentwise Type I error rate was $\alpha_{EW} = 1 – (1 - \alpha_{PC})^9$ or ($\alpha_{EW} = 1 - 0.5987 = 0.4013$), which translates to an approximately 40% chance of making a Type I error. To significantly reduce my chances of making a Type I error in any future study, I would recruit at least 10 subjects per dependent variable (Tabachnick and Fidell, 2007) so that I could more properly employ a multivariate approach (MANOVA) in my statistical analyses.

Summary

Given the dearth of research concerning the incorporation of vestibular-ocular reflex exercises in sports injury rehabilitation protocols, this study can help educate athletic trainers and other physical medicine clinicians regarding the benefits of doing so. Virtually all outcome measures were improved through participation in the VOR group. While most of these improvements were not statistically significant, they were nonetheless encouraging and this study should be replicated with a larger sample size.

It is important to remember that the VOR exercises utilized in this study can be done in almost any kind of rehabilitation setting, at little cost to the patient or the clinician. With proper, detailed instruction, these VOR exercises can be incorporated into many home exercise programs for patients with orthopedic injuries.

After doing this thesis project, I have identified a couple of new questions that I would like to be answered. The first question is that if I had used true control subjects and more subjects if I would have found more evidence in favor of my hypotheses. I would also like to know if the VOR protocol can be demonstrated to be cost effective in the clinical setting.

Appendix A

IRB APPLICATION

APPLICATION REFERENCE NUMBER: 2010N8777

Application status: Approved

SECTION 1

Title of project: The Influence of Vestibular-Ocular Reflex Training on Static and Dynamic Postural Stability in Subjects with Chronic Ankle Instability

Project type: Academic/Class

If Academic/Class, Course #: **AT 5399B**

If funded research, name of funder:

If you are a student, please provide the following information about the faculty member that you work with on this project:

Faculty First Name:	**Rod**	Faculty Last Name:	**Harter**
Faculty Email Address:	**rod.harter@txstate.edu**	Faculty Phone Number:	**512-245-2972**

Department/Office: **HPER**

Is the faculty member aware of the project? **Yes**

Do you require a signed hard copy of the IRB's decision? **No**

SECTION 2

Does the project involve the use of the following as research subjects:

Children under the age of 18: **No**

Nursing home patients: **No**

Prisoners: **No**

Pregnant women or fetuses: **No**

Persons with a physical illness, injury , or disability **Yes**

Mentally or psychologically impaired persons **No**

Are you offering any incentives to subjects in return for participation? **Yes**

Will you be asking subjects to provide:

Name? **Yes**

Social Security #?

Phone #? **Yes**

Address?

Medical/health info? **Yes**

I will NOT be asking subjects to provide their Name, Social Security #, Phone #, Address, or Medical/health info:

Risk: The probability of harm or injury -physical, psychological, social, or economic - occurring as a result of participation in a research study.
On a scale of 1-10, with 1 being no risk and 10 being significant risk, overall risk to subjects in your project. **2**

Benefit: A valued or desired outcome; an advantage.
On a scale of 1-10, with 1 being no benefit and 10 being significant benefit, rate the overall benefits to subjects in your project. **8**

In the space below, briefly describe the method you used to assess risks and benefits associated with your research project.

The prospective subjects will be supervised during the entire course of the intervention. They will be free to stop at any point they feel uncomfortable with any of the exercises. The prospective subjects will have one ankle with chronic ankle instability (CAI). People who have CAI have an inherent risk of falling in everyday life and during physical activity. My study is only using people who are moderately to highly active and the exercises should not put them in much more danger than every day activity. The benefit to them comes from helping them improve their proprioception, strength, and balance with the intervention.

SECTION 3:

Will you be using a Consent Form? **Yes**

Appendix B

Consent Form

IRB Project #: 2010N8777

TITLE: The Influence of Vestibular-Ocular Reflex Training on Static and Dynamic Postural Stability in Subjects with Chronic Ankle Instability

PRINCIPAL INVESTIGATORS:

Jessica Hilgendorf, ATC, LAT
Graduate Student Researcher
113 A EndZone Complex
San Marcos, TX 78666
Jh1808@txstate.edu
512-618-2141

Rod A. Harter, PhD, ATC (Thesis Advisor)
Professor of Athletic Training
Department of Health and Human Performance
A 132 Jowers Center
San Marcos, TX 78666
rod.harter@txstate.edu
512-245-2972

PURPOSE: You have been invited to participate in a research study because you have sprained your ankle on several occasions, and have an orthopedic condition defined "chronic ankle instability." The purpose of this study is to compare the ability of two rehabilitation protocols to improve functional stability in persons with chronic ankle instability. At the beginning and end of the study, we will use computerized devices to measure your ability to balance and maintain postural stability.

PROCEDURES:

You were invited to participate in this research study because you responded to the flier that asked if you have ever had the “feeling of giving way” in one of your ankles, which usually signifies chronic ankle instability. If you decide to participate in this study, you will be expected to participate in 14 experimental sessions (“visits”) over a period of five weeks.

Visit 1 – Screening and Baseline Testing

Prior to any procedures, you will be asked to sign a consent form after all your questions about this study have been answered. You will be given a copy of the consent form for your records. To determine your eligibility for participation in this study, you will be asked to complete a screening questionnaire that includes some basic personal and health information questions. These 12 questions will provide the researchers with information about your sex, age, physical activity level, injury history, and current state of health.

You will also be asked to complete a pencil-and-paper questionnaire known as the Foot and Ankle Ability Measure (FAAM). The FAAM consists of 21 questions that ask you to rate your perceived ability at accomplishing the various tasks listed. These forms will help in determining if you are eligible to participate in this study. You are not required to answer any or all of the questions in either the demographic form or the FAAM. In the next paragraph, sample questions from these two evaluative tools are provided.

Sample Questions

Screening Questionnaire:

Have you had a feeling of “giving way” in either ankle in the past six months? Yes ☐ No ☐

If “yes”, in which ankle have you experienced “giving way”? Right ☐ Left ☐ Both ☐

FAAM Questionnaire:

	No Difficulty	Slight Difficulty	Moderate Difficulty	Extreme Difficulty	Unable to do	N/A
Walking on even Ground without shoes	☐	☐	☐	☐	☐	

Once it is determined that you are eligible to participate in this study, you will be asked to perform four baseline tests on computerized devices used to measure balance, postural stability and vision accuracy. This research equipment is located in Jowers Center and the Health Professions Building at Texas State University. The baseline testing will last approximately 45 minutes.

Visits 2 through 13 – Ankle Rehabilitation Program Sessions

After completion of your baseline testing, you will be randomly assigned to 1 of 2 ankle rehabilitation program groups. Each program is 4 weeks in length. One of the researchers will contact you to arrange a schedule for the days and times of your 12 sessions. You will be expected to come to the End Zone Complex at Bobcat Stadium at Texas State University 3 times a week for 4 weeks (total = 12 visits)and participate in a 20-30 minute ankle rehabilitation protocol. You will be asked to perform three different tasks during the individual sessions. Some of the rehabilitation program tasks are experimental and may require head movement while performing an exercise.

Visit 14 – Posttesting

After your 4-week rehabilitation program is over, you will once again be asked to perform the original four baseline tests of balance, postural stability and vision accuracy at Jowers Center and the Health Professions Building. These final tests will take approximately 45 minutes to complete.

At any time during the study, you have the option of not continuing with your participation without any fears of repercussion. Whether you choose to participate or not you will be given a home rehabilitation program and an elastic resistance band (Theraband™) to help assist you in ankle strengthening exercises. If requested, you will be provided with the results of the study upon its completion.

Your total time commitment to this study will be approximately 6 to 8 hours over a 5 week period. To summarize, there are 14 total visits: a screening/baseline testing session (1 hour), 12 20 to 30 minute rehabilitation sessions over a 4-week period (4 to 6 hours total), and one post-testing session (45 minutes).

POTENTIAL RISKS AND DISCOMFORTS:

There are a few minor risks or possible discomforts associated with this study. There is a small chance that you may lose balance during the testing or rehabilitation exercises and fall. You may also experience some pain and/or some minor swelling in your ankle. If at any time you feel uncomfortable during the exercises, please do not hesitate to inform the researchers and we will end that session. You may withdraw from the study at any point with no fear of any repercussions from faculty and staff. If you withdraw due to injury we will provide first aid and assist you in contacting the appropriate medical personnel. Any costs of medical treatment that you may need are not covered by the researchers or by any other member of the Texas State University System.

POSSIBLE BENEFITS:

By participating in this study you will receive instructions for a home ankle rehabilitation program and an elastic resistance band (Theraband™) to help you improve your level of ankle muscle strength and function. In addition, the exercise program sessions you will be performing are designed to help you improve your daily functional level.

AVAILABLE TREATMENT ALTERNATIVES:

There are several physical therapy clinics and related medical facilities in the San Marcos area where you can engage in an ankle rehabilitation program similar to those offered through participation in this study. If you have medical insurance, it is likely that a significant percentage of the costs of this type of program administered by a physical therapist will be reimbursed.

COMPENSATION/INCENTIVES:

All participants in this study, including those who withdraw, will be given a home ankle injury rehabilitation program and an elastic resistance band (Theraband™) for use with the home based rehabilitation program.

CONFIDENTIALITY:

Your participation in this study is completely confidential. Only the principal investigators will have access to your personal identifiers and to any information that may be linked with your identity. All information that you complete will have an identification number rather than your name to ensure your confidentiality. All data will be stored in a locked cabinet in the Athletic Training Research Laboratory and destroyed after five years. If the results of this study are published, none of your personal identifying information will be disclosed.

REQUEST FOR FURTHER INFORMATION:

Please discuss or express any concerns or questions regarding this study with the investigators at any time. You should feel confident and secure about your involvement in this study. You may also contact the IRB chairperson Dr. Jon Lasser at 512-245-3413.

DISCLOSURE AND FUNDING:

The researchers have no financial or other potential conflict of interest in performing this project. Summary findings will be provided to the participants upon request.

AVAILABLE SOURCES OF INFORMATION:

For questions about this study call:

Study Coordinator: Dr. Rod A. Harter	Graduate Student Researcher: Jessica Hilgendorf
Phone Number: (512) 245-2972	Phone Number: (512) 618-2141

For questions you may have about your rights as a research subject call:
Institutional Review Board Chair: Dr. Jon Lasser Compliance Specialist: Ms. Becky Northcut
Phone Number: (512) 245-3413 Phone Number: (512) 245-2102

AUTHORIZATION:
"I have read and understand this consent form, and I agree to participate in this research study. I understand that I will receive a copy of this form. I voluntarily choose to participate, but I understand that my consent does not take away any legal rights in the case of negligence or other legal fault of anyone who is involved in this study. I further understand that nothing in this consent form is intended to replace any applicable Federal, state or local laws. I also understand that I may withdraw from this study at any time without penalty."

Name of Participant (Printed): _______________________________________

Signature of Participant: _______________________________________

Date: ________________________

Signature of person obtaining consent: ______________________________________

Date: _________________________

Study Coordinator (Signature):______________________________________

Date: _________________________

Appendix C

PARTICIPANT SCREENING QUESTIONNAIRE

Ankle Study Screening Questionnaire

Please answer the questions below honestly and to the best of your knowledge. You can answer every question, some of the questions, or none of the questions. Your participation is totally voluntary.

Name: ________________________________

Phone Number (used to schedule ankle rehabilitation sessions): ___________________________

✶✶

1. Male ☐ Female ☐

2. Are you between the ages of 18 and 35? Yes ☐ No ☐

3. How many days a week do you currently exercise? 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5+ ☐

4. What is the typical intensity of your workouts? Mild ☐ Moderate ☐ Vigorous ☐

5. What is the typical length of your workouts?

   ☐ <10 min

   ☐ 10-20 min

   ☐ 20-29 min

   ☐ ≥ 30 min

6. Do you have a history of previous ankle sprains? Yes ☐ No ☐

If “yes”, how many sprains have you had in each ankle? Right _______ Left _______

If “yes”, did any of the sprains occur in the past 6 months? Yes ☐ No ☐

7. Have you had a feeling of “giving way” in either ankle in the past six months? Yes ☐ No ☐

If yes, which ankle have you experienced “giving way”? Right ☐ Left ☐ Both ☐

8. Have you had any lower extremity injury in the past 6 months other than an ankle sprain? Yes ☐ No ☐

9. Have you had a concussion in the last 12 months? Yes ☐ No ☐

10. Do you have any inner ear problems, either from injury or current illness? Yes ☐ No ☐

11. Do you have any vision problems that are not corrected with prescription eyewear? Yes ☐ No ☐

12. Do you easily experience symptoms of motion sickness? Yes ☐ No ☐

Appendix D

REVIEW OF LITERATURE

This literature review will focus an important part of the human neurological system, the vestibular-ocular reflex (VOR). The neurological system is vital for human function, and facilitates somatic motor and sensory control. The VOR fits into the neurological system because it affects postural stability. The three major components of postural stability include: visual, vestibular, and somatic systems. Within these systems reflexes are initiated to allow for bodily functions to occur. The topics to be addressed in this review will include how the VOR fits into the neurological system, the VOR functions, and how the VOR is initiated.

The neurological system is vital for human function, and facilitates somatic motor and sensory control. The vestibular system is the first sensory system to develop in humans[1]. A function of the vestibular system, the VOR is considered a low latency reflex that allows for a person to focus on an object when the head is in motion [2, 3]. When the head rotates right to left or up and down the VOR causes the eyes to move in the opposite direction of the head motion so that the object stabilizes on the fovea and the image is in focus [4-9].

Several investigators have addressed the various functions of the VOR. The first area of research interest that will be reviewed is the vestibular-ocular reflex’s affects on dynamic visual acuity [5, 6, 10]. The second of these areas is the capacity of the VOR to respond positively to training programs [7, 11]. A third area of interest regarding the VOR is the clinical research that has incorporated activities that engage the VOR and add value totraditional orthopedic and neurologic rehabilitation programs, particularly for patients with vestibular problems [5, 12].

The VOR and Dynamic Visual Acuity

Dynamic visual acuity (DVA) refers to the accuracy with which one sees when the head is in motion[6]. Dynamic visual acuity is a measure of vestibular function that shows how well a person can see objects either during predictable or unpredictable movements of the head[5]. The eye movement in the opposite direction occurs at the same speed as the head movement in the other direction. Automatically, there is a reflex arc comprised of the interconnections among the vestibular afferents, the vestibular nucleus, and the ocular motor nuclei that results in eye movement in the opposite direction of head movement[13]. Eye motion and head movement work together in most activities of daily living to allow effective shifting of a person’s gaze to explore the surrounding environment[14]. During human movement, head movement increases to a rate of at least 2 Hz[4]. During the head movement that accompanies walking or running, the VOR causes eye saccades that maintain gaze saccade accuracy by making gaze velocity independent of head movement[4]. Gaze velocity is how fast a person can see objects in their visual field.

Images on the retina are kept small during head movement[15]. For fast moving objects such as speeding cars, the eyes cannot pursue the image fast enough, so the head also has to move to keep up[10]. Although the VOR needs to function properly, if a person is attempting to view two different things or places at once, the VOR needs to shut itself down so the person can view those other two images. The fovea is in the center of the retina and this is where visual acuity comes from. Visual acuity is how clear an image appears and is influenced by the optic nerve (CN II). Visual acuity is also possible due to the number of cones located in the fovea.

As mentioned previously, side-to-side head movement at a rate of approximately 2 Hz initiates the VOR[16]. When the VOR is activated, it functions in concert with both the eyes and ears. The retina, more specifically the fovea, and the semi-circular canals of the inner ear work together. The eye movements that result from motion occur depend on the following: rotation angle, radius of rotation, distance to the visual target, and the distance between the pupils[7].

There are three pairs of semicircular canals which have two otoliths. The semicircular canals contain the endolymph that is pushed around the canals and brushes against the hairs which causes a neural signal to the brain. The signal tells the brain where the head is moving in space and maintains balance. These vestibular canal receptors, which act like sensors, allow the VOR to work properly[12]. Angular head movements are detected by the three pairs of semicircular canals while linear head accelerations are detected by two pairs of otoliths, which induce the compensatory eye movements that occur opposite of head direction[9]. When the head is oscillated, the semicircular canals generate activity that is approximately in phase with head velocities for frequencies from .04 Hz to 1 Hz. If the otolith organs are activated at these frequencies, activities within the otolith organs are directly related to head position and the effects of gravity[16].

The VOR is also associated with the vestibular spinal reflex, which works similarly to that of the VOR, but involves upright posture and balance[11]. The cerebellum controls both balance and eye movements, and plays a significant role in VOR function. The cerebellum is the part of the brain that receives the input from the semicircular canals. If an injury occurs to the cerebellum then the ability of functional balance and eye function may be out of sync. This can cause vestibular dysfunction in the patient.

The VOR is important because people need to have good visual acuity when attempting to view objects, specifically for objects that are located further than 1 meter away[6]. Recall that saccades are fast, lateral eye movements that redirect an individual's gaze. When the VOR is not working properly, compensatory saccades are used[6]. Compensatory saccades are also referred to as vestibular catch up saccades which work like the regular saccades only they occur at a latency of between 40 ms to 100 ms which is shorter than the regular saccade which occurs at a latency of 200 ms[6]. These compensatory saccades are used when either vestibular hypofunction occurs or when retinal slip happens[6]. Retinal slip occurs when there is unwanted movement of an image on the retina due to the eyes not being able to adequately follow a moving object. Vestibular hypofunction can lead to retinal slip[6]. Retinal slip is corrected for when the VOR is functioning properly. An uncorrected retinal slip can lead people to feel dizzy and nauseous due to the blurry image that appears because of the diminished visual acuity[5, 6, 12]. The compensatory saccades and regular saccades help with centering an object's image back on the fovea, so that visual acuity will occur again. Saccades are also used when the VOR needs to be suppressed to look at two or more different objects. Humans learn how to suppress the reflex at about 3 weeks of age[14]. The VOR is suppressed during activities of daily living because certain activities require the eyes to move in the same direction as the head movement.

Di Fabio et al hypothesized that elderly people had a higher risk of falling because they couldn't properly suppress the VOR[14]. Their study involved 36 female subjects who averaged 80 years old. They were asked to stand and walk 3 steps, and during this their eye movement, trunk movement, and head movement were measured. The patients who were at a higher risk of falling also could not suppress the VOR when needed[14]. These authors found results similar to that of patients who had bilateral vestibular deficiencies, and that these patients used eye movements rather than more head movement to look at objects.

As mentioned previously, the VOR can be impaired by old age, disease and/or injury to the cerebellum or any part of the vestibular system. Symptoms such as postural imbalance, gaze instability, and vertigo can last for years after an injury to the vestibular system[17].

VOR Exercises in Orthopedic Rehabilitation

Several recent studies have addressed the importance of using VOR rehabilitation exercises in patients with VOR hypofunction. The exercises have also been used in helping patients with balance problems. Vestibular rehabilitation is used for both peripheral and central vestibular system problems[11]. Venosa and Bittar demonstrated that patients who experienced acute vertigo and had VOR exercises incorporated into their rehabilitation programs had better balance, decreased incidences of dizziness, and less need for medication than the control group[18]. Eighty-seven percent of the study group was no longer taking medication by the end of the 21-day treatment time period[18]. The study group also reported 0% of abnormal Romberg tests at the end of the 21 day treatment time period[18]. Ninety-three percent of the study group had abnormal Romberg tests during the initial evaluation. One VOR exercise had the patient keep his or her gaze on an immovable object while he or she rotated his or her head to the right and left. A second exercise required the patient to rotate his head from side to side, focusing the gaze on a moving object.

VOR rehabilitation is important because as the VOR is improved, visual acuity also improves[5]. Incorporating gaze stability exercises into a vestibular rehabilitation program was also found to improve dynamic visual acuity[5]. The exercises have been shown to improve the overall health of an individual because of the great improvements in balance and helping an individual have a safer walking gait[11].

In a study by Cohen et al, vestibular rehabilitation with balance re-training plus repetitive head exercises resulted in greater improvements in balance and suggested that gradual increase of head movement, repetition, visual/vestibular interaction, and use of greatest range of motion frequency and velocity works best[19]. Thirty-eight adult subjects diagnosed with disorders of the vestibular system were put into two groups, a home program group and an activity group who performed their exercises at a facility. Each group had a set number of vestibular exercises that needed to be performed. Performance results were compared at the 4 week and 13 week marks[19].

Individuals without vestibular disorders are likely to have little or no visual acuity problems[6]. DVA has been shown to improve during active head motion that incorporates gaze stability[6]. The Gaze Stabilization Test (GST) is a diagnostic test that is administered with a Neurocom computerized posturography device and is used to measure visual acuity at different head velocities. The GST can be used to quantitatively measure a patient's disability or to monitor improvements throughout vestibular rehabilitation[12].

Vestibular rehabilitation incorporates gaze stability exercises. GST exercises required subjects to focus on visual targets during head motion. Schubert and associates used both dynamic and static balance exercises along with gaze stability exercises to determine if DVA would improve with vestibular rehabilitation exercises[6]. The GST was designed to test vestibular function specifically the VOR because subjects need to move their head quickly while focusing on a stationary target. Subjects with reduced GST scores have reduced balance. While walking, the maximum the VOR demands for a younger adult is 90 degrees per second[7]. Schubert's study had 9 subjects, with 5 patients who had vestibular hypofunction and 4 control patients. DVA scores improved for all of their patients who participated with a mean of 51%±25% [6].

Chronic Ankle Instability

Twenty-five percent of all injuries in athletics are ankle sprains with 85% being lateral ankle sprains and according to different researchers, a range of 30% to 78% have recurrent episodes[20-22]. Chronic ankle instability (CAI) is believed to occur from mechanical instability, ankle strength deficits, and ligament deafferentation.

Proprioceptive deficits due to the damaged somatosensory receptors in the ankle could lead to postural reflex impairments.

In a recent study, McKeon et al administered a 4 week rehabilitation protocol to 29 CAI patients that involved dynamic balance stabilization activities. These authors found that balance training significantly altered relationship between shank rotation and rear foot inversion/eversion in those with CAI[23]. McKeon's protocol emphasized dynamic stability after predicted and unpredicted changes in direction and landing from a hop and found significant improvements in self-reported and dynamic and static control[23].

Rozzi[24] et al also performed a 4 week rehabilitation intervention on subjects with CAI and unaffected subjects. The intervention was performed 3 times per week and involved bilateral and unilateral static and dynamic balance exercises. The intervention was found to improve single leg balance abilities in both groups.

Ross et al[25] performed a 6 week rehabilitation intervention on 30 subjects with CAI and 30 healthy subjects. The training group had to perform different balance exercises that included; balancing on a foam pad, performing ankle circles on a wobble board, and did resistance bands in the four hip motions. Results showed that coordination training could improve dynamic postural instabilities in patients with CAI.

Patient-Based Outcome Measures following Ankle Injury

There are a variety of self-reported outcome instruments that are used to assess treatment effects in individuals with foot and ankle pathologies. The most common tools associated with chronic ankle instability are the Foot and Ankle Ability Measure (FAAM) [22,24] and the Foot and Ankle Disability Index (FADI)[26,27].

Both the FAAM and the FADI have sets of questions geared at both the general population and also the athletic population. The FAAM is a 21-item ADL and 8 item Sport subscale questionnaire[22]. The FADI is a 26-item ADL and 8-item Sport subscale questionnaire[26]. Both of these instruments use a Likert scale for patients to rate their ability/inability to perform certain activities for each item. Both the FAAM and FADI have patients rate each item from “unable able to do” to “no difficulty”. Each answer is worth 0 to 4 points. The answer of “no difficulty” is worth 0 points and “unable to do” is worth 4 points. Slight, moderate, and extreme difficulty constitutes the rest of the options and is worth 1, 2, and 3 points respectively. Scores are added up individually for both the ADL and sport subscales. These totals can then be divided by the most points possible and the result will show a percentage of the patient’s perceived impairment.

Martin and Irrgang observed that to properly interpret the scores of an outcome instrument, there needs to be evidence of content validity, construct validity, reliability, and responsiveness[27]. These authors performed a systematic review of foot and ankle outcome instruments and found that the FAAM fit all 4 of the previously mentioned criteria[26].

Content validity was found to be present if the instrument could measure the areas of body structure and function, and activity and participation[26]. Construct validity was found to exist if a strong relationship between the scores on the instrument and other scores of a related construct were found[27]. Reliability was found if repeated measurements on the same person remain similar[27]. Evidence of responsiveness shows if there is either an improvement or decrease in scores over time[27]. As stated previously the FAAM was found to fit all of these criteria while the FADI was not found to have content validity[27]. If content validity is not present then it is unlikely that the measurement has measured all that it intends to.

There are many great studies done on the VOR and patients with CAI separately, but none that put both together. It is important that literature that discusses athletes and incorporating the VOR is written to further the understanding of what the VOR is, why it is important, and if it is necessary to train/retrain the VOR after injury.

References

1. Nandi R, Luxon LM. Development and assessment of the vestibular system. *Int J Audiol*. 2008; 47: 566-577.
2. Di Girolamo S, Picciotti P, Sergi B, Di Nardo W, Paludetti G, Ottaviani F. Vestibulo-ocular reflex modification after virtual environment exposure. *Acta Otolaryngol*. 2001; 121: 211-215.
3. Zhou W, Xu Y, Simpson I & Cai, Y. Multiplicative computation in the vestibular-ocular reflex (VOR). *J Neurophysiol*. 2007; 97: 2780-2789.
4. Juhola M, Aalto H, Hirvonen T. A signal analysis technique of vestibulo-ocular reflex stimulated with impulsive head movements. *Ann Biomed Eng*. 2006; 34(7): 1213-1225.
5. Scherer M, Migliaccio AA, Schubert MC. Effect of vestibular rehabilitation on passive dynamic visual acuity. *J Vestib Res*. 2008; 18(2-3): 147-157.
6. Schubert MC, Migliaccio AA, Clendaniel RA, Allak A, Carey JP. Mechanism of dynamic visual acuity recovery with vestibular rehabilitation. *Arch Phys Med Rehabil*. 2008; 89(3): 500-507.
7. Wood SJ, Black FO, Reschke MF, Kaufman GD, & Paloski WH. Effects of eccentric rotation on the human pitch vestibulo-ocular reflex. *Acta Oto-Laryngologica*. 2009; 129: 521-526.
8. Sugita-Kitajima A & Koizuka I. Somatosensory input influences the vestibulo-ocular reflex. *Neurosci Lett*. 2009; 463: 207-209.
9. Dieterich M & Brandt T. Vestibulo-ocular reflex. *Curr Opin Neurol.* 1995; 8: 83-88.

10. Hasegawa T, Yamashita M, Suzuki T, Hisa Y, Wada Y. Active linear head motion improves dynamic visual acuity in pursuing a high-speed moving object. *Exp Brain Res*. 2009; 194(4): 505-516.
11. Meli A, Zimatore G, Badaracco C, De Angelis E, Tufarelli D. Vestibular rehabilitation and 6-month follow-up using objective and subjective measures. *Acta Oto-Laryngologica*. 2006; 126: 259-266.
12. Badaracco C, Labini F, Meli A, Angelis E, Tufarelli D. Vestibular rehabilitation outcomes in chronic vertiginous patients through computerized dynamic visual acuity and gaze stabilization test. *Otology & Neurology*. 2007; 28: 809-813.
13. Hirvonen M, Aalto H, Migliaccio AA, & Hirvonen TP. Motorized head impulse rotator for horizontal vestibulo-ocular reflex. *Arch Otolaryngol Head Neck Surg*. 2007; 133: 157-161.
14. Di Fabio RP, Emasithi A, Greany JF, & Paul S. Suppression of the vertical vestibulo-ocular reflex in older persons at risk of falling. *Acta Otolaryngol.* 2001; 121: 707-714.
15. Laurutis VP, Robinson DA. The vestibulo-ocular reflex during human saccadic eye movements. *J Physiol*. 1986; 373: 209-233.
16. Dai M, Raphan T, & Cohen B. Adaptation of the angular vestibulo-ocular reflex to head movements in rotating frames of reference. *Exp Brain Res*. 2009; 195: 553-567.
17. Sztrum T, Ireland DJ, & Lessing-Turner M. Comparison of different exercise programs in the rehabilitation of the patients with chronic peripheral vestibular dysfunction. *J Vestibul Res.* 1994; 4 (6): 461-479.

18. Venosa AR & Bittar RS. Vestibular rehabilitation exercises in acute vertigo. *Laryngoscope*. 2007; 117: 1482-1487.
19. Cohen H, Kane-Wineland M, Miller LV, Hatfield CL. Occupation and visual/vestibular interaction in vestibular rehabilitation. *Otolaryngo Head Neck Surg*. 1995; 112: 526-532.
20. Ross SE, Guskiewicz KM, Gross MT, Yu B. Balance measures for discriminating between functionally unstable and stable ankles. *Med. Sci. Sports Exerc.* 2009; 41 (2): 399-407.
21. Arnold BL, De La Motte S, Linens S, Ross SE. Ankle instability is associated with balance impairments: a meta-analysis. *Med. Sci. Sports Exerc.* 2009; 41 (5): 1048-1062.
22. Carcia CR, Martin RL, Drouin JM. Validity of the foot and ankle ability measure in athletes with chronic ankle instability. *J Athl Train*. 2008; 43 (2): 179-183.
23. McKeon PO, Paolini G, Ingersoll CD, et al. Effects of balance training on gait parameters in patients with chronic ankle instability: a randomized controlled trial. *Clin Rehabil*. 2009; 23: 609-621.
24. Rozzi SL, Lephart SM, Sterner R, Kuligowski L. Balance training for persons with functional unstable ankles. *J Orthop Sports Phys Ther.* 1999; 29 (8): 478-486.
25. Ross SE, Guskiewicz K. Effect of coordination training with and without Stochastic Resonance Stimulation on dynamic postural stability of subjects with functional ankle instability and subjects with stable ankles. *Clin J Sport Med.* 2006; 16(4): 323-328.

26. Hale SA, Hertel J. Reliability and sensitivity of the foot and ankle disability index in subjects with chronic ankle instability. *J Athl Train.* 2005; 40 (1): 35-40.

27. Martin RL & Irrgang JJ. A survey of self-reported outcome instruments for the foot and ankle. *J Orthop Sport Phys.* 2007; 37 (2): 72-84.

VITA

Jessica Renee Hilgendorf was born in Milwaukee, Wisconsin, on February 22, 1986, the daughter of Kay Ellen Hilgendorf and Blaine Earl Hilgendorf. After completing her work at Cedarburg High School, Cedarburg, Wisconsin, in 2004, she attended Northern Michigan University in Marquette, Michigan. She received a Bachelor of Science from Northern Michigan University in May 2008. In August 2008, she entered the Graduate College of Texas State University-San Marcos. After completing her Master of Science degree in Athletic Training at Texas State, she was employed at Christus St. John's Hospital and works at Clear Falls High School in League City, Texas as an assistant athletic trainer.

Permanent Address: 1799 FM 528 Apt. 16103
Webster, Texas 77598

This thesis was typed by Jessica R. Hilgendorf.