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14. ABSTRACT

The purpose of this research study was to investigate the relationship between blast-induced traumatic brain injury (TBI), specifically the auditory (i.e., hearing) and vestibular (i.e., balance) symptoms of military Warfighters who were recently deployed in support of Operation Iraqi Freedom (OIF) and Operation Enduring Freedom (OEF). The study employed a prospective, between-subjects research design comparing an experimental group (service members who have been diagnosed with BI-TBI) to a control group (service members who do not have clinical symptoms consistent with BI-TBI). A total of 96 volunteers were recruited and consented, with a final enrollment of 68 participants. Results show that there are differences between the vestibular function of service members without history of BI-TBI and those with a history of BI-TBI that could be diagnosed clinically with instrumentation that proved to be reliable and well tolerated by service members with TBI.

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INTRODUCTION:

The purpose of this study was to evaluate and characterize the vestibular, auditory, and oculomotor sequelae to blast exposure in Warfighters diagnosed with blast-induced traumatic brain injury (BI-TBI). The results of this study were intended to contribute to the development of objective diagnostic measures appropriate for the BI-TBI population, and to the development of empirical vestibular, auditory, and oculomotor return-to-duty standards. It was believed that the range of sensory findings measured in a sample of BI-TBI patients would provide an observational basis for measuring treatment progression, as well as empirical methods for establishing the severity of the sensory loss due to blast exposure.

BODY:

Data collection and data analysis are complete for this project. Detailed data analyses are forthcoming in the final report.

A total of 96 volunteers were recruited and consented, with a final enrollment of 68 participants (see table below).

	Consented	Screened	Enrolled
Non-TBI group	29	29	26
BI-TBI group	67	67	51
Totals	96	96	68

For inclusion in the BI-TBI group, subjects met the below criteria:

- Males or females from 19-55 years of age and of all races
- Diagnosed with BI-TBI from injuries sustained in a combat zone

Exclusion criteria from either group included the following criteria:

- Brain injury resulting from a penetrating wound to the head, neck, face or brain (to include gunshot wounds)
- Presence of severe aphasia
- A patient involved in a previous military or sports event with a history of traumatic brain injury incurred outside OIF/OEF
- History of neuropsychiatric disorders antedating the head injury (e.g. hypochondriasis, major depression, schizophrenia)
- Pregnancy

- History of participation in organized boxing or “tough man” competitions
- Prior disorders of hearing and balance including:
 - Meniere’s disease
 - Chronic migraine
 - Multiple sclerosis
 - Vestibular neuritis
 - Vestibular schwannoma
 - Sudden sensorineural hearing loss
 - Cerebrovascular disorders
 - Whiplash injury
 - Systemic disorders: e.g. chronic renal failure, cirrhosis of the liver, etc.
 - Medications and drugs which depress the sensorium precluding patient compliance with the testing (considered on a case-by-case basis)
 - Previous contraindicating surgeries at the discretion of the study physicians or audiologists

Experimental Design:

The study employed a prospective, between-subjects research design comparing an experimental group (Soldiers who have been diagnosed with BI-TBI) to a control group (Soldiers who do not have clinical symptoms consistent with BI-TBI).

Study hypotheses were as follows:

The study group diagnosed with blast-induced traumatic brain injury (BI-TBI) will exhibit more auditory and vestibular abnormalities than the control group in the following ways:

- 1) Off-set rotational chair testing will yield more asymmetries, abnormal velocities and gain results. The Saccade, Smooth Pursuit, OKN, and Unilateral Centrifugation subtests will yield asymmetries in velocities and gain post blast exposure.
- 2) Tympanometry test results (a measure of the integrity of the outer and middle ear systems) will yield more flaccid eardrum mobility (Type Ad), consistent with total or partial disarticulation of the ossicular chain.
- 3) Tympanometry will yield more results consistent with perforated tympanic membranes (Type B with large external auditory canal volume).

- 4) Pure tone audiometric test results will indicate more hearing loss (conductive, sensorineural or mixed).
- 5) Subjective measures recorded on the Dizziness Handicap Inventory (DHI), Department of Veteran's Brain Injury Center (DVBIC) Questionnaire, and Blast Exposure Survey (and other medical case history information revealed during the informal intake/consent process) will capture more complaints of auditory and vestibular symptoms.
- 6) Visual deficits that rely on central processing, but not peripheral processing, will have strong correlations with executive attentional mechanisms.

Apparatus:

The Neuro-Kinetics I-Portal Neuro-Otologic Test Center (NOTC) System was used to collect the vestibular and oculomotor data. Standard FDA approved clinical audiometers and immittance units calibrated to ANSI standards were used to collect the hearing acuity and middle ear test data, respectively. Questionnaires and screening tools were utilized to collect information about volunteer participants' auditory and vestibular symptoms, blast exposure, and to further qualify the presence or absence of a BI-TBI

Dependent variables

The dependent measures collected in this study included the results of a battery of questionnaires and screening tools, audiometric and vestibular tests. A brief description of each dependent measure and a summary of statistical analysis follow.

Subjective screening measures qualified the type and severity of a patient's BI-TBI, auditory and vestibular symptoms, and blast exposure. After the volunteer was assessed by a physician and consented to participate in the study, the following questionnaires and screening tools were administered:

Questionnaires

Dizziness Handicap Inventory (DHI)

This validated questionnaire was developed clinically and is commonly used by clinicians to qualify and quantify symptoms associated with dizziness, light-headedness, vertigo, migraine associated dizziness, and to assist with identifying complaints of dizziness related to anxiety, depression, post-traumatic-stress disorder, etc. This tool captured subjective symptoms associated with BI-TBI prior to completing the objective measures.

Department of Veteran's Brain Injury Center (DVBIC) 3 Question Screening Tool

This is one of two validated screening tools for TBI recommended by the Institutes of Medicine. This measure was administered as a tool for qualifying the general symptoms associated with BI-TBI prior to completing the objective auditory and vestibular test battery.

Blast Exposure Survey

The three-question blast screening tool was developed at the U.S. Army Aeromedical Research Laboratory specifically for this protocol. This screening tool is intended to assist in qualifying, not quantifying, a research participant's blast exposure. It is a means of allowing the research team to categorize the approximate distance and type of blast to which the participant was exposed, and document the amount of time since the blast exposure. This instrument is located in Appendix C.

Auditory Test Battery

The audiometric test battery included air and bone conducted pure-tone thresholds, a test of middle-ear function (tympanometry), and otoscopy to identify any abnormalities of the ear canal or tympanic membrane (eardrum). A more detailed description of these evaluations is below.

Tympanometry

A certified audiologist measured the mobility and integrity of the eardrum and middle ear system using a Grason-Stadler GSI TympStar Middle Ear Analyzer (a device commonly used in standard clinical practice). To perform this test, a small probe (rubber eartip) was placed in the entrance of the external auditory meatus (ear canal) to completely seal the opening to the canal. A 226 Hertz (Hz) tone was introduced through this probe while a mild positive and negative pressure was applied. This test measures the flexibility of the tympanic membrane and can, for example, indicate the abnormal presence of fluid in the middle ear system consistent with an ear infection, severe cold, allergies or sinus problems.

Otoscopy

A certified audiologist performed an otoscopic examination of the outer ears. This is a standard clinical evaluation which is performed by looking in the participant's ear canals with a lighted otoscope for the purpose of verifying that the tympanic membranes are visible and appear normal, and that the ear canals are free of debris and cerumen (ear

wax). If cerumen or evidence of outer/middle ear pathology is present, the participant was referred for appropriate medical management before participation in the current study.

Air and bone-conduction audiometry

A certified audiologist administered an audiometric evaluation. Air-conduction audiometric thresholds were measured and recorded for 0.125, 0.25, 0.5, 1.0, 2.0, 3.0, 4.0, 6.0 and 8.0 kHz (routine conventional audiometric thresholds) and were obtained at higher frequencies by recording at 9.0, 10.0, 11.2, 12.5, 14.0 and 16.0 kHz using circumaural headphones. Bone-conduction thresholds were measured at .5, 1.0, 2.0 and 4.0 kHz. Threshold is defined as the "lowest hearing level at which responses occur in at least one-half of a series of ascending trials, with a minimum of two responses out of three required at a single level." Testing was performed in a sound treated booth certified to limit background noise to acceptable clinical levels as specified by the American National Standards Institute.

Vestibular Test Battery

The Neuro Kinetics, Inc. I-Portal NOTC system includes an off-set rotary chair assembly, light tight enclosure, pursuit tracker oculomotor stimulus, optokinetic stimulus, and the I-Portal 100Hz VOG Goggle. Data from these procedures were collected by personnel trained to use the I-Portal system on the following comprehensive vestibular and visual (oculomotor) subtests (that are described below according to the general anatomy and physiological target area and examiner instructions for testing):

- Spontaneous nystagmus
- Smooth Harmonic Acceleration (.01, .08, .32, .64, 1.75)
- Saccades Horizontal and Vertical
- Smooth Pursuit Horizontal (0.1, 0.2, 0.4, .71)
- Smooth Pursuit Vertical (0.1, 0.2, 0.4, .71)
- Gaze Horizontal
- Gaze Vertical
- OKN Trapezoidal (20, 40, 60)
- Step Test (60, 240)
- Visual Enhancement (.08, .16, .32, .64)
- Visual Suppression (.08, .16, .32, .64)
- Subjective Visual Vertical

- Subjective Visual Horizontal
- Off Vertical Axis Rotation (OVAR)

KEY RESEARCH ACCOMPLISHMENTS:

- There are differences between the vestibular function of Soldiers without history of BI-TBI and those with a history of BI-TBI
- The research test protocol proved to be useful in a clinical setting
- The test protocol could be tolerated by Soldiers with TBI symptoms and did not appear to exacerbate symptoms
- The Neuro-Kinetics I-Portal NOTC System instrumentation proved to be reliable and safe
- The test system's built-in scoring metrics were adequate to reveal differences between groups

REPORTABLE OUTCOMES:

No manuscripts, abstracts, or presentations have resulted from this research at this time. However, as a result of this work, normative vestibular function parameters for healthy military members have been established for the Neuro-Kinetics I-Portal Neuro-Otologic Test Center (NOTC) System.

Additionally, this work has supported development of research protocols for the Medical Research and Materiel Command's (MRMC) Military Operational Medicine Research Program (MOMRP) task area P: Return-to-Duty Standards and Strategies after Neurosensory Injury. Specifically, the work conducted under this grant was leveraged to facilitate the MOMRP-funded project titled "Development of auditory, visual, and vestibular test batteries to establish objective return-to-duty standards for concussive mTBI patients".

CONCLUSION:

This study found statistically significant and clinically important differences between service members who have suffered the effects of a blast-induced traumatic brain injury. It was also observed that there are specific subtests of the vestibular test battery that are more sensitive to the differences than others. Importantly, it was also discovered that identification of the differences can be accomplished with currently available clinical equipment. The cost of the equipment used for this study may be prohibitive for some

clinics, but further examination of the subtests that were sensitive to the identified differences may lead to the realization that the evaluation can be conducted on more affordable equipment.

Multiple manuscripts should result from this work. There are not currently established clinical normative databases for many of the vestibular testing subtests, and data from this study could form the basis for such a database. It was also observed that a certain subgroup of our test population performed in an unexpected manner that we suspect is due to experience with military training. This effect will be examined more thoroughly.