

RESULTANT EFFECTS OF HEAD IMPACTS ON VESTIBULAR FUNCTION IN
DIVISION I MALE LACROSSE PLAYERS

by

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LIST OF ABBREVIATIONS

Abbreviation	Description
HIC	Head Injury Criteria
THI	Total Number of Head Impacts
VOR.....	Vestibular Ocular Reflex
<i>g</i>	<i>g</i> Force (peak linear acceleration)
DVA	Dynamic Visual Acuity
GST.....	Gaze Stabilization
MGV.....	Maximum Gaze Velocity
VAD	Visual Acuity Difference
PCS	Post-Concussion Syndrome

ABSTRACT

Context: Examination of the cumulative effects of number and magnitude of head impacts on the vestibular function among men's lacrosse players. **Objective:** To determine the influence of total number of head impacts (THI) peak linear acceleration, Head Injury Criteria (HIC), and on vestibular function as assessed by vestibular ocular reflex (VOR) function over the course of one competitive season. **Design:** Pre-test/post-test design. **Setting:** Laboratory-based study. **Patients or other Participants:** 41 male lacrosse players, average age 20.6 ± 1.4 years, at an NCAA Division I university. **Main Outcome Measures:** VOR parameters as assessed by the *inVision*TM system to determine overall function and symmetry of the vestibular system included: maximum gaze velocity and percent of directional bias of the gaze stabilization test yaw; visual acuity difference and percent of directional bias of the dynamic visual acuity test for yaw and pitch head movements. **Results:** The total number (270.3 ± 158.2) and magnitude of head impacts, as assessed by peak linear acceleration ($50.9g \pm 158.2g$) and HIC (33.9 ± 38.3), were not significantly related to changes in vestibular function after one competitive, lacrosse season ($R = 0.535, 0.201, 0.383$, respectively, $p > 0.05$). Significant improvement was seen in DVA yaw from pre- to post-test (0.14 ± 0.16 to 0.1 ± 0.14 ; $p = 0.048$); however, no other significant changes were seen in VOR measures ($p > 0.05$). Self-reported incidence of concussion significantly predicted measures of greater vestibular asymmetry, specifically among participants who described previous medical histories of 3 or more concussions ($R = 0.535$; $p = 0.036$). **Conclusion:** The

results of this study revealed that participant concussion history had the greatest influence on changes in VOR percent bias measures and vestibular asymmetry in collegiate male lacrosse players over the course of one competitive season. These findings support the inclusion of vestibular assessment and treatment in concussion management protocols to improve patient care and health related quality of life among lacrosse participants with previous medical histories of concussion.

CHAPTER 1

Introduction

Sport-related concussion is currently one of the most complex and disconcerting injuries for clinicians and athletes alike¹. Often associated with prolonged symptoms, long-term consequences, decreased quality of life, and injury recurrence, concussion is defined as a trauma-induced alteration in mental status that may or may not involve loss of consciousness.¹ Annual prevalence of reported and unreported sport and recreation-related concussion in the United States is estimated at 3.8 million.^{1,2} Recent studies also suggest that the long-term consequences associated with concussion may be attributed to the cumulative effects of the number and magnitude of head impact exposures throughout an individual's athletic career.¹

Recent advances in technology allows accelerometers to be secured within the helmets of athletes who participate in collision sports to assess number and magnitude of head impact exposures; with the majority research having been conducted among football, hockey, and soccer players. Quantifying the exposure of head impacts across different collision sports provides insight to the risk associated with participation in each respective sport, and aids in the developed of improved diagnostic measures of concussion.^{3,4} The capability of a single accelerometer to collect 3-D data at a sampling frequency of approximately 1,000 Hz generates a large amount of reportable data-per one impact exposure. Total number of head impacts (THI), peak linear acceleration, and Head Injury Criteria (HIC) have been established as meaningful values in assessing the magnitude of head impacts and acceleration^{3,5} Beckwith and associates reported that, on

days when football players were diagnosed with concussion, a higher occurrence of head impacts was recorded; and peak linear acceleration and HIC scores were the most sensitive to immediate diagnosed concussion with mean severities of $112.1g \pm 35.4g$ and 321 ± 239.4 HIC.⁶

Limited research has examined head impact exposures in men's lacrosse; although epidemiological research collected from the 1988-89 season through the 2003-2004 season, reported that concussion was among the top 3 to 5 most common injuries sustained during games and practices.⁷⁻⁹ Furthermore, concussion rates in men's lacrosse were reported at 0.26 per 1000 A-E (95% CI= 0.23, 0.39); totaling 8.6% of all injuries.⁷ Comparable reports of the percent of total injuries represented by concussion can be seen in football and women's soccer.⁷⁻¹⁰ Updated information regarding concussion injury rates in collegiate men's lacrosse are unknown though the sport continues to grow, with the addition of over 155 sponsored varsity teams since 2004. Therefore, analyses of head impact exposure, and the consequential deficits associated with concussion in this athletic population can be used to obtain a better understanding of the cumulative effects of number and magnitude of head impact exposures.¹ Current research suggests that while the relationship between concussion and long-term brain health is unclear, understanding the effects and trends of head impact exposures in high risk athletics may improve concussion management strategies and reduce the risk of subsequent injuries that typically result in more severe impairments and possibly death.^{1,3-6,11,12}

Post-concussion syndrome (PCS), a commonly reported long-term consequence of concussion, is characterized by the prolonged presence of concussive symptoms for

weeks or months after the initial injury.¹³ Individuals who report long-term concussion symptoms have also indicated low levels of life satisfaction, feelings of alienation, as well as post-traumatic stress related symptoms.¹⁴ The prevalence of PCS in the athletic population continues to be investigated, with current research suggesting the development of PCS in approximately 29% of athletes following concussion.¹³

Dizziness has been identified as one of the most common reported symptoms associated with concussion and PCS. Previous studies have described widely varying incidence rates of dizziness in the first few days after sustaining a concussion, with prevalence ranging from 23% to 81%.¹⁵⁻¹⁹ Moreover, reports of dizziness following a concussion have been associated with prolonged recovery and vestibular system pathology/hypofunction.^{1,17, 20-23}

The vestibular system regulates the vestibular-ocular reflex (VOR) within the central nervous system and functions to stabilize images on the retina during rapid head movement. Assessment of the VOR and subsequently symmetrical vestibular function, examines an individual's ability to dynamically perceive objects accurately and maintain the direction of gaze on an external target by reflexively driving the eyes in the opposite direction of head movement.²⁴ Typically, the VOR is assessed in the horizontal (yaw) and vertical (pitch) planes of common head motion. Researchers have concluded that concussion or mTBI can cause disturbances and long-term deficits in this reflex.^{23,25} Altered functioning, and long-term deficits in this reflex can result in abnormal input of sensory information regarding moving and stationary objects in one's environment. Moreover, this can be especially dangerous to an athlete in a competitive environment, due to consequential impairments in motor output that could increase their risk of

sustaining subsequent injury that could be potentially fatal. Therefore, a comprehensive assessment of vestibular function following a concussion, and more importantly before clearing an athlete for return to participation, is imperative.

Computerized assessment of VOR as assessed by the gaze stabilization (GST) and dynamic visual acuity (DVA) tests, of the *inVision*TM system by NeuroCom[®], are reliable, stable, and valid measures for assessing vestibular function, and detecting deficits.²⁶⁻²⁸ Ward and associates reported test-retest reliability of the GST within 7 to 10 days was fair to good for pitch; ICC (95%CI) = 0.54 (0.14-0.79) and yaw 0.59 (0.21-0.81) planes of motion respectively.²⁷ Test-retest reliability of the DVA within 7 to 10 days was poor-fair; ICC (95% CI)= 0.10 not significant and 0.49 (0.08-0.76) in pitch and yaw movements. Inability of the VOR to maintain gaze stability during head movement can cause dizziness due to oscillopsia, defined as the experience that objects in the visual surround that are known to be stationary are perceived as moving.²⁹ Longitudinal assessment of VOR in athletes will allow for accurate detection of vestibular deficits over time, and will determine the potential contribution or association of vestibular pathology/ hypofunction with concussion or in PCS.

Recent examination of the long-term consequences associated with concussion as reported by former athletes has raised immense concern within the athletic training profession. While there have been many studies suggesting the impact of concussion on vestibular function, limited research exists regarding vestibular function after sustaining a concussion among athletic populations specifically. Furthermore, there is little to no research examining the number and magnitude of head impact exposures and how they relate to the most common long-term symptoms associated with concussion such as

dizziness. It is important to simultaneously track THI, peak linear acceleration, and HIC scores of head impact exposures, as well as VOR function measures, to determine their relationship with persistent complaints of dizziness over time. This information will be crucial in determining the contribution of either or both the number and magnitude of head impact exposures on the effects and long-term consequences of concussion.

This study was designed to be the first to examine the effects of number and magnitude of head impact exposures on vestibular function, as assessed by evaluation of the VOR, in a collegiate division I men's lacrosse team. The specific aims of this study were to examine the impact of THI, average peak linear acceleration, and average HIC scores on vestibular function; and to examine vestibular function in a collegiate men's lacrosse team over the course of one competitive season. We hypothesized that significant correlations would exist between total number of head impacts, average peak linear acceleration, and average HIC scores, and vestibular function (VOR) status post season, as well as a significant difference between pre-season and post-season vestibular function in an collegiate division I men's lacrosse team. The results of this study will provide insight regarding the presence and severity of vestibular deficits in relation to the number and magnitude head impact exposure in collegiate men's lacrosse players over the course of one season. Ultimately, results of this study may support the inclusion of vestibular assessment and treatment in concussion management protocols that could potentially improve patient care, and reported quality of life despite previous medical history of concussion.

The co-chairs of this project supported the lead author in the submission of a successful \$1,000 graduate student research grant proposal to the Free Communications

Committee of the Southwest Athletic Trainers' Association (SWATA) in May 2014 to partially fund this study. Following the completion of this master's thesis, abstracts of the findings will be submitted for presentation at both the 67th annual meeting of the National Athletic Trainers' Association in Baltimore in June 2016, and the 62nd annual meeting of SWATA in Dallas in July 2016. The primary manuscript from this thesis will be submitted for publication to the *Journal of Athletic Training*.

CHAPTER 2

Manuscript

Resultant Effects of Head Impacts on Vestibular Function in
Division I Male Lacrosse Players

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ABSTRACT

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collegiate male lacrosse players over the course of one competitive season. These findings support the inclusion of vestibular assessment and treatment in concussion management protocols to improve patient care and health related quality of life among lacrosse participants with previous medical histories of concussion.

Key Words: Vestibular-ocular reflex, concussion, Head Injury Criteria scores, lacrosse

INTRODUCTION

Sport-related concussion is currently one of the most complex and disconcerting injuries for clinicians and athletes alike¹. Often associated with prolonged symptoms, long-term consequences, decreased quality of life, and injury recurrence, concussion is defined as a trauma-induced alteration in mental status that may or may not involve loss of consciousness.¹ Annual prevalence of reported and unreported sport and recreation-related concussion in the United States is estimated at 3.8 million.^{1,2} Recent studies also suggest that the long-term consequences associated with concussion may be attributed to the cumulative effects of the number and magnitude of head impact exposures throughout an individual's athletic career.¹

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population continues to be investigated, with current research suggesting the development of PCS in approximately 29% of athletes following concussion.¹³ Dizziness has been identified as one of the most common reported symptoms associated with concussion and PCS. Previous studies have described widely varying incidence rates of dizziness in the first few days after sustaining a concussion, with prevalence ranging from 23% to 81%.¹⁵⁻¹⁹ Moreover, reports of dizziness following a concussion have been associated with prolonged recovery and vestibular system pathology/ hypofunction.^{1,17, 20-23}

The vestibular system regulates the vestibular-ocular reflex (VOR) within the central nervous system and functions to stabilize images on the retina during rapid head movement. Assessment of the VOR and subsequently symmetrical vestibular function, examines an individual's ability to dynamically perceive objects accurately and maintain the direction of gaze on an external target by reflexively driving the eyes in the opposite direction of head movement.²⁴ Typically, the VOR is assessed in the horizontal (yaw) and vertical (pitch) planes of common head motion. Researchers have concluded that concussion or mTBI can cause disturbances and long-term deficits in this reflex.^{23,25} Altered functioning, and long-term deficits in this reflex can result in abnormal input of sensory information regarding moving and stationary objects in one's environment. Moreover, this can be especially dangerous to an athlete in a competitive environment, due to consequential impairments in motor output that could increase their risk of sustaining subsequent injury that could be potentially fatal. Therefore, a comprehensive assessment of vestibular function following a concussion, and more importantly before clearing an athlete for return to participation, is imperative.

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crucial in determining the contribution of either or both the number and magnitude of head impact exposures on the effects and long-term consequences of concussion.

This study was designed to be the first to examine the effects of number and magnitude of head impact exposures on vestibular function, as assessed by evaluation of the VOR, in a collegiate division I men's lacrosse team. The specific aims of this study were to examine the impact of THI, average peak linear acceleration, and average HIC scores on vestibular function; and to examine vestibular function in a collegiate men's lacrosse team over the course of one competitive season. We hypothesized that significant correlations would exist between total number of head impacts, average peak linear acceleration, and average HIC scores, and vestibular function (VOR) status post season, as well as a significant difference between pre-season and post-season vestibular function in an collegiate division I men's lacrosse team. The results of this study will provide insight regarding the presence and severity of vestibular deficits in relation to the number and magnitude head impact exposure in collegiate men's lacrosse players over the course of one season. Ultimately, results of this study may support the inclusion of vestibular assessment and treatment in concussion management protocols that could potentially improve patient care, and reported quality of life despite previous medical history of concussion.

METHODS

Participants

A total of 41 NCAA division I men's lacrosse players at a single university were recruited to participate in this study. These individuals (mean age, 20.62 ± 1.4 yrs; height, 181.89 ± 6.58 cm) provided consent for participation in the current study in conjunction with an ongoing study at Sacred Heart University in Fairfield, Connecticut. The Institutional Review Boards at Sacred Heart University as well as Texas State University approved this study. Exclusion criteria included those less than 18 years of age, and participants with cervical spine pathology or abnormal cervical range of motion. Participants reported their respective lacrosse positions, which were defined as one of the following: goalie, midfielder, long-stick midfielder, attack, and defense. Participants who required corrected vision by means of either glasses or contacts totaled 41.5%. Participants who indicated a previous history of concussion during the preseason assessment totaled 82.9%. Furthermore, 39% of participants reported a previous history of 3 or more concussions. A complete summary of study participant demographic information and results are found in Table 1.

Approximately 5 months separated the pre-season and post-season vestibular-ocular reflex data collection sessions associated with this study. During this time, a total of 9 participants were lost to the study. Eight players discontinued their participation on the lacrosse team, while 1 participant was unable to schedule his post-test assessment due to a final exam week scheduling conflict. Thus, only 32 of the 41 original study group participated in the post-season VOR testing.

Instrumentation

VOR data collection was performed by the lead author of this study using the *inVision*[™] system by NeuroCom[®], a division of Natus[®]. The GST yaw was administered first and requires each participant to identify the orientation of the optotype “E” at an appropriate logMAR, while dynamically moving their head at increasing velocities. The logMAR unit describes the apparent size of an image based on a ratio of its absolute size to distance from the eye; equivalent to Snellen chart vision measures. The InterSense Inertia Cube 2, 3-axis, integrating gyro headband measures velocity of head motion (degrees/second) and direction of head movement within the yaw and pitch planes of head motion. Input from the headband regulates the appearance of the optotype “E” if and when proper velocity of dynamic head movement has been reached, and the head is positioned within the testing direction.²⁴ The DVA test requires the participant to identify the orientation of the optotype “E” during yaw and pitch head movements at a static velocity.

Accelerometer data including THI, average peak linear acceleration, and average HIC were collected for each participant using the GForce Tracker[™] (GFT). One GFT was assigned to each participant for the duration of the season; and sensors were placed inside the helmet, in its crown. All participants wore NOCSAE-approved Warrior Regulator 2[™] helmet (Warrior Sports, Inc., Warren, MI). Head impact data were sampled and collected at 3,000 Hz during both practices and games to capture the true nature of head impacts over the course of one collegiate lacrosse season. These data were collected throughout the entire 2014-2015 NCAA lacrosse season; however, only true pre/post-season (January through May 2015) data were used for this study.

Experimental Procedures

Participant eligibility was determined and written consent was obtained; each participant completed pre-season VOR assessments in January 2015 over the course of 3 days with approximately 10 tests administered per day. Post-season testing was completed in May 2015 with similar testing hours, during both testing sessions participants were asked to sign up for a 30 minute time slot that worked best for them. This allowed us to include the largest possible number of participants given the variation in class, practice, and final schedules. The GST yaw was completed first, to determine the ability of the participant's VOR to maintain gaze stability during active head movement. DVA yaw and pitch testing order was randomly assigned with a random number generator; those assigned a number 1 completed the DVA pitch test first, followed by the DVA yaw; inverse order was implemented for those assigned a number 2. The DVA tests determine the ability of the VOR to maintain visual acuity during active yaw and pitch head movements. The testing procedure listed above was consistent for both pre and post-testing sessions and took approximately 15 to 30 minutes per participant to complete.

Gaze Stabilization Protocol

Participants were seated in a chair 3.05 meters away from a 48.3 cm monitor and were asked to wear a bonnet head covering under the InterSense Inertia Cube 2, 3-axis, integrating gyro headband, to ensure proper hygiene precautions and comfort. Initialization (or zero calibration) of the InterSense Inertia Cube 2, 3-axis, integrating gyro headband tracker was performed prior to securing the headband on the participant.

Due to the demand of high velocity head movement in men's lacrosse the task velocity setting for the GST was self-paced and set for high performance given their high level of athletic activities. Participants completed a brief GST practice session, prior to beginning the test, to familiarize themselves with the requirements of the assessment.

A practice session was included to help control for a learning effect, the significant threat to the internal validity of the GST. During the practice session participants were encouraged to use the feedback bars that displayed the accuracy of the speed and distance being performed by each participant. This feedback allowed the participant to adjust movement to meet the trial requirements.

Once the participant had demonstrated clear understanding of the test and was comfortable with the test activity, they performed the actual test mode. The VOR test has not shown any learning effects; therefore, we wanted to make sure the participant was comfortable with the test to avoid any error. The headband sensor and feedback bars provided real-time head motion feedback as participants were instructed to move their head at the required velocity, and to identify the orientation of the optotype. The optotype only appeared if and when the participant moved at the required velocity and distance within the testing plane. Once the participant successfully identified the orientation of at least 3 of 5 optotype presentations per side (Left, Right), the head velocity needed to trigger the presentation of the optotype was increased and the process repeated until the patient failed to achieve the minimum number of correct responses. If the patient failed to correctly identify 3 of 5 optotype orientations within the first few trials, the velocity required to trigger the appearance of the optotype was decreased and the process repeated until three correct orientations were identified. Additionally,

multiple trials are administered per test by the program to allow for bilateral randomized assessment in order to prevent anticipation of timing, location, and orientation of the optotype by the participant.^{21,22,24}

Dynamic Visual Acuity Test Protocol

Participants were again allowed to practice head movements, yaw and pitch, prior to the DVA tests to familiarize themselves with the requirements of the test. Once the participant felt comfortable with how the test ran, they completed the actual test mode. Participants were informed that the optotype would only appear while the head is moving at the required velocity and distance. Participants were then instructed to begin moving their head to start the test, adjust their movement to accommodate the requirements of the trial until the optotype appeared, then verbally identify orientation of the “E”. Upon correct identification of at least 3 of 5 optotype presentations, of a given size per direction the optotype size was decreased and the process was repeated until the participant could no longer accurately identify the optotype orientation. Again, to prevent the participant from predicting the direction and timing of the optotype appearance, trials involving the two directions were randomly intermixed by the program.^{9,10,20}

***inVision*TM VOR Measurements**

Vestibular function as assessed by the GST was represented by the ability of the VOR to maintain a stable gaze during active head movement; represented by maximum gaze velocity (MGV) scores expressed in degrees per second of the maximum head velocity at which the participant could maintain visual acuity. Vestibular impairment

measures of the DVA were represented by loss in visual clarity, or the visual acuity difference (VAD), expressed in logMAR during head movement due to the inability of the VOR to maintain gaze clarity on an external target by driving the eyes in the opposite direction of the head movement. All VOR measurements are numeric in nature, and consist of the following data outcomes: average GST yaw expressed by right and left MGVS in deg/sec, and overall DVA yaw and DVA pitch expressed by (right and left) and (up and down) VAD in logMAR scores respectively. Additionally, each VOR test, GST yaw, DVA yaw, and DVA pitch reported an overall percent of directional bias; this measure represented the percent and direction of asymmetry in each individual's vestibular system.

Accelerometer Measurements

All accelerometer measurements were numeric in nature and consisted of the following: THI, average peak linear acceleration, and average HIC scores over the course of the 2015 competitive season. The THI measurement represented the total number of head impact exposures, above 20 g over the course of the competitive season. Inclusion of only those impacts above 20 g allowed for the elimination of inapplicable data collected by the accelerometers such as a participant dropping their helmet on the ground, given the accelerometers were consistently recording data. Average peak linear acceleration, expressed in g force represents the average force of gravity of head impacts sustained over the competitive season. Average HIC is a mathematical measurement of the likelihood of head injury that takes into consideration the peak g force and duration of impact by using a standard formula.^{11,30} This measurement was used to assess likelihood

of head injury over the 2015 competitive season.

Experimental Design

We used a prospective cohort pretest posttest design to assess the resultant effects of THI, average peak linear acceleration, and average HIC score, on the VOR in male lacrosse athletes from one collegiate division I team over the course of the 2015 season. There were three independent variables including magnitude of head impacts (average peak linear acceleration, and average HIC), quantity of impacts (THI), and time. Quantity of impacts was represented by THI over the course of the 2015 competitive season. Time was represented by the difference in pre-season and post-season assessments of the outcome measures.

The main outcome measures used to determine vestibular function as assessed by the VOR included the GST yaw, DVA yaw, and DVA pitch tests. Dependent variables included right and left MGv of the GST yaw, and were expressed in degrees per second; and (right and left) and (up and down) VAD of the DVA yaw and pitch respectively, expressed in logMAR scores.

STATISTICAL ANALYSIS

Descriptive statistics were generated using IBM SPSS version 21 to describe the participants as well as dependent variable means and standard deviations. Following mean comparison, independent t-tests and one-way ANOVAs were used to examine the differences in mean variables. Paired samples t-tests were used to analyze pre-test and post-test VOR data results. Finally, a multiple regression analysis was used to explore

contributions of accelerometer variables on post-season VOR measurements. An alpha level of 0.05 was set for all data results.

RESULTS

Pre-season VOR Assessments

Preseason assessment of participant vestibular function (N = 41) showed mean measures of the maximum velocity at which the participants were able to maintain visual accuracy to the left at 185 ± 63.97 deg/sec. and to the right at 177.90 ± 55.16 deg/sec. Average percent bias between left and right head movement MGVS scores was 12.29 ± 10.37 percent; which represents the average asymmetry in the vestibular system at preseason on the GST test. Preseason differences in visual acuity between static and dynamic head movements in the yaw plane of motion averaged (0.14 ± 0.16 logMAR) to the left and (0.11 ± 0.14 logMAR) to the right. Preseason bias in yaw VAD measures, between the left and right directions, averaged 4.49 ± 3.94 percent; which represents the average asymmetry in the vestibular system at preseason on the yaw DVA test. Average VAD in the pitch plane of motion was (0.12 ± 0.15 logMAR) up and (0.13 ± 0.16 logMAR) down. Preseason bias in pitch VAD measures, between the up and down directions, averaged $5.72 \pm 5.89\%$; which represents the average asymmetry in participants' vestibular system at preseason on the pitch DVA test.

During preseason VOR testing, participants were asked if they were experiencing any symptoms following each portion of the VOR test. Overall, 19.5% (N=8) of participants indicated that they experienced symptoms during the VOR assessment. Table 3 the reported symptoms as well as their reported severity, on a scale from 1-10.

Table 1. Participant's report of concussion history and number of previous concussion(s) with respect to their lacrosse position.

POSITION		No	Yes	1	2	3+
		Concussion History		Previous Concussion Number		
Goalie N=3	N	2	1	0	0	1
Mid-fielder N=19	N	5	14	3	4	7
Long-stick Midfielder N=3	N	0	3	1	2	0
Attack N=7	N	0	5	1	2	2
Defense N=9	N	0	9	1	2	6
Total N=41	N	7	34	8	10	16
Percent		17.10%	82.90%	19.50%	24.40%	39%

Season Experience

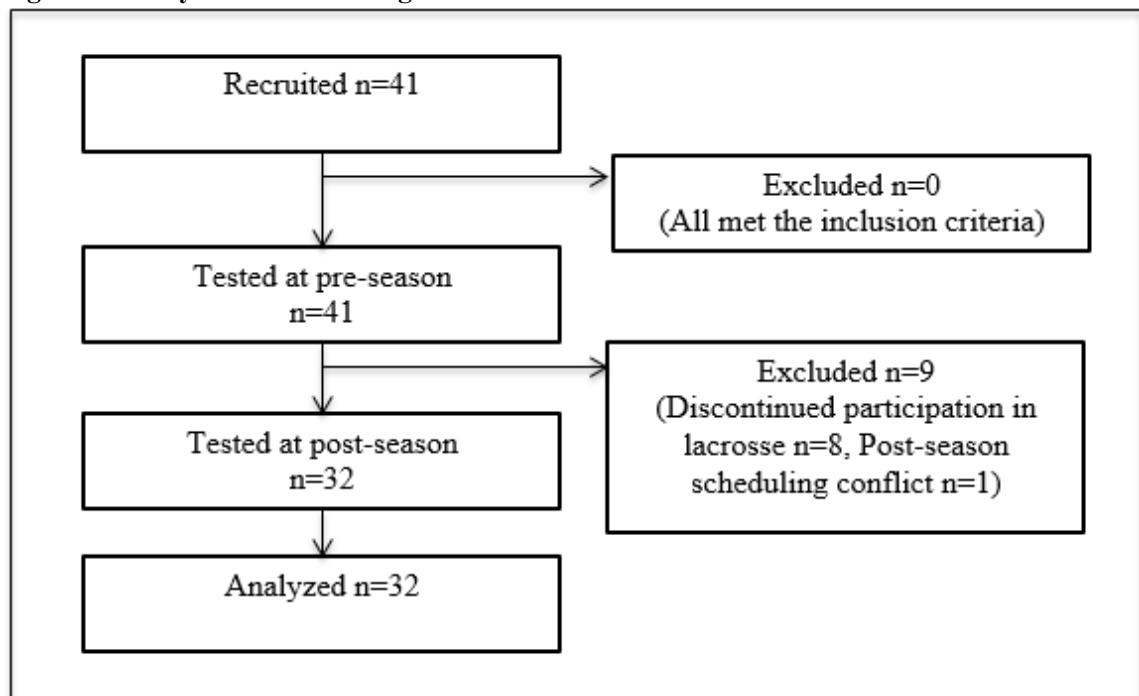
A total of 8,648 impacts were recorded during the 2015 lacrosse season among the 32 participants who participated in the post-season assessment. Participant individual THI numbers ranged from 43 to 594, with an average of 270.3 ± 158.2 head impacts during the season.

The average peak linear acceleration experienced by each participant ranged from 39.1g to 86.86g, mean = $50.91g \pm 158.2g$. Average HIC scores experienced by the participants ranged from 8.2 to 227.3, and averaged (33.9 ± 38.3).

Four one-way ANOVAs were conducted to examine the differences in mean accelerometer measures (THI, average peak linear acceleration g, and average HIC) between the five different lacrosse positions (see Table 1). Two of the outcome measures, average peak linear acceleration, and average HIC, reported significance for Levene's test ($p < .001$) and required that we use the Welch correction for these variables.

There was no significant difference among participant lacrosse positions in THI, $F(4,27) = 0.45$, $p = 0.77$. No significant differences in average peak linear acceleration were found among participants' lacrosse positions, $F(4,6.76) = 2.31$, $p = 0.16$. There was a significant difference among participants' lacrosse positions and average HIC scores, $F(4, 7.33) = 3.97$, $p = 0.05$. Post-hoc comparisons using the Games-Howell test indicated that the average HIC in midfielders (28.6 ± 16.1) was significantly higher than average HIC scores in long-stick midfielders (13.8 ± 3.7), $p = 0.03$. However no significant differences in average HIC scores were seen among goalies (104.0 ± 108.6), Face off (28.6 ± 16.1), Attack (27.6 ± 8.5), and Defense (13.6 ± 6.8).

Figure 1. Study CONSORT Diagram



Post-season Assessments

Thirty-two participants completed post-season VOR assessments. A paired-samples t-test was conducted to compare pre and post-season VOR variable measures. The maximum velocity at which the participants were able to maintain visual accuracy showed an 8% increase. Average right MGVS between pretest (177.90 ± 55.16 degrees per second) and posttest measures (192.23 ± 48.08 degrees per second) were not significantly different $t(29) = -1.05$, $p = 0.301$. An 8% increase was also seen in average left MGVS between pretest (185.10 ± 63.97 degrees per second) and posttest measures (199.93 ± 50.77 deg/sec), and were not significantly different $t(29) = -1.18$, $p = 0.247$. These results suggest that there is no difference in the MGVS at which the participants were able to maintain visual acuity, after the completion of one season. Additionally, no significant difference was seen in bias percentage of the GST between pretest ($12.89 \pm 10.59\%$) and posttest ($9.46 \pm 7.57\%$), $t(27) = 1.43$, $p = 0.164$. This finding suggests continued asymmetry in participants' vestibular systems over the course of one season.

Dynamic Visual Acuity

Paired-samples t-tests were conducted to compare pre and posttest differences in participant visual acuity between static and dynamic head movements; in the yaw and pitch planes of motion. The VAD yaw between static and dynamic head movement, significantly decreased 28% to the left from pretest (0.14 ± 0.15 logMAR) to posttest (0.1 ± 0.14 logMAR), $t(31) = 2.06$, $p = 0.048$. This finding suggests that on average, participants lost less visual acuity to the left between static and dynamic head movement

during the posttest assessment. No significant difference was seen in right VAD yaw measures between pretest (0.11 ± 0.14 logMAR) and post test (0.11 ± 0.12 logMAR), $t(31) = -.25$, $p = 0.805$. Average increase in vestibular system asymmetries was not significant as assessed by directional bias percentage in VAD yaw measures, between pretest ($4.49 \pm 3.94\%$) and posttest ($4.72 \pm 4.57\%$), $t(31) = -0.03$, $p = 0.979$.

Similarly, DVA pitch showed no significant difference between pre and posttest VAD measures. Results of the paired samples t-tests showed no significance difference between the VAD up measures at pretest (0.12 ± 0.15 logMAR) and posttest (0.14 ± 0.11 logMAR), $t(31) = -0.79$, $p = 0.433$; and the VAD down pretest (0.13 ± 0.16 logMAR) and posttest (0.12 ± 0.09 logMAR), $t(31) = 0.590$, $p = 0.560$. Lastly, no significant difference was seen in directional bias percentage in the DVA pitch test, between pretest ($5.72 \pm 5.89\%$) and posttest ($4.28 \pm 4.42\%$), $t(31) = 1.10$, $p = 0.278$. Non-significant findings regarding the difference between pre and posttest directional bias percentage on both DVA assessments (yaw and pitch) suggest continued asymmetry in participants' vestibular systems over the course of one season. Results of the paired samples t-tests are presented in Table 2.

Table 2. VOR assessment results (Paired samples t-tests) (Mean \pm Standard Deviation, T, P<0.05)

VOR OUTCOME MEASURES	Pre-Season	Post-Season	T	Sig.
MGV L degrees/sec	185.1 \pm 63.97	199.93 \pm 50.77	-1.18	0.247
MGV R degrees/sec	177.9 \pm 55.16	192.23 \pm 48.08	-1.05	0.301
GST % Bias	12.89 \pm 10.59	9.46 \pm 7.57	1.43	0.164
Pitch VAD U (logMAR)	0.12 \pm 0.15	0.14 \pm 0.11	-0.79	0.433
Pitch VAD D (logMAR)	0.13 \pm 0.16	0.12 \pm 0.09	0.59	0.56
Pitch DVA % Bias	5.72 \pm 5.9	4.28 \pm 4.42	1.11	0.278
Yaw VAD L (logMAR)	0.14 \pm 0.16	0.1 \pm 0.14	2.06	0.048
Yaw VAD R (logMAR)	0.11 \pm 0.14	0.11 \pm 0.12	-0.25	0.805
Yaw DVA % Bias	4.69 \pm 4.2	4.72 \pm 4.57	-0.03	0.979

Symptom Presence

A related samples McNemar Test was conducted to determine the significance of symptom presence from pretest to posttest. A total of 18 of the 32 participants (56.3%) who participated in the posttest VOR assessment, reported experiencing symptoms during the VOR test. A significant difference was seen in symptom presence between pre- and post-test, indicating deficits in vestibular function, $p = 0.01$. Table 3 summarizes symptom presence and participant-reported severity of symptoms during VOR testing.

Table 3. Participants' reports of symptom presence during pre-season and post-season VOR testing, (Related Samples McNemar test) (Frequency, percent, $p < 0.05$)

SYMPTOM PRESENCE	Pretest		Posttest		Statistical Significance
	Frequency	Percent	Frequency	Percent	
Yes	8	19.5	18	56.3	0.01
No	33	80.5	14	43.8	
Total	41	100.0	32	100.0	

Regression Analysis

A standard multiple regression was conducted to see if THI, average peak linear acceleration, average HIC, concussion number, and symptom presence during the posttest predicted GST absolute percent bias change from pre to posttest measures. The results of the regression showed that THI, average peak linear acceleration, average HIC, concussion number, and symptom presence during the posttest did not significantly explain the amount of variance in GST absolute percent bias change, representing 29% of the variability; $F(5,22) = 1.76$, $p = 0.16$, $R^2 = 0.29$, $d = 0.4085$ (medium to large effect). Number of previous concussions significantly predicted the GST absolute percent bias change, ($\beta = 0.43$, $t(27) = 2.23$, $p = 0.036$). The other four variables did not significantly contribute to the multiple regression model. Table 4 represents the contribution of each of the independent variables to the GST absolute bias percentage change.

Regression analysis to predict DVAV absolute percent bias change in pre and posttest measures from the same independent variables showed a low relationship $R = 0.20$, and no significance in predicting DVAV absolute percent bias change. These independent variables only explained 4% of the variability in DVAV absolute percent bias change, $F(5,26) = 0.22$, $p = 0.952$, $R^2 = 0.04$, $d = 0.0417$ (trivial effect). Table 4 summarizes the contributions of each independent variable to the DVAV absolute percent bias change.

Finally, a regression analysis was conducted to predict DVAH absolute percent bias change in pre and posttest measures from THI, average g, average HIC, history of concussion number, and symptom presence at posttest. The variables showed a low relationship $R = 0.38$, no significance in predicting DVAH absolute percent bias change,

and represented only 15% of the variability, $F(5,26) = 0.89$, $p = 0.501$, $R^2 = 0.15$, $d = 0.1765$ (small effect). Table 4 represents the contribution of each independent variable to the DVAH absolute percent bias change.

Table 4. Results of the multiple regression analysis assessing THI, Average peak linear acceleration and Average HIC on VOR measures. (Mean \pm Standard Deviation, $p < 0.05$)

		Mean \pm Standard Deviation	N	Standardized Coefficients	t	Sig.	R	R Square
				Beta				
GST Absolute Bias Percent Difference	GST Absolute % Bias	6.64 \pm 19.57	28		-.343	.735	.535	.286
	THI	270.25 \pm 158.17	28	.207	.759	.456		
	Avg. g	50.90 \pm 8.27	28	-.065	-.165	.870		
	Avg. HIC	33.93 \pm 38.27	28	.277	.637	.531		
	Concussion History (n)	1.78 \pm 1.21	28	.426	2.234	.036*		
	Total Symptom Severity	2.5 \pm 2.97	28	.155	.806	.429		
Pitch DVA Absolute Bias Percent Difference	DVAV Absolute % Bias	2.25 \pm 10.73	32		.638	.529	0.201	.040
	THI	270.25 \pm 158.17	32	.002	.126	.901		
	Avg. g	50.90 \pm 8.27	32	-.279	-.542	.593		
	Avg. HIC	33.93 \pm 38.27	32	.080	.647	.523		
	Concussion History (n)	1.78 \pm 1.21	32	.553	0.315	.755		
	Total Symptom Severity	2.53 \pm 2.97	32	-.477	-.651	.521		
Yaw DVA Absolute Bias Percent Difference	DVAH Absolute % Bias	2.90 \pm 8.03	32		-1.259	.291	0.383	.146
	THI	270.25 \pm 158.17	32	.142	.518	.609		
	Avg. g	50.90 \pm 8.27	32	.396	1.056	.301		
	Avg. HIC	33.93 \pm 38.27	32	-.268	-.647	.524		
	Concussion History (n)	1.78 \pm 1.21	32	.089	0.478	.637		
	Total Symptom Severity	2.53 \pm 2.97	32	.114	.598	.555		

Participant History of Concussion

Initial posttest comparisons of means revealed significance differences in multiple VOR outcome measures in those with a history of concussion, therefore, further t-test and ANOVA assessments were conducted in order to further explain these differences. An independent t-test was conducted to examine the difference between those who reported having a history of concussion and those who reported no previous history of concussion on posttest GST bias percentage and GST absolute percent bias change from pre- to post-test assessment. Average posttest GST bias percentage in those without a history of concussion was $(3.71 \pm 3.82\%)$, whereas those with a history of concussion averaged $(11.2 \pm 7\%)$; $t(30) = -2.69$, $p = 0.001$. The results of this t-test suggest that those with a history of concussion had significantly greater asymmetries in their vestibular systems following the lacrosse season than those without a history of concussion. Average GST absolute bias percentage change between pre and posttest, in those without a history of concussion was $(-12.0 \pm 12.93\%)$, while those with a history of concussion averaged $(11.72 \pm 18.07\%)$, $t(26) = -2.995$, $p = 0.001$. This finding suggests that those with a history of concussion had significantly greater absolute bias percentage changes following the lacrosse season, further indicating greater vestibular system asymmetries.

A one-way ANOVA was conducted to examine the effect of participants grouped according to reported previous history of 0, 1, 2, or 3 or more concussions, on the following posttest VOR measures: GST bias percentage, GST absolute bias percentage change, and DVA yaw bias percentage. One of the outcome measures, posttest DVA percent bias yaw, showed significance in Levene's Test ($p = 0.03$) and required that we use the Welch correction for this variable. There was a significant difference among

participants' reported concussion history on posttest GST bias percentages $F(3,28)= 5.43$ deg/sec, $p = 0.01$. Post-hoc comparisons using the Games-Howell test indicated that the average percentage among those who reported no history of concussion ($3.71 \pm 3.82\%$) was significantly lower than those who reported a history of 3 or more concussions ($10.92 \pm 5.78\%$), $p = 0.02$. However, no significance was seen in those with a history of 1 concussion ($6.67 \pm 3.72\%$) and 2 concussions ($16.17 \pm 9.28\%$). This finding suggests greater vestibular asymmetries in those with a previous history of concussion, compared to those without a history of concussion. There was a significant group difference among participants' reported concussion history for GST absolute bias percentage change $F(3,24)=3.32$, $p = 0.04$.

Post-hoc comparisons using the Games-Howell post hoc test for significance indicated that the average absolute change in bias percentage among those who reported no history of concussion ($-12.0\% \pm 12.93\%$) was significantly lower than those who reported a history of 3 or more concussions ($11.82\% \pm 17.65\%$), $p = 0.03$. However, no significant differences were seen in those with a history of 1 concussion ($5.20\% \pm 6.30\%$) and 2 concussions ($17\% \pm 25.32\%$). Finally there was a significant difference among participants' reported concussion history on posttest DVA (Yaw) bias percentages, $F(3,11.44)= 11.7$, $p < 0.01$. Post hoc comparisons using the Games-Howell test indicated that the average percent bias among those who reported a history of 1 concussion ($0.33\% \pm 0.52\%$) was significantly lower than those who reported a history of 3 or more concussions ($6.54\% \pm 4.05\%$) $p < 0.01$. However, no significance differences were observed between those with a history of no concussions ($3.86\% \pm 4.41\%$) and those who reported 2 previous concussions ($6.17\% \pm 5.60\%$).

DISCUSSION

To our knowledge this study was the first to examine the effects of the number and magnitude of head impacts on vestibular function in NCAA division I male lacrosse players over the course of one competitive season. We hypothesized significant differences in vestibular functioning between pre and post-season assessments, as well as significant contribution of head impacts on postseason vestibular function. There were changes in post-season vestibular function as assessed by examination of the VOR as measured by the gaze stabilization test (yaw movements), and Dynamic Visual Acuity test (yaw and pitch movements). Dynamic visual acuity yaw left test results were significantly lower at posttest, while there were no significant differences in DVA yaw right, GST yaw and DVA pitch tests over the course of the 2015 season. Due to the head movements required of lacrosse players, it is possible that pre-season visual acuity deficits were recovered through training of the vestibular system during specific activities of daily living and lacrosse training. It has also been noted that changes in DVA may be due to the development of compensations following vestibular impairment.^{28,31}

Normative data for DVA visual acuity loss indicates that a loss of 2 LogMAR (0.2) indicates clinical significance of vestibular dysfunction, and the inability of an individual to maintain visual acuity during normal activities of daily living.²¹ Therefore, the significant improvement of VAD yaw left from pre-test to post-test should be carefully examined. While the average loss in acuity observed in this study was 0.1 LogMAR, the large variance in this score suggest that approximately 6 of the participants were at and above clinical significance of vestibular dysfunction. Moreover, clinically

significant vestibular dysfunction as assessed by VAD measures of visual acuity loss was observed in all DVA testing directions, in up to 11 participants. These findings may be explained by the reports of previous history of concussion in 82% of the participants due to the potential presence of vestibular dysfunction upon injury, and often prolonged and or untreated symptoms.³² Although, the experience of head impacts was tracked between pre-test and post-test VOR assessments, the two testing sessions were approximately 16 weeks apart. Test re-test reliability of the inVision™ system has shown a good to excellent test re-test reliability within and between testing sessions between 7 to 10 days; this may explain the limited statistical significance of our findings.^{20,26,27} However, previous research does suggest the potential of head impacts influencing the function of the vestibular system; therefore, continued longitudinal and repeated measures examination of this system may provide more insight to its vulnerability to head impacts.

Participant performance on the GST yaw test at the conclusion of the 2015 season showed no significant difference in velocity from that of their preseason measurements. Normative data for the GST suggests maintenance of visual acuity at a velocity of 120 deg/sec is required for normal activities of daily living, while competitive sports/athletes require velocities ranging from 160-to180 deg/sec.²¹

The average velocity achieved by the participants in this study met the expectations for participation in competitive sport; however, a wide variation in average measures suggests that some of our participants were not achieving the high performance velocities. Decreased ability of a collegiate lacrosse athlete to maintain visual acuity during rapid head movements raises concern due to the physicality of the game and required hand-eye coordination. Current research has shown that decreased functioning in

the vestibular system may increase the risk of sustaining subsequent injury, due to decreased perception of one's environment.³²⁻³⁴

Symptom Presentation

Participant reports of experiencing symptoms during the testing session were assessed in order to clinically assess the function of the vestibular system. Our study showed a significant increase of participant reported symptoms at the conclusion of the lacrosse season. In healthy individuals, the head movements required of the VOR assessment should not elicit symptoms commonly seen in those with vestibular dysfunction or pathology.³⁵ Clinically, reports of symptom presentation from over 56% of participants during the posttest assessment is concerning, and requires further investigation. There are a couple possible explanations for this finding; it is possible there may have been an influence of head impacts on vestibular function and, the clinically significant loss in visual acuity, as seen in DVA scores, causing a symptomatic response from the system.

A more likely explanation can be constructed around participant's reports of previous history of concussion and the symmetry bias in the VOR assessments. Results of our study indicated that participants with a history of concussion of 3 or more, presented with significantly higher percentages of directional bias in their vestibular systems. Current research suggests that greater asymmetries in the vestibular system often result in a symptomatic response.³⁵ Therefore, our findings of significant symptom presentation may be explained by the significant asymmetry in the vestibular systems of those who reported a history of concussions.

Number and Magnitude of Head Impacts

The number and magnitude of head impact exposures experienced by the participants of this study during one competitive season did not significantly contribute to the change in vestibular function measures post season. The impact measures recorded in this study may be higher than expected for this population as limited research has been done examining head impact exposure in men's lacrosse, compared to other contact sports such as football and hockey. The overall average peak linear acceleration experienced by these participants at 50.91g is comparable to those seen in football and hockey.^{3,5,6,14,30,36} Recently, Crisco et al. reported that in 116 collegiate football players, during the 2007 and 2008 fall football seasons, peak linear acceleration of the majority of head impacts received were less than 20g, and reached 61g at the 95th percentile.³⁶

These findings, along with that of the self-reported previous history of concussion in these participants, reveal the need for the inclusion of men's lacrosse in studies examining both the magnitude of head impacts and prevalence of concussion. The incidence and prevalence of concussion in NCAA men's lacrosse was last reported in 2007, and direct comparisons with the findings in the present study must be made with caution as much has changed in regard to the athlete's perception of the reporting of concussions in the last 8 years.⁸ This dramatic change in public attitude to concussion may partially explain why the level of self-reported previous history of concussion in our sample, was so much higher than we expected.

Influence of Head Impacts on VOR Measures

The results of the multiple regression analyses revealed that THI, average peak linear acceleration, and average HIC did not significantly contribute to, or predict, the absolute change seen in VOR percent bias measures from pre to posttest in any of the 3 models. Nor did they significantly explain the variance in VOR percent bias measures. Due to the significant effect we had observed in other measures in this study regarding participant history of concussion, we decided to include the variable that quantified the previous history of concussions (0, 1, 2 or 3 or more), as reported by the participants, into the regression analysis. Additionally, the total symptom severity score, experienced by the participants, during the posttest was added into the regression equation in order to determine if the symptoms experienced by participants during the testing session had an effect on the outcomes of the test. The addition of these variables improved the explained variance in VOR absolute changes in percent bias, as assessed by the adjusted R Square. Furthermore, we found that previous history of concussion significantly predicted the absolute change in GST bias percentage. The beta value describing the relationship between the absolute changes in participant vestibular system asymmetry, as assessed by the GST yaw, and the number quantifying previous concussion history indicated a positive relationship ($\beta = 0.43$). Therefore, we concluded that those who reported higher numbers of previously sustained concussions exhibited greater asymmetries in their vestibular systems.

Previous research by Schneider et al. examined the presentation and treatment of the comorbidity of concussion and vestibular pathology, considering similar of mechanisms of injury and symptomatic presentation.^{33,37} This may explain the predictive

nature of concussion history on changes in vestibular symmetry seen in this study.

We believe that further longitudinal investigation of a larger sample size of male lacrosse players; examining repeated measures of VOR function via the *inVision*[™], as well as head impact measures is required in order to fully understand the experience of head impact exposure and vestibular function in this competitive, contact sport. Due to the short nature of the assessment's test-retest reliability, repeated measures testing would have given us a better snapshot of the changes in vestibular function over the course of a season, with respect to weekly exposure of head impacts.

Our findings indicated that changes in vestibular function in collegiate male lacrosse players during one competitive season, while not statistically significant, showed clinically significant numbers of participants exhibiting signs and symptoms associated with vestibular dysfunction. The number and magnitude of head impact exposure in this study did not significantly influence vestibular function; however, they were surprisingly comparable to current trends in head accelerations seen in other collegiate contact sports. The presence of these similarities require further investigation to better understand the nature of the sport in order to develop better treatment strategies regarding injury prevention, management and treatment strategies. Finally, the percentage of participants reporting a history of one or multiple concussions, as well as its predictive ability of vestibular asymmetry; combined with significant symptom presentation during VOR testing represents an alarming relationship between concussion, and vestibular function in these collegiate athletes. Additional longitudinal research examining head accelerations and history of concussion in athletes who participate in contact sports must be done to determine their cumulative effects on vestibular function. The production of this research

will allow medical professionals to develop a more comprehensive treatment and rehabilitative strategy for the management of sport related concussion.

CONCLUSION

The NCAA division I male lacrosse players examined in this study showed non-significant changes in VOR scores over the course of one competitive season as a result of the number and magnitude of head impacts they experienced. However, 82% of the participants reported having one or multiple previous concussions, which had a significant effect on vestibular system asymmetry that often results in symptomatic presentation associated with vestibular dysfunction. The presence of these symptoms significantly increased over the course of one competitive season. These findings are of particular importance to researchers, clinicians, athletes, and coaches alike who are actively participating in adding to the body of concussion research in an attempt to improve management strategies and overall patient care.

Concussion prevalence in men's lacrosse was last reported using NCAA ISS data collected from 1988-2004; and represented 11.7% of lacrosse injuries.⁸ Since then the growth, popularity, and evolution of the sport has significantly changed. Current concussion research in this athletic population is extremely limited; therefore the current prevalence of concussion is unknown. The participants in our study experienced similar average peak head accelerations and reported remarkable histories of previous concussion as seen in earlier studies of concussion in contact sports.^{3,6-10,36,38-40} Examination of vestibular function in this specific population revealed multiple cases of dysfunction as indicated by vestibular system asymmetries, and symptomatic presentation. Our findings

support the work of others who have identified a relationship between head impacts, concussion history, and vestibular dysfunction.

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CHAPTER III

SUMMARY AND RECOMMENDATIONS FOR FUTURE RESEARCH

The primary purpose of this study was to examine the effects of number and magnitude of head impact exposure on vestibular function in collegiate male lacrosse players over the course of one competitive season. We sought to determine which of the components of head impact exposures had the greatest influence on vestibular function.

Participant vestibular function was assessed via the VOR using the *inVision* system. Each participant completed pre and postseason VOR assessments including the GST yaw, and DVA (yaw and pitch movements) tests. Following each component of the VOR test participants were asked to identify any symptoms they were experiencing, as well as rate them on a scale from 1 to 10 (“1” being mild, and “10” being severe requiring immediate medical attention). Additionally, each participant’s helmet was fitted with a GForce Tracker™ prior to each practice and competition, to assess head impact exposures over the course of the competitive season (January 2015 to May 2015). Participants also provided information regarding their previous history of concussion prior to preseason testing; none of the participants in this study sustained a diagnosed concussion during the 2015 season.

We observed significant improvement in the DVA yaw left test over the course of the 2015 season. This was the only direction of the VOR DVA assessments that exhibited significant decrease in the amount of visual acuity lost between pre and postseason assessments. The remainder of VOR assessments showed no significant changes in vestibular function and asymmetry over the course of the competitive season. These

findings indicate that for the GST assessment, there were no significant changes in participant vestibular system asymmetry as well as the speed of head movement at which participants were able to maintain visual acuity. Furthermore, no significant changes were seen in vestibular system asymmetry outcomes of the DVA assessment; and all directions other than yaw left, showed no significant change in the amount of visual acuity lost between static and dynamic head movement.

Our study found no significant relationship between the number and magnitude of head impact exposures experienced by the participants and changes in their post-season VOR measures. Rather, our study found that the participants' reports of previous history of concussion showed the greatest predictive capacity of greater post-season vestibular system asymmetries as assessed by the GST yaw. Specifically, those with a self-reported history of 3 or more previous concussions had significant effects on vestibular system asymmetry as seen in both GST and DVA yaw testing at post-season.

We acknowledge that our study had limitations. The NCAA lacrosse season is relatively short (approximately 16 weeks), and as such, the single season duration of our prospective study likely limited our ability to observe changes in the VOR outcome measures.

Future studies should examine the VOR and head impact variables in a repeated measures design to determine if there are significant changes in vestibular function due to the number and magnitude of head impacts.

Future researchers should examine the nature of head impact exposures experienced by collegiate male lacrosse players through longitudinal studies that involve multiple teams and larger sample sizes. The results of the present study reported similar

head impact measures as those experienced in other collegiate contact sports. In addition, we found a high incidence of prior multiple concussions among our study participants, suggesting that this population (male elite intercollegiate lacrosse players) require further evaluation in order to develop more effective concussion management strategies.

A possible limitation of this study was the means by which participants reported their previous history of concussion. Current research examining the reliability of athlete/patient reports of previous history of concussion may not be reliable, lacking true diagnosis, as well as underreporting. Therefore, future research would benefit from the determination or creation of a reliable tool that gives an accurate representation of an individual's concussion history, or verifies the self-reported incidence of concussion with those concussions documented and managed by licensed medical professionals.

Recommendations for future study

- Conduct repeated measures of VOR every 7 to 10 days to improve reliability of vestibular system function measures in relation to head impacts.
- Track team and player head impact and VOR measures over subsequent (multiple) seasons to improve our understanding of the nature of collegiate men's lacrosse and vestibular function in contact sport athletes.
- Examine and employ the most reliable tool to determine an individual's previous history of concussion.
- Employ the use of a reliable outcome measure for symptom report during the VOR assessment.
- Examine the reliability and concurrent validity of field based VOR assessments.

APPENDIX SECTION

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APPENDIX A

INSTITUTIONAL REVIEW BOARD SYNOPSIS

Resultant Effects of Head Impacts on Vestibular Function in Division I Male Lacrosse Players

1. *Identify the sources of the potential subjects, derived materials or data. Describe the characteristics of the subject population, such as their anticipated number, age, sex, ethnic background, and state of health. Identify the criteria for inclusion or exclusion. Explain the rationale for the use of special classes of subjects, such as fetuses, pregnant women, children, institutionalized mentally disabled, prisoners, or others, especially those whose ability to give voluntary informed consent may be in question.*

Participants will include approximately 45 NCAA Division I varsity male lacrosse players at Sacred Heart University, Fairfield, Connecticut. Exclusion criteria include minors, those less than 18 years of age, and participants with cervical spine pathology or abnormal cervical range of motion. We will not need to include the use of special classes of participants.

2. *Describe the procedures for recruitment of subjects and the consent procedures to be followed. Include the circumstances under which consent will be solicited and obtained, who will seek it, the nature of information to be provided to prospective subjects, and the methods of documenting consent. (Include applicable **Consent Form** (s) for review.) If written consent is not to be obtained, this should be clearly stated and justified.*

Participant recruitment efforts will be minimal, as we will be collaborating with an ongoing study at Sacred Heart University. The IRB-approved study at Sacred Heart University is an ongoing study that began in the spring of 2014. An annual renewal and addendum to the current project has been submitted to the Sacred Heart IRB for the inclusion of the variables examined in this study to both the testing procedure and informed consent form (See Attachments; reference: AppendixE and Consent). Prior to the beginning of the NCAA intercollegiate lacrosse season in the spring of 2015, researchers will meet with the team to discuss and provide information regarding the study and testing procedures. Informed consent will be obtained before data collection begins.

3. *If your planned recruitment process involves emailing Texas State students, staff, faculty or other individuals using their active Texas State email address, provide details in the **Synopsis**. (In addition, the IRB will require a draft of your recruitment email, using the enclosed template and formatted as illustrated in the example in this document, submitted in addition to other required documents.*

We will not be using Texas State e-mail to recruit volunteers for this

study.

4. *If you plan to distribute a survey to collect information directly from individuals who comprise a significant proportion of one or more Texas State affiliation groups, as defined in Section 04 of UPPS No. 04.01.02, Information Resources Identity and Access Management, you must follow the review and approval procedures outlined in UPPS No. 01.03.05, Administrative Surveys, and provide information in your **Synopsis** regarding review and approval.*

We will not be employing surveys as part of the data collection for this portion of the study.

5. *Describe the project's methodology in detail. If applicable, detail the data collection procedures, the testing instruments, the intervention(s), etc. If using a survey, questionnaire, or interview, please provide a copy of the items or questions.*

The vestibular-ocular reflex (VOR) assessment in this study will be a part of the data collection process of an ongoing study at Sacred Heart University. Additional assessments, being administered, monitored and analyzed by the Sacred Heart University team of investigators, include questionnaires such as the HANDS depression screen, AUDIT alcohol and drug use screen, Phillip Carter's General IQ test as well as the Concussion Vital Signs neurocognitive assessment. Additionally, the participants will be wearing lacrosse helmets, fitted with an accelerometer sensor to track concussive and sub-concussive forces over the course of the season. This sensor data will be collected and analyzed regularly throughout the spring competitive lacrosse season by the team of investigators from Sacred Heart University. Questionnaire, neurocognitive assessment, and VOR data will be collected and analyzed both pre and post-season. Data collection will occur with the team as a whole, on a designated day as determined by the lead author of the ongoing study at Sacred Heart University.

Once participant eligibility has been determined and written consent has been obtained each participant will complete the following testing protocol via the inVisionTM system by NeuroCom[®]. Participants will be seated in a chair 13' away from a 17" computer monitor. Participants will be asked to wear a bonnet head covering under an InterSense Inertia Cube 2, 3-axis, integrating gyro accelerometer headband, to allow for cleanliness and participant comfort (see Attachment image of the set up and sensor headband; reference: VOR). Participants will complete the Gaze Stability Test (GST) first in order to determine the ability of their VOR to maintain a stable gaze during active head movement, within the horizontal plane.

Upon completion of the GST, the lead author of this study will select a sealed envelope from an array of envelopes containing the randomly-assigned testing order for plane of head movement during the Dynamic Visual Acuity Test (DVA), and the test will be administered accordingly. Participants will complete the DVA Test to determine the ability of their VOR to maintain visual acuity

during active head movement, in both horizontal and vertical planes of head motion. Participants will be allowed rest periods between GST and DVA tests. The testing procedure listed above will remain consistent for both pre and post-testing sessions and will take approximately 15 to 20 minutes per participant to complete.

6. *Describe any potential risks — physical, psychological, social, legal or other — and state their likelihood and seriousness. Describe alternative methods, if any, that were considered and why they will not be used.*

There are no significant risks associated with these testing procedures. Participants who have vestibular changes may experience discomfort from shaking their head during the testing session as well as dizziness. Information regarding the exclusion of individuals with cervical spine pathology or abnormal cervical range of motion will be included in informed consent.

7. *Describe the procedures for protecting against or minimizing any potential risks and include an assessment of the likely effectiveness of those procedures. Include a discussion of confidentiality safeguards, where relevant, and arrangements for providing mental health or medical treatment, if needed.*

All participating athletes will sign a HIPAA waiver allowing the research team access to their medical history pertaining to head injuries sustained during the course of the study, which may lead to the development of either of the exclusion criteria. Previous medical history screening will be completed as a component of the collaborative study and is also completed as a part of the inVision VOR test, to ensure the absence of either one of the exclusion criteria. Screening in both portions of the full testing protocol significantly decreases the likelihood of an individual participating in VOR testing that should be excluded. In addition, if the individual describes any pain or discomfort during the testing procedure the test will be stopped, and the participant will be excluded without any repercussions. Participant confidentiality will be maintained and secured, as all data collected via the inVision VOR test will be coded. Each participant will be assigned an identification number e.g. 01-045; only the primary investigators will have access to the master code document. Once data from the inVision program is extracted, analyzed and correlated to the coded participant, it will be destroyed. The test results will be extracted and analyzed within 24 hours of completion and will be kept on a passcode-protected computer; access to this information will be limited to the investigators listed.

8. *Describe and assess the potential benefits to be gained by the subjects, as well as the benefits that may accrue to society in general as a result of the proposed study.*

A potential benefit of this study to society and the profession of athletic training is gaining a better understanding of the effects of head impacts on

functioning of the vestibular system which is responsible for balance and gaze stability during rapid head movement. Damage to this system results in balance and dizziness problems often associated with concussions; therefore, identification of altered functioning of this system as a result of head impacts may allow for the implementation of better treatment strategies following a concussion. A benefit to the participant will be information regarding their vestibular function after one competitive season.

9. *Clearly describe any compensation to be offered/provided to the participants. If extra credit is provided as an incentive, include the percentage of extra credit in relation to the total points offered in the class. Also, if extra credit is provided, describe alternatives to participation in your research for earning extra credit.*

There will be no financial compensation provided to the participants in this study.

10. *Discuss the risks in relation to the anticipated benefits to the subjects and society.*

The benefits highly outweigh the risks of this study. Concussions are a serious injury affecting the athletic population and the identification of deficits in specific neurological systems, as a result of head impacts, will allow for the development of better treatment strategies.

11. *Identify the specific sites/agencies to be used as well as approval status. Include copies of approval letters from agencies to be used (note: these are required for final approval). If they are not available at the time of IRB review, approval of the proposal will be contingent upon their receipt.*

This collaboration has been agreed upon by both lead authors from Sacred Heart University and Texas State University, (see Attachment; reference: AppendixE); for the naming of the lead author of this study as a co-investigator.

12. *If you are a student, indicate the relationship of the proposal to your program of work and identify your supervising/sponsor faculty member.*

The principal investigator and lead author is a graduate student in the Master of Science degree program Athletic Training at Texas State University. This project is being completed as a master's thesis; supervising faculty members are Dr. Rod Harter and Dr. Denise Gobert (co-chairs).

13. *In the case of student projects, pilot studies, theses, or dissertations, evidence of approval of Supervising Professor or Faculty Sponsor should be included. Thesis and dissertation proposals must be approved by the student's committee before proceeding to the IRB for review.*

A formal thesis proposal meeting was held on October 21, 2014, at which

time my committee members approved my thesis proposal as written, and signed the required Graduate College form (see Attachment; reference: Proposal).

14. *If the proposed study has been approved by another IRB, attach a copy of the letter verifying approval/disapproval and any related correspondence. If the proposed study has not been reviewed/approved by another IRB, please state this explicitly.*

The Sacred Heart University IRB has approved this study (See Attachment; reference: AppendixE), an annual renewal and addendum for the IRB-approved ongoing project has been submitted and includes the VOR variable in the consent form and names the lead author of this study as a new co-investigator. Data collection at SHU has been scheduled for January 11th 2015.

15. *Identify all individuals who will have access, during or after completion, to the results of this study, whether they be published or unpublished.*

The following individuals will have access to the results of this study: Dr. Rod Harter, Dr. Denise Gobert, Dr. Theresa Miyashita, and Christina Vander Vegt.

16. *Provide date of completion of the required CITI training on the protection of human subjects. Applicants must provide training dates for themselves and for supervising faculty member. All training must be current and not expired.*

Christina Vander Vegt: 09/10/2013 (Reference #11247869)
Dr. Rod Harter, Texas State University, 02/11/2014 (Reference #7054667)
Dr. Denise Gobert, Texas State University: July 2014
Dr. Theresa Miyashita, Sacred Heart University: 11/2012

APPENDIX B

INFORMED CONSENT FORM (Consent Form to be in a Research Study)



Sacred Heart University

Consent to Participate in a Research Study Adult Subjects

IRB Study #:

Consent Form Version Date: December 4, 2014

Title of Study: Correlation between concussive and subconcussive impacts on quality of life and neurocognitive assessments in male lacrosse players.

Principal Investigator: Theresa Miyashita, PhD, ATC

SHU Department: Athletic Training

Phone number: (203) 365-4509

Co-Investigators: Eleni Diakogeorgiou, MBA, ATC; Kaitlyn Marrie, MS, ATC; Kelly Copperthite, MS, ATC; Mary Jo Mason, Ph.D., LPC, Christina VanderVegt, ATC

Student Co-Investigators: Thomas Barcia, Noelle Cahill, Kelsey Carpenter, Nicole Castellucci, Claudia Kostich, Taylor Langon, Robert Lewis, Kaitlyn Nadler, Michaela O'Neil, Francesca Prestia, Brianna Quijano, Vincenzo Recine, Christopher Spagnoletti, Kevin Stimmel, David Wallace

You are being asked to take part in a research study involving accelerometers on your lacrosse helmets. The investigators listed above are in charge of the study.

What are some general things you should know about research studies?

Research studies are designed to gain scientific knowledge that in the future may help other people. You may not receive any direct benefit from participating. There may also be risks associated with participating in research studies.

Your participation is voluntary. You may refuse to participate, or may withdraw your consent to participate in any study at any time, and for any reason, without jeopardizing your future at this institution or your relationship with your doctor. If you are a patient with an illness, you do not have to participate in research in order to receive treatment.

Details about this particular study are discussed below. It is important that you understand this information so that you can decide in a free and informed manner whether you want to participate. You will be given a copy of this consent form. You are urged to ask the investigators named above, or staff members who may assist them, any questions you have about this study at any time.

As a SHU Student

You may choose not to be in the study or to stop being in the study before it is over at any time. This will not affect your standing at SHU. In addition, the researchers have the right to end your participation in the research study should you fail to comply with the procedures outlined below. If this happens, your standing at SHU will not be affected. You will not be offered or receive any special consideration if you take part in this research.

If necessary, services are available via the SHU Counseling Center (203-371-7955) if you were to experience any emotional stress resulting from this study as well as the Wellness Center at SHU should any physical problems occur (203-371-7838).

What is the purpose of this study?

The purpose of this study is to determine if there is a correlation between the number of bodily impacts sustained during the competitive lacrosse season and variables assessing the quality of life and neurocognitive tests. Specific variables being assessed in this study include: depression screens, alcohol and drug use screens, IQ, neurocognitive tests, previous medical history, and vestibular-ocular reflex (VOR).

How many subjects will participate in this study?

If you decide to participate, you will be one of 50 subjects in this research study for the current year.

How long will your participation last and what will you be doing?

You will be asked to attend a pre-test meeting where we will obtain baseline information. During this meeting you will complete **surveys** regarding: depression, alcohol and drug use, and IQ. We will obtain your baseline neurocognitive results from your August 2014 testing. You will also fill out a previous medical history form regarding previous concussions, mental illness history, and family history of mental illness/disease. These surveys will take approximately 3 hours to complete.

Additionally, you will complete a vestibular-ocular reflex (VOR) test. This test is an FDA approved clinical assessment for patients with vestibular deficits. The VOR test determines the function of your vestibular (inner ear) system by assessing your ability to maintain a stable gaze with your eyes while moving your head up, down and side to side. You will be seated 13 feet away from a computer monitor that will display the letter “E” facing various directions (up, down, left, right). You will be asked to move your head back and forth within the testing direction, at a specific speed; you will wear a headband with an accelerometer sensor attached to ensure you are moving your head in the right direction, at the required speed. When prompted you will be asked to identify which direction the “E” was facing and the researcher will record your responses. This test will be completed on specified pre and post-season testing session days with the lacrosse team as a whole, and will take approximately 20 minutes to complete.

APPENDIX C

REQUEST FOR ANNUAL UPDATE

Submit (by email) completed form

to: James “*lim*” Carl, Ph.D.

Dean, Isabelle Farrington College of
Education Executive Secretary, IRB

SacredHeart
University Fairfield,
CT 06825-1000 [carl](mailto:carl@sacredheart.edu)
[@sacredheart.edu](mailto:carl@sacredheart.edu)
203-396-8454

PROPOSAL TITLE: Correlation between concussive and subconcussive impacts on
quality of life and neurocognitive assessments in male lacrosse players

IRB DATE OF APPROVAL AND RELEASE: December 3, 2014

INVESTIGATORS: Theresa Miyashita, Eleni Diakogeorgiou, Kaitlyn Marrie, Mary Jo
Mason, Christina VanderVegt (NEW)

DEPARTMENT: Physical Therapy & Human Movement Sciences
FACULTY RESEARCH

EMAIL ADDRESS: miyashitat@sacredheart.edu

TELEPHONE NUMBER: (203) 365-4509

POINTS OF INFORMATION FOR ANNUAL UPDATE

1. When did the study actually begin? January, 2014
2. What is the funding status of the study? N/A
3. What is the estimated completion date of the study? Unknown, ongoing
4. How many subjects are currently in the study? 42
5. Were there any problems or complications in the study that involved risk to the subject or others? NO
6. Are there any changes in the research protocol that affects the subject? YES
An additional assessment variable will be added. Specifically we would like to add vestibular ocular reflex (VOR) to our pre and post test assessments. For each player this will add approximately 15 minutes to the pre/post test assessment protocols. This assessment does not subject the participant to any physical risk.
7. Additional Comments:
The placement of our sensor will also be changing with the upcoming data collection session. The team is changing helmets, so our sensor placement will be

moved internally towards the top of the helmet between the shell and pad. This does not alter the mechanics or protective qualities of the helmet.

PRELIMINARY RESULTS

Provide a brief summary of any preliminary results in the space below.

We are still analyzing data.

ADDITIONAL MATERIALS REQUIRED

1. Copy of current informed consent form(s).
2. Reprint of any publication derived from the study.

Signature of Investigator



Date

12/5/14

FOR IRB USE ONLY

ACTION TAKEN: _____ DATE: _____ SIGNATURE: _____

IRB
CHAIRPERSON

APPENDIX D

Review of Literature

Concussion or mild traumatic brain injury (mTBI) is currently one of the most complex and disconcerting injuries in the athletic and sports medicine community¹. Often associated with prolonged symptoms, long-term consequences, decreased quality of life, and injury recurrence; concussion is defined as acceleration or deceleration forces to the moving brain by either a direct impact or sudden rotational or shearing forces that causes transient disturbance in brain function, caused by a complex pathophysiological process.^{1,41} Concussion affects 1.6-3.8 million athletes per year, and makes up for 5.9% of all athletic injuries, with 30% of concussions affecting those within 5-19 years of age.^{1,2,41} It is important to recognize that concussion incidence is exclusively dependent upon patient reporting, therefore, due to recent examination of underreporting or failure to report concussion and concussion symptoms by athletes; true incidence is reasonably higher than currently documented.^{1,41,42} Recent studies also suggest that long-term consequences associated with concussion may be attributed to the cumulative effects of the magnitude and total number of head impact exposures throughout an individual's athletic career.¹

Concern regarding persistent symptoms and potential long-term consequences following concussion such as increased risk of developing post-concussive syndrome, depression, neurodegenerative disease such as Alzheimer's, chronic traumatic encephalopathy (CTE), and an overall decreased quality of life; has lead to the exploration of rehabilitative interventions.^{1,13,43-47} Current research suggests persistent dizziness and balance deficits following concussion indicate potential involvement or comorbidity of vestibular pathology.^{1,33, 10} Therefore the purpose of this literature review

is to cover the following topics: (a) concussion pathophysiology, (b) vestibular pathophysiology, (c) tracking head impacts and accelerometers, (d) long-term consequences associated with concussion, (e) assessment of vestibular function, (f) vestibular pathology and the athlete, and (g) vestibular rehabilitation following concussion. A thorough search of current literature from 1996 to 2014 was completed using multiple research databases such as Medline, EBSCO, CINAHL, and PubMed. Additional resources were obtained through a review of reference lists and by hand search.

CONCUSSION PATHOPHYSIOLOGY

The definitions of concussion are widely varied in the literature; for the purpose of this study - concussion will be operationally defined as the result of traumatic acceleration or deceleration forces to the moving brain by either a direct impact or by sudden rotational or shearing forces that causes transient disturbance in brain function; caused by a complex pathophysiological process.^{1,41,48,49} A direct blow to either the head or the body that transmits linear and/or rotational forces to the brain is the most common mechanism of concussion injury.^{1,41,48}

Currently, there are many theories regarding the consequential tissue trauma to the brain as a result of a head impact. Leading theories suggest the cascade of events following a concussion due to shearing forces causes neuronal dysfunction and vascular damage; concussion also disrupts the normal ionic, metabolic, and physiological processes of the brain.⁵⁰⁻⁵⁴

Upon brain injury a release of glutamate, an excitatory neurotransmitter, can

cause neuronal depolarization resulting in ionic shifts; an influx of calcium levels and efflux in potassium levels within the brain disrupt the sodium potassium pump which increases the need for glucose in order to reestablish homeostasis.^{50,51,53} As the need for energy increases there is also a decrease in cerebral blood flow, thus resulting in a cellular energy crisis.⁵⁰⁻⁵⁴ Increases in calcium levels detrimentally affect cellular mitochondrial functioning, decreasing the ability to meet energy needs. Glycolysis is activated to meet the energy needs, which consequently produces lactate as a byproduct. Increased lactate levels can cause further neuronal dysfunction and the continual accumulation of cerebral edema.⁵⁰⁻⁵⁴

Prolonged increased levels of calcium result in the accumulation of intracellular edema, which can cause further neuronal dysfunction and axonal death. This increases the susceptibility for secondary injury to the brain; current research using transcranial magnetic stimulation revealed the continued presence of impairments within the brain after athletes reported being asymptomatic.^{52,54,55} Therefore, the concern for sustaining a secondary injury before the brain has fully recovered, such as second impact syndrome, remains highly important, regardless of the athlete's subjective reporting of symptomatic alleviation and recovery.

Shearing forces and injury to the brainstem can not only disrupt normal regulation of heart rate and blood pressure, but also can disrupt or damage one or multiple of the many cranial nerves that run through this area. Damage to one or more of the 12 cranial nerves can result in a multitude of symptoms representative of an absence of the sensory, motor, or reflexive responsibilities of these nerves; often associated with concussion. Common symptoms elicited as a result to damage to the brainstem include but are not

limited to headache, dizziness, balance deficits, and altered vision.

Signs and symptoms of concussion vary, are unique to the individual, and injury. The most common reported symptom of concussion is headache, with dizziness coming in at a close second.^{12,22,33,41,48,56} Additional common symptoms include nausea, vomiting, loss of consciousness, blurred vision, memory loss, and ringing in the ears. The non-specific nature of these symptoms makes the diagnosis of concussion difficult. Many of these symptoms can be the result of a different and potentially unrelated medical condition. Therefore, it is important to encourage and demonstrate a trustworthy environment with athletes, where they can feel comfortable reporting their experience with injury and symptom presence to allow for a more accurate diagnosis.

LONG-TERM CONSEQUENCES OF CONCUSSION

Long-term consequences associated with concussion alter functional capabilities of the body including, but not limited to physical, psychosocial, and cognitive.⁴⁷ Non-resolution of these deficits can lead to PCS, characterized by the prolonged presence of concussive symptoms for weeks or months after the initial injury.^{1,38,39,47,57} Patients who report long-term concussion symptoms have also indicated low levels of life satisfaction, feelings of alienation, as well as post-traumatic stress related symptoms.^{14,44,46,58} Additionally, recent examination of the long-term effects of multiple concussions has indicated development of depression, decreased cognitive and motor function, early onset of neurodegenerative disease, and the development of CTE.^{13,43,45-47,56}

Post-concussion syndrome is characterized by the prolonged presence of

concussive symptoms for weeks or months after the initial injury¹³. Individuals who report long-term concussion symptoms have also indicated low levels of life satisfaction, feelings of alienation, as well as post-traumatic stress related symptoms¹⁴. The prevalence of PCS in the athletic population continues to be investigated, with current research suggesting the development of PCS in approximately 29% of athletes following concussion.¹³ Dizziness has been identified as one of the most common reported symptoms associated with concussion and PCS; with 23-81% of individuals reporting dizziness within the first few days following a concussion, 1.2% at 6 months, and 32.5% at 5 years after concussion.^{18,19,59} Recent studies suggest the high prevalence of dizziness, following concussion, may be associated with vestibular pathology or hypofunction.²⁰⁻²³

Development of depression in athletes, who have sustained a concussion, continues to be a topic of concern as it is one of the most often reported prolonged symptoms.^{43,55,60} The development of depression is likely due to the decreased activation of the dorsolateral prefrontal cortex, medial frontal, and temporal lobes of the brain upon injury.^{43,44,55,60} These three portions of the brain are responsible for memory, working memory, behavior, and emotions; decreased activation and loss of grey matter in these areas of the brain have been associated with depressive symptoms and ultimately the diagnosis of clinical depression.^{55,60} Depression has been associated with executive dysfunction, negative affect, and prominent anxiety in individuals with concussion.^{14,43,44,55,60,61}

In 2007, Guskiewicz et al. reported a correlation between football players who have sustained a head injury and their chance of being diagnosed with depression.⁴³ Findings of this study showed that football players who previously sustained one or two

concussions were one and a half times more likely to be diagnosed with lifetime depression, and players who reported 3 or more concussions were three times more likely to be diagnosed with life-time depression.

Cognitive deficits experienced by those with concussion include, mental foginess, memory problems, difficulty concentrating, and decreased speed of information processing.⁵⁶ Ionic shifts in the brain, described earlier, can decrease neuronal activity due to decreased synapse firing, this suppression in activity can lead to cognitive deficits as well as loss of consciousness and memory loss following a concussion.^{38,58,62,63} Similar findings were reported by Gaetz et al in 2000; indicating that those with a history of multiple concussions also experienced difficulty with headaches, memory problems and what was described as the “inability to think”.⁶⁴

Kiraly et al (2007) identified a correlation between a history of head trauma and the early onset of neurodegenerative diseases such as Parkinson’s and Alzheimer’s.⁶⁵ Neurodegenerative disease significantly affects an individual’s quality of life and its onset can lead to a viscous cycle of depressive and anxious personality tendencies. Therefore, it is important for health care providers to address the early signs of the development of these neurodegenerative diseases, and implement as many preventative and rehabilitative measures necessary to avoid their onset.

Development of chronic traumatic encephalopathy (CTE) is also associated with concussion as a cumulative long-term neurologic consequence of repetitive exposure to concussive and sub-concussive impacts characterized by a buildup of tau proteins in the brain.^{1,66} Presentation of CTE includes progressive memory and cognitive deficits, depression, suicidal behavior, poor impulse control, aggressiveness, Parkinsonism, and

eventually dementia.⁴⁷

The diverse long-term effects of concussion are extremely troubling to the athletic population and the sports medicine team that care for them. The current consensus statement regarding concussion management states, “low-level exercise for those who are slow to recover may be of benefit, although the optimal timing following injury for initiation of this treatment is currently unknown”.⁴⁸ This statement identifies a lack of understanding regarding the potential benefits of low-level exercise and or neurocognitive training on those who are at risk for the development of PCS. Currently, studies examining the effects of specific types of training parameters on the recurrence of concussive symptoms are being conducted to address this issue and potentially decrease the incidence and damage of the long-term effects of concussion.

VESTIBULAR PATHOLOGY

Along with somatosensory and visual input, the vestibular system plays a key role in postural control. Additionally the vestibular system is responsible for eye-head coordination, and regulation of heart rate and blood pressure, based on where the body is at in space, via its contribution to the autonomic nervous system.

The role of the vestibular system in postural control is most active during movement, as the vestibular-ocular reflex (VOR) functions to use proprioceptive input to identify where the body is at in space in relationship to other aspects of the environment, and whether they are moving or stationary. Proprioceptive information is received by the vestibular nuclei located in the lateral aspect of the brainstem; accurate detection of this information results in optimal reflexive eye movement of the VOR to maintain

stabilization of images on the fovea, the most central and optimal location on the retina for accurate visual acuity.²⁹ The VOR allows for optimal eye movement, stable vision during movement, and proper eye-head coordination.

Due to the location of the brainstem just superior to the foramen magnum, it is susceptible to injury, especially in a whiplash, flexion extension mechanism commonly seen in concussion. Combination linear and rotational forces on the head can also disrupt the brainstem where the vestibular nuclei lie. Damage to this area can alter the proprioceptive information received by the vestibular nuclei, thus altering the reflexive motor output of the VOR. Damage can be done to the vestibular system both peripherally and centrally. Peripheral damage such as benign paroxysmal positional vertigo is commonly seen as a result of head trauma or concussion.^{14-16,19,35,67,68}

The most common patient signs and symptoms of vestibular pathology related to head trauma are dizziness seen in 55%, visual disturbances in 49%, and balance problems in 43%.^{19,33,69} Vestibular signs and symptoms are very closely related to those of a concussion, thus indicating the importance of examination of vestibular function following a concussion to identify possible vestibular involvement of disruption. Lau et al. (2011) identified the presence of dizziness at the time of injury as the number one predictor of prolonged recovery or post-concussion syndrome (PCS).¹⁷ Proper symptom documentation and identification of vestibular involvement following concussion could improve patient referral rates for vestibular rehabilitation to potentially prevent prolonged recovery or PCS.³³

Optimal functioning of the vestibular system is important for athletes due to our heavy reliance on this system for postural control during movement. Accurate

interpretation and proprioception within an athletic environment is necessary for accurate postural control and reflexive ability to maintain image stabilization and eye-head coordination.^{15,22,35} A disruption of this system can increase an athlete's risk for a subsequent concussion due to the vestibular systems inaccuracy of proprioception and postural control.^{1,4,6}

Of the three systems used for balance maintenance, the vestibular system is most active during movement.^{33,35,70} Responsible for eye-head coordination, regulation of heart rate and blood pressure, and proprioception and postural control; optimal performance of the vestibular system is essential for accurate motor output. The vestibular system is responsible for the maintenance of postural control during head movement, stabilization of images on the fovea of the retina during head movement, and detecting head motion. Accurate sensory input received by the vestibular end organs in the inner ear, allows for accurate and optimal afferent vestibular-ocular reflexive responses.^{21,35} The sensory information received by the vestibular end organs is that of angular and translational head motion, as well as the tilt of the head relative to gravity.²⁹ This information is used to allow the VOR to stabilize images on the fovea, the most central and optimal location for accurate visual acuity.²⁹ Damage to the peripheral vestibular end organs can alter the sensory information received and consequently alter the reflexive output of this system. The damage, potentially associated with sport-related concussion, will likely result in mismatching of sensory information leading to dizziness and balance dysfunction.³³ Furthermore, potential persistence of this dysfunction can increase the athlete's risk for subsequent concussion.³³

ASSESSMENT OF THE VESTIBULAR SYSTEM

The vestibulo-ocular reflex (VOR) is regulated by the vestibular system and functions to stabilize images on the retina during rapid head movement. Assessment of VOR and consequently vestibular function, examines the patient's ability to perceive objects accurately and maintain the direction of gaze on an external target by reflexively driving the eyes in the opposite direction of head movement.²⁴ Numerous studies have concluded that concussion can cause disturbances and long-term deficits in this reflex.^{23,25} The inability to accurately stabilize images on the retina during rapid head movement alters an athlete's ability recognize objects and or persons in their sporting environment and whether they are stationary or moving. This dysfunction can be detrimental not only to the performance and perceptive abilities of an athlete but can also increase their risk for sustaining an additional injury due to their impaired perception and proprioception in an athletic or competitive environment.

Altered vestibular functioning is a concerning complication for the athlete due to its functional responsibility in the interpretation of sensory input for balance maintenance. Alterations in sensory input alters and triggers inappropriate motor responses, this in turn can put an athlete at risk for sustaining an additional concussion or injury.

Computerized dynamic visual acuity (DVA) and gaze stabilization (GST) tests, as assessed with the *inVision*TM system by NeuroCom[®], are reliable, stable, and valid measures for assessing vestibular deficits.²⁶⁻²⁸ Dizziness can be caused by the inability of the VOR to maintain gaze stability during head movement, thus resulting in oscillopsia, the experience that objects in the visual surround that are known to be stationary are

moving.²⁹ Longitudinal assessment of VOR in collision sport athletes may allow for accurate detection of vestibular function and potential presence of deficits in this system.

Current research suggests that due to the mechanism of sustaining a concussion, the potential to disrupt the otoliths in the inner ear and the development of BPPV is possible.^{10,23,29,31} We know that concussion can result in motor control deficits due to an alteration in sensory input. We also know that in order for optimal motor control we need proper sensory input from the visual, vestibular and proprioceptive systems. Following concussion motor control deficits are seen in gait, postural control and hand movement.¹ Improper or altered integration of the three systems that contribute to optimal sensory input and consequently motor output may increase the risk for subsequent injury.^{1,33}

COLLISION-SPORT ACCELEROMETRY

Accelerometers have been secured within the helmets of athletes who participate in collision sports to assess linear and rotational acceleration as well as quantify the total number of head impact exposures.^{3,4} Due to the immense amount of reportable accelerometer data, per one impact exposure, measurements of linear acceleration (g) force and Head Injury Criteria (HIC) have been established as two important variables in assessing the magnitude of head acceleration.^{3,5,6,30,36} However, majority of the research involving the use of accelerometers to measure these variables has been conducted among football, hockey, and soccer players; men's lacrosse has yet to be evaluated. Longitudinal analyses of these measurements, total number of head impact exposures, and the consequential deficits associated with concussion can be used to obtain a better

understanding of the cumulative detrimental effects of the magnitude and total number of head impact exposures.^{1,3,6,36} Current research suggests that while the relationship between concussion and long-term brain health is unclear, understanding the effects and trends of head impact exposures may improve concussion management and reduce the risk of subsequent injury, resulting in PCS.^{1,3,6}

Recent examination of the long-term consequences associated with concussion, as reported by former athletes, has raised serious concern among medical professionals and athletes alike. While there have been many studies suggesting the impact of concussion on vestibular function, limited research exists regarding vestibular deficits after sustaining a concussion among athletes specifically. Additionally, there is little to no research examining the effects and trends of the magnitude and total number of head impact exposures and how they relate to the most common long-term consequences associated with concussion such as dizziness. This information will be crucial in determining the contribution of either or both the magnitude and total number of head impact exposures on long-term consequences of concussion.

SUMMARY

The literature examining sport related concussion is greatly expanding, and rightfully so due to the multifaceted and greatly consequential potential outcomes of sustaining such injury. This review specifically focused on the current literature examining potential neurological involvement of the vestibular system following concussion as a result of head impact exposure. The current body of knowledge regarding these topics is relatively homogenous; in that each topic has been examined individually.

Research examining the effects of the mechanism of head injury as assessed by head impacts and accelerations on neurological systems that could be responsible for specific symptomatic presentation is limited. Examination of these effects could contribute to the evidence necessary to develop better management, and treatment strategies of SRC.

The outcomes of this study could provide beneficial information to the growing body of knowledge of SRC by examining the nature of head impact exposure in collegiate men's lacrosse, and its relationship with vestibular system functioning. Men's lacrosse is currently understudied when compared to other collision sports that have been shown to have higher rates of concussion. Few studies exist examining the nature of head impact exposure as well as the incidence of concussion in this sport. This study will provide important information regarding head impact exposure and concussion history in this athletic population.

To our knowledge this will also be the first study examining the effects of head impact exposure on vestibular function as assessed by the VOR. Current research has shown that concussion and vestibular pathology have similar mechanisms of injury as well as symptomatic presentation. Therefore this study will provide information regarding the true involvement and vulnerability of the vestibular system in collision sports that report higher rates of concussion prevalence. Moreover, as dizziness is one of the most common symptomatic presentations of both SRC and vestibular pathology, as well as a predictor of prolonged recovery or PCS this study may provide beneficial information regarding the systems involved in the development of PCS. Ultimately aiding in the development of improved evaluation and treatment concussion management strategies.

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APPENDIX E
Grant Proposal Form

**Resultant Effects of Head Impacts on Vestibular
Function in Division I Male Lacrosse Players**

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**Southwest Athletic Trainers' Association Master's Student Grant
Application**

Section 1: Cover sheet:

Attached

Section 2: Institutional Human Research Assurances Approval

Submission of the protocol entitled “Effects of incidence versus magnitude of head impacts on vestibular function in Division I male lacrosse players” to the Institutional Review Board at Texas State University is planned for early fall 2014. Anticipated approval will occur approximately 2-4 weeks following submission. No participant will be tested until appropriate approval has been attained, as data collection is not scheduled to begin until January 2015.

Sacred Heart University IRB approval of 12/04/2013 - Correlation between concussive and subconcussive impacts on quality of life and neurocognitive assessments in male lacrosse players.

Section 3: Abstract

Context: Limited information is known regarding the cumulative effects of head impacts on the vestibular function among men’s lacrosse players. **Objective:** To examine the influence of linear acceleration (g), Head Injury Criteria (HIC), and Total Number of Head Impacts (THI) on vestibular function (VOR) over the course of one competitive season. **Design:** Quasi-experimental pretest/posttest prospective cohort design. **Setting:** Laboratory-based study. **Patients or other Participants:** Participants will include 50 male lacrosse players at an NCAA Division I university. **Main Outcome Measures:** A variety of statistical analyses will be employed to determine the relationships between linear acceleration (g), HIC, and total number of head impacts experienced by male lacrosse players and vestibular function (as measured by the NeuroCom® *InVision* system over the course of one competitive season. This information will help identify the presence of any vestibular deficits exhibited by the NCAA Division I lacrosse players. **Anticipated Results:** Upon the completion of data collection, the results will be analyzed using Pearson’s Correlation Coefficient, a paired standardized Student T-Test, and factor analysis. The findings from this study have the potential to determine the presence of vestibular deficits in relation to the exposure of head impacts over the course of one intercollegiate lacrosse season.

Section 4: Budget

	Description	Item Cost	Category Subtotal
A.	Equipment:		6,170
	<i>inVision</i> ™ by NeuroCom®; Portable Set-Up	6,000	
	<i>inVision</i> Software Update: Windows 7	100	
	External Hard drive: 1TB by: Western Digital Elements, Irvine, California	70	
B.	Supplies (expendables):		32
	Disposable Hair Bonnets by: First Aid Only, Vancouver, WA 1 case (100/Case)	32	
C.	Travel:		1,225
	Round-trip Airfare: Austin to La Guardia Airport January 5 th -12 th 2015: Pretest Data Collection (Sacred Heart University, Fairfield, CT)	350	
	Round-trip Airfare: Austin to La Guardia Airport May 2015: Post-test Data Collection (Sacred Heart University, Fairfield, CT)	375	
	NATA Annual Meeting: Baltimore, MD, Airfare and one night's lodging to present research findings, June 22-25, 2016	500	
	Total Project Costs		7,427
	AMOUNT REQUESTED FROM SWATA		\$1,000
	AMOUNT TO BE REQUESTED FROM THE COLLEGE OFN'S GRADUATE Student Research Grant Program: Texas State University		\$500

Budget Justification

inVision™ (NeuroCom®, a division of Natus® Clackamas, OR) is being supplied and made portable through sponsorship by the Department of Physical Therapy at Texas State University

Disposable hair bonnets will be used to ensure cleanliness and preservation of equipment
*pkg 100= (50 participants x 2 data collection sessions)

In order to make the *inVision*™ system portable, the software must be transferred onto a laptop computer. This laptop requires software updates to support the *inVision*™ system. Additionally, an external hard drive is required to hold the driver for the *inVision*™ system.

Travel Costs are estimated based on minimum purchase time of 3 months prior to date of travel. *See Appendix C. 2*

NOTE: Graduate students conducting thesis and dissertation research projects at Texas State University may apply for a maximum of \$500 from the College of Education Graduate Student Research Grant program to help support their studies. This intramural funding

program has a 100% acceptance/funding rate for submitted applications. Principal investigator Vander Vegt will submit a grant application for \$500 to this entity in Fall 2014.

Section 5: Institutional Resources and Environment

Testing Environment: Sacred Heart University: Fairfield, CT

The Pitt Center Meeting Room will be the location for both the consenting and vestibular-ocular reflex testing during the current study.

Instruments: Supplied by Texas State

- *inVision*™ (NeuroCom®, a division of Natus® Clackamas, OR) quantifies a patient's ability to maintain visual acuity and stable gaze during active head movements.
- InterSense Inertia Cube 2, 3-axis, integrating gyro mounted on headband, monitors the velocity and direction of head movements
- *inVision*™ V8.3 software and Windows 7 operating system

Personnel:

Christina Vander Vegt, ATC, LAT

Graduate Student of Athletic Training, Graduate Research Assistant,
Texas State University, San Marcos, TX

- Ms. Vander Vegt will be the primary investigator; she will be responsible for study design, data collection, data and statistical analysis, final manuscript production, as well as presentation of results.

Rod A. Harter, Ph.D., ATC, LAT, FNATA, FACSM

Professor of Athletic Training; Director, Undergraduate Athletic Training Education
Program, Department of Health and Human Performance

Associate Dean for Research and Sponsored Programs, College of Education
Texas State University, San Marcos, TX

- Dr. Harter will assist with the development of the study design, data collection protocol, statistical analyses, and the interpretation and reporting of project results. Dr. Harter is a veteran sports injury researcher, with more than \$7,500,000 dollars of funded research projects over the course of his academic career.

Denise Gobert, PT, Ph.D., NCS, CEEAA

Associate Professor of Physical Therapy, Department of Physical Therapy
Director, Neuromuscular Research Lab, College of Health Professions,
Texas State University, San Marcos, TX

- Dr. Gobert has over 20 years of experience treating persons with neurological disorders. Her specific clinical research involves rehabilitation strategies used for persons with vestibular and concussion related movement disorders. She will assist in the development of assessment protocols, test interpretation, and reporting of project results.

Theresa Miyashita, Ph.D., ATC, PES, CES

Director of Athletic Training Education Program; Assistant Professor, College of
Health Professions

Sacred Heart University

- Dr. Miyashita will assist with organization of data collection, and statistical analysis. The

proposed study is collaborating with an ongoing study currently being conducted by Dr. Miyashita; data from this study will be used to correlate with the VOR data being collected in the proposed study.

Section 6: Purpose and Rationale

Concussion or mild traumatic brain injury (mTBI) is currently one of the most complex and disconcerting injuries in the athletic and sports medicine community¹. Often associated with prolonged symptoms, long-term consequences, decreased quality of life, and injury recurrence, concussion is defined as a trauma-induced alteration in mental status that may or may not involve loss of consciousness¹ and affects 1.6-3.8 million athletes per year.^{1,2} Recent studies have also suggested that the long-term consequences associated with concussion may be attributed to the cumulative effects of the quality and quantity of head impact exposures throughout an individual's athletic career.¹

Post-concussion syndrome (PCS), a commonly reported long-term consequence of concussion, is characterized by the prolonged presence of concussive symptoms for weeks or months after the initial injury¹³. Individuals who report long-term concussion symptoms have also indicated low levels of life satisfaction, feelings of alienation, as well as post-traumatic stress related symptoms¹⁴. The prevalence of PCS in the athletic population continues to be investigated with current research suggesting the development of PCS in approximately 29% of athletes following concussion.¹³ Dizziness has been identified as one of the most common reported symptoms associated with concussion and PCS; with 23-81% of individuals reporting dizziness within the first few days, 1.2% at 6 months, and 32.5% at 5 years after concussion.^{18,19,59} Recent studies have suggested that the high prevalence of dizziness, following concussion or mTBI, may be associated with vestibular pathology or hypofunction.²⁰⁻²³

Accelerometers have been secured within the helmets of athletes who participate in collision sports to assess linear and rotational acceleration as well as quantify the total number of head impact exposures.^{3,4} Due to the immense amount of reportable accelerometer data, per one impact exposure, measurements of linear acceleration (g force) and Head Injury Criteria (HIC) have been established as two important variables in assessing the quality of head acceleration.^{3,5} However, majority of the research involving the use of accelerometers to measure these variables has been conducted among football, hockey, and soccer players; men's lacrosse has yet to be evaluated. Longitudinal analyses of these measurements and total number of head impact exposures, and the consequential deficits associated with concussion can be used to obtain a better understanding of the cumulative effects of the quality and quantity of head impact exposures.¹ Current research suggests that while the relationship between concussion and long-term brain health is unclear, understanding the effects and trends of head impact exposures may improve concussion management and reduce the risk of repeat injury, resulting in PCS.

The vestibulo-ocular reflex (VOR) is regulated by the vestibular system and functions to stabilize images on the retina during rapid head movement.

Assessment of VOR and thus vestibular function, examines the patient's ability to perceive objects accurately and maintain the direction of gaze on an external target by reflexively driving the eyes in the opposite direction of head movement.²⁴ Numerous studies have concluded that concussion and mTBI can cause disturbances and long-term deficits in this reflex.^{23,25} Computerized dynamic visual acuity (DVA) and gaze stabilization (GST) tests, as assessed with the *inVision*[™] system by NeuroCom®, are reliable, stable, and valid measures for assessing vestibular deficits.²⁶⁻²⁸ Dizziness can be caused by the inability of the VOR to maintain gaze stability during head movement, thus resulting in oscillopsia, the experience that objects in the visual surround that are known to be stationary are moving.²⁹ Assessment of VOR in athletes, over the course of their athletic career, will allow for accurate detection of vestibular deficits. Detection of these deficits will determine the potential contribution of vestibular pathology/ hypofunction in concussion or PCS; as well as the likelihood of these athletes to benefit from a vestibular rehabilitation program.

Recent examination of the long-term consequences associated with concussion and mTBI as reported by former athletes has raised immense concern within the athletic training profession. While there have been many studies suggesting the impact of concussion and mTBI on vestibular function, limited research exists regarding vestibular deficits after sustaining a concussion among athletes specifically. Additionally, there is little to no research examining the effects and trends of the quality and quantity of head impact exposures and how they relate to the most common consequences associated with concussion or mTBI such as dizziness. It is important to simultaneously track HIC, g force and total head impact exposures, as well as the deficits in the systems associated with the common long-term consequences of concussion, over time. This information will be crucial in determining the contribution of either or both the quality and quantity of head impact exposures on the long-term consequences of concussion.

Therefore, this study is designed to be the first to determine the quality and quantity of head impact exposures via linear acceleration (g), HIC, and total number of impacts measurements and their influence on vestibular function, as assessment by the VOR, in a Division I men's lacrosse team. The results of this study will quantify the development of vestibular deficits in collegiate men's lacrosse players over the course of one season, thus indicating their likelihood to benefit from a vestibular rehabilitation exercise program to treat and or prevent the dizziness often associated with PCS; ultimately improving patient care, and consequently a potential improvement in patient reported quality of life despite history of concussion.

Specific Aims and Hypothesis:

Specific Aim #1: To examine the impact of linear acceleration (g), HIC, and total number of head impacts on vestibular function over the course of one competitive season.

Hypothesis #1: Linear acceleration (g), HIC, and total number of head impacts will be significantly related to vestibular function status post season.

Specific Aim #2: To examine vestibular function in a Division I men's lacrosse

team over the course of one competitive season.

Hypothesis #2: There will be a significant difference between pre-season and post-season vestibular function measurements in a Division I Men's Lacrosse team.

Section 7: Experimental Design and Methods

Design

A quasi-experimental pretest/posttest prospective cohort design will be used to assess the resultant effects of HIC, g force and Total Number of Head Impacts (THI) on the vestibulo-ocular reflex (VOR) among the Division I men's lacrosse team over the course of one season. There will be three independent variables including quality of head impacts, quantity of impacts (THI), and time. Average quality of impacts will be assessed over the course of one competitive season and will have 2 levels: average linear acceleration above 60(g), and average HIC scores. Quantity of impacts will be represented by THI over the course of one competitive season. Time will represent the pre and post-test assessments of the dependent variables.

The main outcome measures of vestibular function will include the Gaze Stabilization Test (GST) and Dynamic Visual Acuity (DVA) test scores. Specifically, the Maximum Gaze Velocity (MGV) of the GST; expressed in (degrees per second) will be used. MGV will only be assessed in the YAW plane. The dependent variable for DVA will be the Visual Acuity Difference (VAD) the DVA will have 2 levels according to plane of motion: horizontal (YAW) and vertical, (PITCH) planes and; expressed in (logMAR) scores; a unit describing the apparent size of an image based on a ratio of its absolute size to distance from the eye; equivalent to Snellen chart vision measures.

Participants

Participants will consist of 50 NCAA Division I men's lacrosse players at a single university. Exclusion criteria will include those less than 18 years of age, and participants with cervical spine pathology or abnormal cervical range of motion.

Instrumentation

VOR data collection will be performed using the *inVision*™ system by NeuroCom®, a division of Natus®. The DVA test displays the optotype "E" at decreasing sizes, LogMAR, as well as varying orientations (Up, Down, Left, Right), while the participant dynamically moves their head in the specified plane of motion at a specific velocity. The GST is administered by displaying the optotype "E" at an appropriate logMAR, while the participant dynamically moves their head in a specified plane of motion at increasing velocities. The InterSense Inertia Cube 2, 3-axis, integrating gyro headband measures velocity of head motion (degrees/second) and direction of head movement (Left, Right, Up, Down) and only triggers the appearance of the optotype "E" if and when proper velocity of dynamic head movement has been reached and the head is positioned within the testing direction.²⁴

Accelerometer data including HIC, g, and THI data will be collected using the G-Force tracker. This data will be collected by Dr. Miyashita throughout the entirety

of the season; only true pre/post (January- May) 2015 season data will be used for this study.

Procedures

Once participant eligibility has been determined and written consent has been obtained each participant will complete the following baseline/ pre-test measures via the *inVision*[™] system by NeuroCom[®]. The GST will be completed first, to determine the ability of the VOR to maintain gaze stability during active head movement within the YAW plane. Upon completion of the GST, an envelope containing the randomly assigned testing order for plane of head movement during the DVA will be opened and administered accordingly. Participants will complete the DVA Test last to determine the ability of the VOR to maintain visual acuity during active head movement, in both YAW and PITCH planes of head motion. The testing procedure listed above will remain consistent for both pre and post-testing session and will take approximately 15-20 minutes per participant to complete.

Participant Preparation

Participants will be seated in a chair 13' away from a 17" monitor. Participants will be asked to wear a bonnet head covering under the InterSense Inertia Cube 2, 3-axis, integrating gyro headband, to allow for cleanliness and participant comfort.

Gaze Stabilization Protocol

Initialization of the InterSense Inertia Cube 2, 3-axis, integrating gyro headband tracker, prior to securing the headband on the participant and the start of the test, is required. Due to the demand of high velocity head movement in men's lacrosse the task velocity setting for the GST is expected to be self-paced at high performance. Participants will be allowed a brief GST practice to familiarize themselves with the requirements of the test; practicing helps control the testing threat to the internal validity of the GST. During the practice session participants are encouraged to use the feedback bars, below the attentional cue where the optotype appears, which display the accuracy of the speed and distance being performed by the participant. This feedback allows the participant to adjust their movement to meet the trial requirement and movement range within 3 degrees on either side of midline.

Once the participant feels comfortable with how the test runs they will enter true test mode. The headband sensor and feedback bars assist the patient as they are instructed to move their head at the required velocity and to identify the orientation of the optotype. The optotype will only appear only if and when the participant is moving at the required velocity and distance within the testing plane. Once the participant successfully identifies the orientation of at least three of five optotype presentations per side (Left, Right), the head velocity needed to trigger the presentation of the optotype is increased and the process is repeated until the patient fails to achieve the minimum number of correct responses. If the patient fails to correctly identify three of the five optotype orientations within the first few trials,

the velocity required to trigger the appearance of the optotype is decreased and the process is repeated until three correct orientations are identified. Additionally, multiple trials will be administered per test, as well as plane of head movement, to allow for bilateral randomized assessment in order to prevent anticipation of timing, location, and orientation of the optotype by the patient. The investigator will record participants' response, each trial.^{21,22,24}

Dynamic Visual Acuity Test Protocol

Participants will be allowed head movement (YAW or PITCH) and DVA practice trials to familiarize themselves with the requirements of the test. Once the participant feels comfortable with how the test runs they will enter true test mode. Participants will be informed that the optotype will only appear while the head is moving at the required velocity and distance. Participants will then be instructed to begin moving their head to start the test, and to adjust their movement to accommodate the requirements of the trial until the optotype appears, then verbally identify the optotype orientation. Upon correct identification of at least three of five optotype presentations, of a given size per direction (Left, Right, Up, Down), the optotype size is decreased and the process is repeated until the participant can no longer accurately identify the optotype orientation. Again, to prevent the participant from predicting the direction and timing of the optotype appearance, trials involving the two directions are randomly intermixed.^{9,10, 20}

inVision™ VOR Measurements

All VOR measurements will be numeric in nature, and will consist of the following data outcomes: Overall GST YAW expressed by MGV in degrees/sec, Overall DVA YAW and DVA PITCH will be expressed by VAD in logMAR scores. For overall GST, vestibular impairment measures will be represented by the ability of the VOR to maintain gaze stability during active head movement; expressed in degrees per second of the maximum head velocity at which the patient can maintain visual acuity. DVA vestibular impairment measures will be represented by significant loss of visual acuity during head movement due to the inability of VOR to maintain gaze clarity on an external target by driving the eyes in the opposite direction of the head movement.

Accelerometer Measurements

All accelerometer measurements will be numeric in nature and will consist of the following: Average HIC score, average linear acceleration (g), and THI over the course of one competitive season. Average HIC is the mathematical measure of the likelihood of head injury over the course of one competitive season. HIC measurements take into consideration the peak g and duration of impact by using a standard formula.^{11,30} Average linear acceleration, expressed in (g) force represents the average force of gravity sustained over the course of one competitive season. The THI measurement will represent the total number of head impact exposures, above 60 (g) over the course of one competitive season.

Data Processing

Each participant will be assigned a G force Tracker-sensored helmet with an associated number (1-50) to protect participant information. These helmets will be worn during practice and competitive sessions throughout the season. Dr. Miyashita will download accelerometer data weekly from the accelerometers over the course of the lacrosse season.

Power Analysis

Current analysis of the reliability of the GST and DVA assessments reported the following. Test-retest reliability of GST within a single session was excellent; ICC (95%CI) = 0.75 (0.58-0.86) in the yaw plane. Test-retest reliability of DVA within a single session was good; ICC (95%CI) = 0.60 (0.36-0.77) and 0.56 (0.30-0.74) in the PITCH and YAW planes respectively.²⁷ Test-retest reliability of GST within 7-10 days was good; ICC (95%CI) = 0.59 (0.21-0.81) in the YAW plane. Test-retest reliability in the DVA within 7-10 days was poor-fair; ICC (95% CI) = 0.10 not significant and 0.49 (0.08-0.76) in the PITCH and YAW planes respectively.²⁷ Herdman et al reported the sensitivity of the DVA at 94.5% and specificity at 95.2%. The positive predictive value was 96.3% and negative predictive value was 93%. Additionally, Ward et al reported the concurrent validity of the GST and DVA as moderately inversely correlated in both PITCH and YAW planes r values = -0.38 and -0.62 respectively ($p < 0.02$). Standard error of the measure (SEM) is 13 – 15%. Ward et al. report a suitable reliable sample size for assessing GST is approximately 40; power level of 0.85. A power analysis using G-Power 3.1 for a conservative approach using an effect size of 0.5 will require 34 subjects for a power of 0.80 to detect a 15% difference in scores. Therefore our proposed sample size of 50 will allow sufficient power to detect significant group differences despite possible unanticipated group attrition rates.

Statistical Analysis

Statistical analysis will include descriptive statistics using IBM SPSS version 21 to describe general post-season variables. Pearson's Correlation Coefficient will be used to explore significant relationships within the data. A paired standardized Student T-Test will be used to analyze pre-post data results. A factor analysis will be used to explore contributions of each independent variable on post-season vestibular function. An alpha level will be set at the 0.05 level.

Section 8: Anticipated Outcomes

Upon completion of this study we anticipate to see deficits in vestibular function in collegiate male lacrosse players; moreover, we anticipate seeing a relationship between these deficits and individual's exposure of head impacts. Current research regarding concussion and mTBI indicate the relationship between blunt head trauma and vestibular deficits causing persistent dizziness and balance problems.^{21,22,71} Blunt trauma can disrupt the vestibular system by displacing the otoliths in the inner ear that function to maintain balance and proprioception; and, the physiologic effects associated with mild brain trauma can cause a peripheral or central lesion thus affecting normal vestibular function.^{25,29,67,72} Establishment of this deficit in the athletic population may be an indication of vestibular pathology as a comorbidity of concussion or mTBI.

Due to the high prevalence of long-term consequences of concussion, studies have indicated the need for further examination of the impact of different characteristics and total number of head impacts on these consequences. We anticipate seeing a significant relationship between the post-season averages in linear acceleration (g), averages in HIC, and THI, and level of vestibular deficits. By establishing the contribution of each of these measures on vestibular deficits in this population, we can contribute to the deficit in existing knowledge regarding the effects of both concussive and subconcussive head impact exposures over the course of one competitive season.

Identification of a longitudinal relationship between accelerometer data and vestibular deficits post-season may add to the deficit in existing knowledge regarding post-concussion syndrome. Additionally, this information may add to the limited existing knowledge regarding effective treatment protocols following concussion. Current research reports the benefits and effectiveness of a vestibular rehabilitation program in individuals who have an established vestibular deficit causing persistent dizziness following a concussion or mTBI.^{22,23,25,32,49,67,72,73} Incorporation of a vestibular rehabilitation program in the athletic population following concussion has the potential to decrease the severity or overall prevalence of persistent symptoms of concussion and PCS. Comprehensive management of concussion in the athletic training setting is missing a structured rehabilitation component and we anticipate that the outcomes of this study will suggest that vestibular rehabilitation in particular is indicated.

Section 9: References

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Section 10: Appendix

Appendix A: Project Timeline

Appendix B: Human Subjects Consent Form

Appendix C: Applicable Forms to Support Study

1. GST/ DVA data example

Appendix: A Project Timeline

TASK/ PROJECT ACTIVITY	June 2014 – June 2016																		
	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	J
IRB Submission																			
Pre-testing																			
Data Reduction																			
Post-testing																			
Data Reduction/ Analysis																			
Abstract Development																			
Submit SWATA Abstract																			
Present results at SWATA convention June 2015																			
Submit NATA abstract																			
Present results at NATA Annual meeting June 2015																			

Appendix B: Human Subjects Consent Form

Anticipated submission of the protocol entitled “Resultant effects of head impacts on vestibular function in male lacrosse players” to the Institutional Review board at Texas State University is for early fall 2014. Anticipated approval will occur approximately 2-4 weeks following submission. No participant will be tested until appropriate approval has been attained.

Appendix C: Applicable Forms to Support Study

1. GST/ DVA data output example

