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Impact of visual disorders on vestibular and balance rehabilitation therapy outcomes in soldiers with blast injury

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Abstract

Introduction: Dizziness and Imbalance are common following blast exposure. Vestibular dysfunction and visual disorders contribute to these symptoms complaints. Vestibular and balance rehabilitation therapy (VBRT) is often recommended to alleviate symptoms of dizziness and improve functional performance; however, it is uncertain if this is the most appropriate therapeutic method for soldiers with complaints of dizziness stemming from vision problems. **Objectives:** The purpose of this retrospective review was to investigate the benefit of VBRT for soldiers with symptoms of dizziness following blast exposure with and without documented vision problems. **Materials and Methods:** We compared performance on functional measures of the vestibular and balance system including dynamic visual acuity testing (DVA), gaze stabilization testing (GST), sensory organization test of computerized dynamic posturography (SOT), and the dizziness handicap inventory pre-post VBRT in 29 soldiers with (n = 21) and without vision disorders (n = 8) who also completed additional vestibular assessment including rotational chair and subjective visual vertical examination. **Results:** Soldiers with dizziness and vision disorders showed protracted recovery following VBRT and no change in perceived dizziness handicap after participation in VBRT. **Conclusion:** Additional therapeutic considerations, including coupling VBRT with specialized vision therapy may be beneficial for resolving symptoms and improving functional outcome.

Keywords: blast injuries, rehabilitation, vestibular function tests.

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INTRODUCTION

Traumatic Brain Injury (TBI) is the signature injury of the wars in Iraq and Afghanistan. TBI is defined as a "traumatically induced structural injury and/or physiological disruption of brain function"[1]. It has been estimated that between 15%-23% of service members experience a TBI during OIF/OEF deployment ranging from mild to severe injuries[2,3]. TBI is most commonly seen and treated injury among soldiers in the OIF and OEF wars and often presents with headaches, dizziness, and fatigue as associated symptoms. A more recent report from the DoD[4], estimates that 194,561 soldiers have sustained a mild traumatic brain injury (mTBI) from the year 2000 through 2012[5].

In the military, the most common causes of mTBI from an external force are direct blunt force trauma to the head, rapid changes in acceleration or deceleration, and atmospheric pressure changes caused by bomb blasts[5]. In a deployment setting, soldiers are typically sustaining attacks from explosions or blasts by rocket-propelled grenades (RPGs) and improvised explosive devices (IEDs). A blast caused by the detonation of an IED initiates with a peak positive pressurization (shock wave) followed in time by a negative pressurization. In a typical blast, the positive pressure phase is initially faster than the speed of sound and has a brief duration. The over pressurization wave is immediately followed by a negative pressure phase that is longer in duration and slower in velocity[6,7]. Blast injuries include primary, secondary, tertiary and quaternary injuries[8].

Primary blast injuries result from the impact of the shock wave to the body's surface, often affecting the more susceptible air and fluid filled organs such as the lungs, brain and sensory structures in the middle and inner ears. Secondary blast injuries are the result of propelled fragments flying through the air; these fragments may cause penetrating injuries. Tertiary blast injury may occur when the individual is thrown from the blast into a solid object such as an adjacent wall or even a steering wheel. These types of injuries are associated with acceleration/deceleration forces and blunt force trauma to the brain similar to that observed following high speed motor vehicle accidents. Finally, quaternary blast injury can result in a severe blast related trauma brought on from significant blood loss associated with traumatic amputations or even from inhalation of toxic gases resulting from the explosion. In summary, TBI resulting from blast exposure can be much more complex compared to TBI from other causes.

Dizzinessand imbalance are common symptoms post-mTBI. Incidence of dizziness or imbalance secondary to mTBI ranges from 24%-83% and potentially up to 90%[6,9,10]. For the soldier with blast injury and mTBI, it is possible that peripheral vestibular pathology, visual impairment, central pathology, peripheral neuropathies, musculoskeletal injuries, vascular disorders, certain medications, and proprioceptive changes all contribute to dizziness. With mild head injuries, this collection of factors results in rates of dizziness that range from 15%-78% and is most often due to pathologies affecting the peripheral vestibular system, CNS, or cervical structures[11].

The presence of dizziness after injury is considered adverse prognostic indicator and may be the most persistent symptom of mTBI that unfavorably affects clinical outcome as well as disease course[6]. In one of the few long-term studies on untreated patients with mild head trauma injury, vertigo persisted in 59% of patients after five years of recovery[11]. Additionally, patients with mild TBI who have symptoms of dizziness and imbalance often experience a slower recovery and are less likely to return to work than patients without dizziness[10].

The pathophysiologic mechanism of trauma to the vestibular end organ is not fully understood. TBI is thought to affect the vestibular system via direct damage to the vestibular end organs or vestibular nerve, disruption to the brainstem pathways and/or disruption to visual motor and ocular motor pathways. All of which can occur as a result of the primary injury or secondary injury[12]. Studies have attempted to document vestibular abnormalities, after mild to moderate TBI, which have yielded inconsistent findings ranging from 32%-65%[13]. For patients with blast injuries and mTBI vestibular pathology should always be considered. Loss of peripheral vestibular information creates greater dependence on visual and proprioceptive components of the sensory system[11].

Vision problems are also among the most common TBI symptoms. Dual sensory disorders must be taken into consideration during vestibular evaluation and treatment because many related activities depend on sensory input from the visual system and may even overshadow a balance disorder. In a report by Weichel & Colyer[14], 66% of military with TBI were also found to have combat ocular trauma. Often the eye is unprotected from debris due to non-compliance with protective eye wear[15], therefore visual disorders may stem from foreign objects damaging the globe. However, other more common visual symptoms result from blast injury including convergence, accommodation and ocularmotor dysfunction[16]. Afferent and efferent visual dysfunction may result from damage to an optic nerve, extra-ocular muscle damage or cranial nerve function, and visual processing disorders from cerebral injury including hemorrhages and diffuse axonial brain injury[15]. In the study by Lew et al.[17], the rate of visual impairment at a VA polytrauma rehabilitation center was 52% compared with only 20% for all other sources of injury to the body resulting from blast exposure[17]. Examination with P300 testing documented diminished amplitudes and prolonged latencies suggesting damage to the visual cortex and or visual pathways that connect the eyes to the cortical visual centers may be affecting those afflicted with TBI[17]. Furthermore, the investigators noted that the majority of patients showed normal to near-normal corrected visual acuity and visual fields; however, 75% self-reported a vision problem, including photosensitivity (59%). Oculomotor problems were evident in 70% of patients and included convergence dysfunction (46%), pursuit and/or saccadic dysfunction (25%), accommodation dysfunction (21%), strabismus (11%), and fixation dysfunction or nystagmus (5%;[17]). The presence of these vision-related problems indicated a high prevalence in this post-combat population with TBI.

Treatment of dizziness and imbalance following TBI often includes physical therapy and medications for the acute symptoms. For a majority of functional vestibular deficits, Vestibular Balance Rehabilitation Therapy (VBRT) is often appropriate. This specialized form of physical therapy includes postural stability training, gait training, canalith repositioning therapy, and visual training that targets impaired vestibulo-ocular reflex function and gaze stability. Extensive evidence in the rehabilitation literature has documented the efficacy of specific vestibular rehabilitation in treating individuals with dizziness and imbalance complaints[18,19].

Objectives

Given the high occurrence of dizziness and imbalance symptoms complaints after blast related mTBI, this study investigated whether VBRT reduced patients' complaints and improved performance on traditional functional measures of the balance/vestibular system. Furthermore, the purpose of this study was to investigate the benefit of VBRT for individuals with history of dizziness resulting from blast exposure and visual disorders as opposed to individuals without visual disorders. We hypothesized that individuals with blast exposure related dizziness/imbalance and documented visual disorders would not show the same rate of improvement on traditional VBRT techniques as individuals without visual disorders. If the results support this hypothesis, the need for coupling additional therapy with vestibular rehabilitation may be warranted for soldiers presenting with dizziness and visual problems post blast injury.

MATERIALS AND METHODS

Participants

A retrospective review of 104 charts of active duty Army soldiers that were enrolled in a traumatic brain injury treatment center was conducted at an active duty military installation in the southern United States. The investigators retrospectively analyzed de-identified records of patients who were referred to the program from August 2010 through March 2011 and whom were later accepted into a TBI program. The inclusion criteria for the retrospective review included: (1) self-reported symptoms of dizziness after blast exposure; (2) history of blast exposure related TBI. Self-reported dizziness was verified in the primary care physician chart note or on the Dizziness Handicap Inventory (DHI) that was completed by most soldiers at entry into the program. From a total of 104 de-identified charts 43 were initially excluded based on injuries sustained other than a blast exposure and/or the denial of any self-reported dizziness. All included soldiers sustained closed head injuries as a result of an IED explosion on mounted or dismounted patrol and/or from RPG explosives. Therefore, subjects were excluded if they sustained a penetrating head injury or sustained mTBI from any other than an explosion (e.g. motor vehicle accident, blunt force trauma from object). Soldiers included in the retrospective review were referred to the TBI family practice and underwent three consecutive weeks of specialty appointments including; TBI primary care physician, optometry, occupational therapy, mental health, physical therapy and if medically indicated neurology, audiology or otolaryngology. After the completion of the intake appointments a multi-disciplinary team (Multi-D) convened to determine if a soldier would be a rehabilitation candidate and developed a treatment plan. The treatment plan was individualized to meet the needs of each soldier. These soldiers continued treatment within each specialty as indicated in the clinical treatment plan. For example, the typical length of therapy was two to three times weekly over the course of approximately eight weeks for VBRT in physical therapy. After the completion of each specialty therapy the Multi-D team determined the point at which the soldier was medically fit to return to duty and medically acceptable to be discharged from the treatment program.

Of the remaining 61 charts, 29 male soldiers engaged in VBRT. Twenty-eight of the 29 selected soldiers also received additional vestibular testing. Each service member obtained a DHI score greater than zero indicating perceived dizziness complaint that was additionally used to verify the dizziness inclusion criteria. An exempt review for retrospective data analysis was obtained through the appropriate Institutional Review Boards at Army Military Installations and a Midwestern University.

Measures

The retrospective review of de-identified data included test scores from the initial primary care questionnaire packet, optometry diagnoses, physical therapy (VBRT) pre and post scores, and vestibular/balance test results on the individuals referred for this medically indicated testing. The primary care intake questionnaire packet given at the WRRC included several neuro-psychological tests; the results of four tests were included in the retrospective review. The OQ (Outcome Questionnaire) measured a wide variety of symptoms of distress, difficulties in interpersonal relationships, social roles, and general quality of life[20]. The 45-item questionnaire has a score range of 0 to 180 with subscales of symptom distress, interpersonal relations and social role. A total score cut-off of 63 or more indicates symptoms of clinical significance.

The post-traumatic stress disorder (PTSD) checklist-military version (PCL-M) is a 17-item measure that is widely used in the DoD and the Department of Veterans Affairs and has excellent reliability and validity. The items on the PCL-M correspond to the Diagnostic and Statistical Manual Fourth Edition (DSM-IV) diagnostic criteria for PTSD. The PCL-M scale ranges from 1 (not at all) to 5 (extremely); scores higher than 50 are considered clinically significant. In the context of screening soldiers post-combat, the PCL performs well using a cutoff value of 30 to 34 as an indication of PTSD symptoms[21]. Scores were classified as within normal limits if less than 10; mild from 11-35; and moderate to severe for scores of 36-68.

Patient Health Questionnaire nine items (PHQ-9) is a self-reported depression scale. It is a measure of severity of depression. The PHQ-9 is based directly on the diagnostic criteria for major depressive disorders in the DSM-IV and is widely used for psychometric purposes. The PHQ-9 score ≥ 10 had a sensitivity of 88% and a specificity of 88% for major depression. PHQ-9 scores of 0-4 represents no depression, 5-9 minimal symptoms, 10-14 mild depression or dysthymia, 5-19 represents moderately severe depression and greater than 20 represents severe depression[22].

DHI (Dizziness Handicap Inventory) developed by Jacobson & Newman[23] is a measure of the self-perceived level of handicap associated with the symptom of dizziness [23]. The DHI is a 25 items scale with scores ranging from 0-100. A score greater than 10 is considered clinically significant and scores ranging from 0-30 indicates mild, 31-60 moderate, and 61-100 severe handicap. This measure has been correlated with the results of posturography tests and is considered valid and reliable.

The 29-selected soldiers were referred to Optometry for a full vision evaluation. The optometrist evaluated visual acuity through use of the Snellen chart, observed ocular structure and overall health, and assessed extra ocular movements. At that time the optometrist entered a diagnosis and offered prescriptions for infections or updated spectacles for visual acuity.

A VBRT certified physical therapist evaluated soldiers during their initial intake assessments at the WRRC and post-VBRT therapy. A medical record review was completed with each soldier prior to initiating care. The review was related to their military status and medical case history. The case history included chief complaints, description of vestibular symptoms (i.e. onset of dizziness or imbalance) and the administration of the DHI. Central and peripheral vestibular function was also assessed with head thrust, head shake, and Dix-Hall pike testing. An objective examination of functional use of the vestibular/balance system via NeuroCom® International FDA approved Computerized Dynamic Posturography and InVision Software was obtained soldier pre- and post -VBRT. Participant scores obtained on the Dynamic Visual Acuity testing (DVA), Gaze Stabilization Test (GST) and Computerized Dynamic Posturography, Sensory Organization test (SOT) were included in the data analysis.

The Dynamic Visual Acuity (DVA) test quantified the extent of visual acuity loss due to the combined influences of underlying vestibular pathology and adaptive responses on image stabilization (e.g. catch-up saccades). Participants sat in a well-lit room, 10 feet from a computer screen. Static visual acuity (SVA) was first measured and expressed in LogMAR units (a unit describing the apparent size of an optotype based on the ratio of its absolute size to distance from the eye[24]. With the head still, SVA will be determined by asking the participant to identify the orientation (right, left, up or down) of the optotype E. If identified correctly, the E was reduced until the participant successfully identifies the correct E orientation for three of five successive trials, based on the Parameter Estimation by Sequential Testing (PEST) algorithm. Next, the participant were asked to complete the perception time test (PTT) by keeping his head still and correctly identifying the orientation of the E flashing on the computer screen, set at a fixed 0.2 logMAR size above the established SVA baseline. PTT identified the minimum target presentation time (in milliseconds) to be used during DVA and GST testing. PTT scores < 60 msec are considered within normal limits. A head-mounted rate sensor (InertiaCube2 Precision Motion Tracker) was placed on the participant's head to determine the orientation and continuously monitor velocity. The participant's head was passively moved in the yaw plane following the protocol described by Herdman et al.[25]. After achieving the desired velocity, the optotype E was flashed on the computer screen based on PTT score. The patient was asked to identify the orientation of the E. The size of the E decrease based on correct responses; threshold was established based on PEST algorithm.

In contrast to the DVA that examined changes in visual acuity with fixed velocity head movements, the

GST identified the maximum head velocity (in degrees per second) while maintaining clear visual fixation on optotype 'E' presented at a fixed optotype size (0.2 LogMAR above static visual acuity score[26];. Patients slowly moved their head in the yaw plane until a trigger velocity was reached. Once the trigger velocity was reached, the optotype would appear and the patient was asked to again identify the orientation of the E. The trigger velocity speed would increase until the patient reported an incorrect orientation of the optotype; the PEST algorithm was again used to determine threshold velocities for yaw plane movements. Threshold response identified the maximum head velocities to maintain visual acuity. If a patient has a vestibular system deficit, the maximum movement velocities over which the VOR system provides effective compensation would decrease. The extent of visual acuity loss is predicted by comparison of the GST velocities to those encountered during daily life activities in question (e.g. driving @ 30 mph 84 deg/sec, competitive sports/high performance avocations 120 deg/sec;[24]).

The Sensory Organization Test of Computerized Dynamic Posturography (SOT) quantifies biomechanical changes to postural control through evaluation of a person's ability to use sensory system input to maintain upright (quiet) stance during increasingly challenging conditions. The SOT is FDA-approved and used routinely for clinical assessment. Participants will be asked to step onto a platform machine and stand on a square forceplate, while securely harnessed to the sides of the platform to protect from falling. The SOT test has six increasingly challenging conditions designed to determine the extent to which the patient is able to maintain quiet stance during the condition. The patients completed three trials of each condition, as outlined by Nashner[27]. Composite equilibrium scores on a scale of 0 (excessive sway) to 100 (no body sway) were obtained.

Lastly, some of the soldiers were referred for further vestibular evaluation, and were assessed by a board certified Audiologist. The audiologist determined if the soldier was a candidate for videonystagmography (VNG) and caloric testing, or rotary chair testing based on present complaints and functional status. Rotary chair testing included the following (1) sinusoidal harmonic acceleration (0.01, 0.32, and 0.64) and (2) Static (on-axis) and Dynamic (off-axis) Subjective Visual Vertical (SVV) examination. Abnormal vestibular test findings were defined as: (1) presence of spontaneous/positional nystagmus with slow component velocity > 5 deg/s; (2) a unilateral weakness greater than 25% on bithermal caloric irrigation testing based on Jongkees' formula[28]; (3) phase, gain or asymmetry values outside the normal threshold values at 0.01, 0.32 and 0.64 Hz as defined by laboratory normative values with Neurokinetics rotational chair; (4) off-axis SVV angle or on-axis SVV angle greater than 4.5 degrees based on laboratory normative values.

RESULTS

Mean, standard deviations, and range of questionnaire results and assessment measure scores were calculated. Soldier data was grouped by those with dizziness resulting from the blast exposure, with and without visual disorders. Independent *t*-tests were performed to compare differences in Neuropsychological Intake Assessment scores and health characteristics between the two groups. A Holmes step-down procedure was performed in order control for multiplicity. Pearson Correlation Coefficients were computed to assess relationships between average Neuropsychological Intake Assessment scores and GST, DVA, SOT and DHI average scores. Preliminary analysis was performed to ensure no violation of the assumptions of normality, linearity and homoscedasticity. A multivariate approach to repeated-measures ANOVA with custom contrast for the fixed effects was performed to evaluate performance pre-and-post VBRT. The independent variables were time, vision problem and their interaction. The dependent variables used were GST, DVA, SOT and DHI mean scores. Significant level was set to 0.05 for all measures. All analyses were performed using SPSS (Version 20, Chicago IL.) and SAS, version 9.2 (North Carolina).

Soldiers included in the final data analysis (n = 29) ranged in age from 23-43 years (Mean = 28.69 years, *SD* = 6.81). Of the 29 selected soldiers, 21 (72%) had abnormal optometric evaluations. The most common noted diagnosis were convergence 62% (n = 13), saccadic 43% (n = 9), and accommodative 38% (n = 8) insufficiency. Soldier demographics, health status characteristics and summary of Neuropsychological Intake Assessment of mTBI results for those with vision disorders (n = 21) and those without vision disorders (n = 8) are summarized in Table 1. No significant differences were observed between the two groups based on demographic and health status characteristics. There was a positive correlation between the two variables of PCL-M and PHQ9, r = .811, $P = <.01$ for both groups suggesting that depression as reported on the PHQ9 was positively associated with Post-traumatic symptoms on the PCL-M for both groups (see Figure 1). In addition, significant positive correlations were noted for scores on the PHQ9 and Pre-VBRT DHI (r = .455, $P = 0.13$), and PCLM and Pre-VBRT DHI (r = .519, $P = 0.004$) for both groups (see Figures 2 and 3); no additional significant correlations were found.

Twenty-eight soldiers received additional vestibular function assessment. Of those soldiers, three were selected for VNG caloric irrigation testing. Two soldiers presented with clinically significant caloric unilateral

Table 1. Demographics, health status characteristics and summary of neuropsychological intake assessment of soldiers with dizziness resulting from blast injury, with vision disorders and without vision disorders.

	Vision Disorder (n = 21)	No Vision Disorder (n = 8)
Age		
Mean	29.23	27.25
SD	5.87	9.16
Range	20-40	21-43
No. of co-morbid conditions		
Mean	8.85	11.13
SD	3.24	3.48
Range	5-16	7-16
No. of medications		
Mean	6.81	6.12
SD	3.30	3.83
Range	1-15	2-13
OQ (0-180 points)		
Mean	61.29	65.63
SD	38.62	20.53
Range	10-155	42-104
PCL-M (0-68 points)		
Mean	31.05	36.25
SD	18.82	11.57
Range	0-64	21-57
PHQ-9 (0-27 points)		
Mean	9.95	13.25
SD	7.00	4.92
Range	0-24	8-23
DHI (0-100 points)		
Mean	35.00	38.00
SD	26.13	12.54
Range	0-90	22-48

Co-morbidities included: PTSD, hearing loss, tinnitus, fatigue, depression, anxiety, back pain, headaches, and migraines. No significant differences were noted between groups based on demographic or health status characteristics. SD: Standard Deviation; OQ: Outcome Questionnaire; PCL-M: PTSD checklist-military; PHQ: Post-deployment Health Questionnaire, DHI: Dizziness Handicap Inventory.

weakness values (30% and 31%); both soldiers also were diagnosed with visual disorders. No clinically significant spontaneous or positional nystagmus was observed for the two groups. Soldiers with and without vision disorders participated in rotational chair assessment; however, no significant differences were observed between rotational chair gain, phase and asymmetry values. In addition, mean gain, phase and asymmetry scores were within the normal range for both groups (see Table 2). There was also no significance differences noted on SVV testing between the two groups; however, those with vision disorders displayed SVV off axis to the right mean values outside the normal range (see Table 2).

A summary of pre-post VBRT test results are provided in Table 3. The results of the repeated-measures ANOVAs with custom contrast for fixed

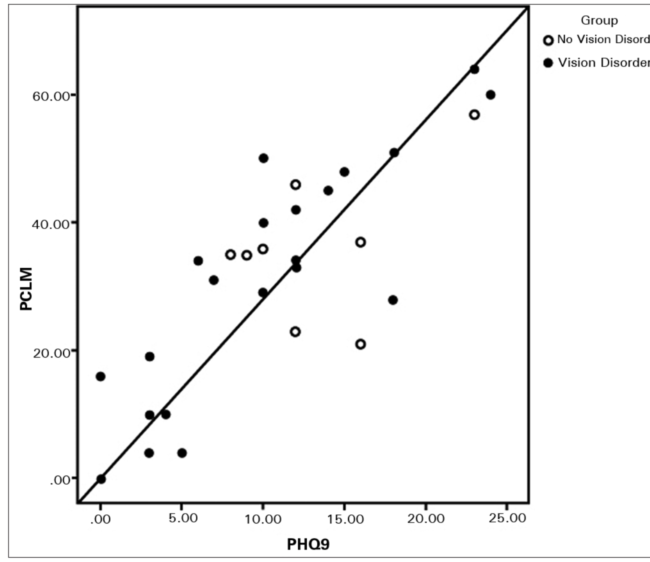

Figure 1. A correlation scatter plot of each soldier with history of dizziness resulting from blast exposure for PCL-M score and PHQ9 score. Filled circles represent soldiers with vision disorders; open circles represent soldiers without vision disorders. Linear line of best fit shows significant positive correlation.

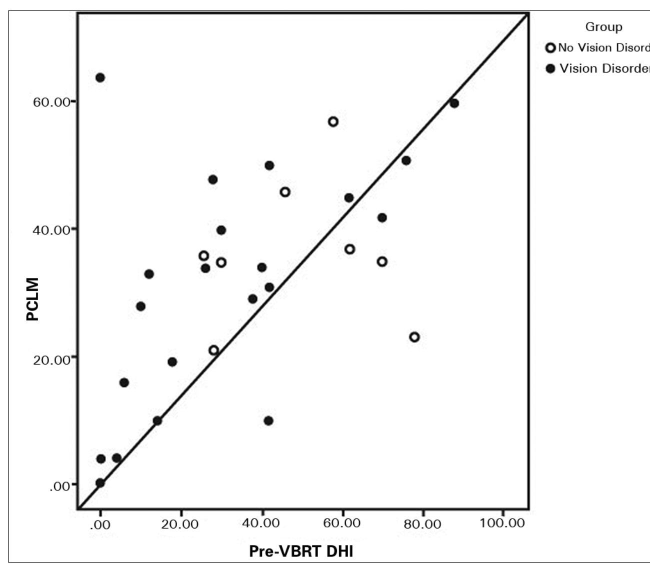

Figure 2. A correlation scatter plot of each soldier with history of dizziness resulting from blast exposure for PHQ9 score and Pre-VBRT DHI score. Filled circles represent soldiers with vision disorders; open circles represent soldiers without vision disorders. Linear line of best fit shows significant positive correlation.

effects for group differences (those with and without visual disorders post-blast exposure) on the VBRT pre-and-post measures were performed. Based on this model, significant effects were found for GST. The time by group effect was significant for GST ($F(1,19.5) = 5.78$, $P = 0.0262$) suggesting that there was a significant difference in scores between groups after participation in VBRT; however no additional group effects were found

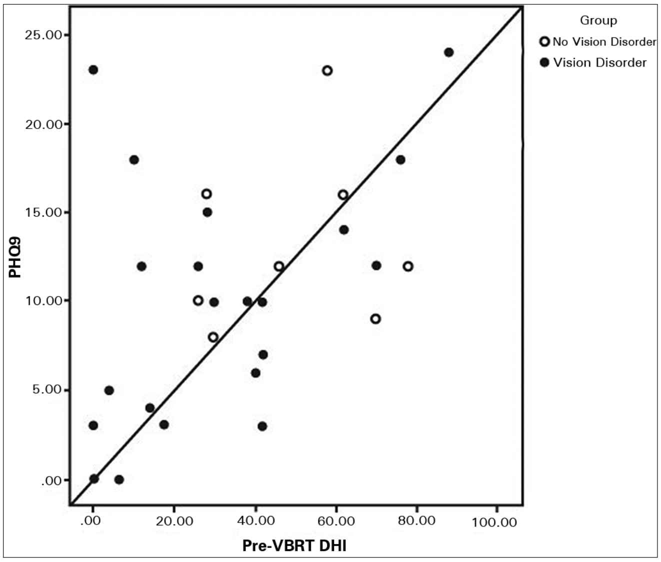

Figure 3. A correlation scatter plot of each soldier with history of dizziness resulting from blast exposure for PCLM score and Pre-VBRT DHI score. Filled circles represent soldiers with vision disorders; open circles represent soldiers without vision disorders. Linear line of best fit shows significant positive correlation.

Table 2. Rotational chair and subjective visual vertical test results.

Test	Group	(n)	Mean	SD
Rotational Chair				
Gain 0.01	VD NVD	20 8	0.3722 0.3310	0.0923 0.0607
Gain 0.32	VD NVD	20 8	0.5630 0.4450	0.2089 0.2106
Gain 0.64	VD NVD	20 8	0.6348 0.6093	0.1727 0.0960
Phase 0.01	VD NVD	20 8	39.5357 41.8189	9.9499 5.001
Phase 0.32	VD NVD	19 7	3.3923 4.7240	3.2321 7.8437
Phase 0.64	VD NVD	20 8	2.9939 3.5757	3.9505 2.2927
Asymmetry 0.01	VD NVD	20 8	2.0190 6.4380	8.8441 8.4893
Asymmetry 0.32	VD NVD	19 7	1.3702 0.4501	8.4552 7.1200
Asymmetry 0.64	VD NVD	20 8	0.4503 1.7337	10.5095 6.3108
SVV				
SVV Static	VD NVD	18 7	0.5278 1.7371	5.7018 3.8891
SVV off-axis Right	VD NVD	19 7	-4.6547 3.800	22.0426 38.3626
SVV off-axis Left	VD NVD	18 7	-1.4756 1.9971	1.6761 1.7940

VD: Vision Disorder Group; NVD: No Vision Disorder Group; SD: Standard Deviation; SVV: Subjective visual vertical. Mean SVV off-axis right value for vision disorder group was considered outside the normative range.

for DVA, SOT or DHI scores pre-post VBRT (see Table 4). Based on GST scores, soldiers without vision disorders improved significantly pre-post VBRT ($t(29) = 2.89$; $P = 0.0101$); however soldiers' with vision problems did not improve significantly pre-post VBRT ($t(29) = -0.08$; $P = 0.9389$). In fact, GST performance slightly declined after VBRT (see Figure 4). Both groups improved on DVA and SOT post-VBRT; however, those with vision disorders did not indicate a change in perceived handicap after participant in VBRT, while those without vision disorders showed improvement on DHI score, but this was not considered statistically significant ($t(29) = -1.61$; $P = 0.1197$) (See Figure 4).

Table 3. Summary of test results (means and standard deviations (SD) pre-post vbrt.

		Vision Disorder (n = 21)	No Vision Disorder (n = 8)
GST (deg/s) Pre-VBRT GST (deg/s) Post-VBRT	Mean (SD) Mean (SD)	144.11 (22.14) 143.50 (25.40)	139.5 (27.82) 176.91 (10.92)
DVA Score (LogMAR) Pre-VBRT DVA Score (LogMAR) Post-VBRT	Mean (SD) Mean (SD)	0.27 (0.18) 0.16 (0.08)	0.26 (0.16) 0.11 (0.06)
SOT Score (%) Pre-VBRT SOT Score (%) Post-VBRT	Mean (SD) Mean (SD)	70.38 (12.58) 78.57 (12.67)	67.25 (13.56) 76.29 (10.73)
DHI Score (%) Pre-VBRT DHI Score (%) Post-VBRT	Mean (SD) Mean (SD)	30.86 (26.25) 29.17 (24.16)	49.75 (20.24) 38.50 (26.72)

GST: Gaze Stabilization test; DVA: Dynamic Visual Acuity test; SOT: Sensory Organization test; DHI: Dizziness Handicap Inventory.

Table 4. Repeated-measures ANOVA with custom contrast for the fixed effects.

Effect	*df*	F	*P*-value
DHI Time x Group	1, 23.9	0.90	0.3516
DVA Time x Group	1, 3.59	0.10	0.7675
GST Time x Group	1, 19.5	5.78	0.0262
SOT Time x Group	1, 19.4	0.01	0.9326

DISCUSSION/CONCLUSION

The potential mechanisms involved in blast injury are still being explored; however, vestibular dysfunction and visual changes rank among the most common symptoms following blast exposure[29]. The ambient

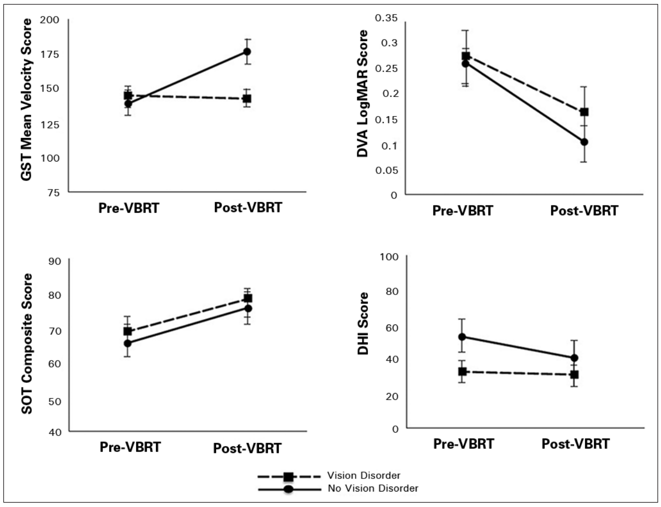

Figure 4. Panels on the left: Increase in Gaze stabilization test (GST) and Sensory Organization test (SOT) scores represent better performance over time between patients with and without vision disorders. Error bars represent standard errors. Panels on the right: Decrease in Dynamic Visual Acuity (DVA) and Dizziness Handicap Inventory (DHI) scores represent improved performance over time between patients with and without vision disorders. Error bars represent standard errors.

vision system is necessary for performing activities of daily living including gaze stability and quiet stance[30]. The vestibular system, including the central vestibular mechanisms (e.g., ocularmotor system) also has control for quiet stance and stable gaze while the head is in motion. Therefore, blast injury can result in impaired visual or vestibular system dysfunction leading to symptom complaints of dizziness, imbalance or spatial disorientation.

The purpose of this study was to investigate the benefit of VBRT for soldiers with symptoms of dizziness following blast exposure with and without documented vision problems. Specifically, this study was proposed to determine if soldier with vision disorders improved at the same rate as those without vision disorders. The results indicated that soldiers with vision disorders did not improve at the same rate as those without vision disorders. Interestingly, mean DHI scores remained the same for those with vision disorders as compared to those without vision disorders; however, those without vision disorders still had higher perceived handicap after participation in VBRT. Given that the mechanisms involved in blast exposure are not fully understood, it is plausible that the individuals without vision disorders had additional central disorders hindering improvement with standard VBRT. Additionally, normal vestibular function was observed via rotational chair testing for both groups. Therefore, dizziness resulting from blast exposure may be due to associated brain injury rather than peripheral vestibular system dysfunction[31]. It may not be specific to a true vestibular disorder[32]. Nevertheless, subjective visual vertical findings were outside of the normative range for individuals with vision disorders. This finding may be attributed to damage to the peripheral or central vestibular system including the brainstem, cortex and cerebellum[15]; therefore, further prospective examination of SVV findings is warranted.

VBRT has been found to be effective in individuals with central disorders. Functional as well as subjective symptoms improve post-rehabilitation[33]; however, the rate of improvement is dependent upon the type of disorder and the severity of the disorder at the pre-therapy baseline session[33,34]. Hoffer et al.[34] noted that military soldiers presenting with dizziness described as spatial disorientation demonstrated prolonged recovery rates ($P < 0.01$) as compared to groups with benign positional vertigo, posttraumatic migraine-associated dizziness or posttraumatic exercise-induced dizziness - therefore the type of posttraumic dizziness guides patient outcomes. Those with posttraumatic spatial disorientation present the greatest challenge for rehabilitation.

Brown et al.[33] reported on functional improvement on walking tasks and reported disability as indicated on the DHI of individuals categorized with central vestibular disorders. Mean improvements were noted in all central disorder groups (cerebellar dysfunction, stroke, central vestibulopathy, mixed central & peripheral vestibulopathy and post-trauma); however, those with cerebellar dysfunction showed the least improvement on the functional disability measures. Interestingly, post-trauma group only demonstrated significant improvement on the DHI. The central vestibulopathology and mixed central and peripheral groups showed the greatest rates of improvement post-VBRT. Of note, all patients continued to report symptoms of dizziness and perceived handicap after VBRT. This further supports that while those with central disorders (including visual disorders) do improve with VBRT, they do not improve at the same rate as those with peripheral vestibular dysfunction. The results reported herein also support that individuals with central disorders as indicated by visual dysfunction did not improve same rate as those without vision disorders. Interestingly, mean DHI scores remained the same for those with vision disorders as compared to those without vision disorders after VBRT; however, those without vision disorders still had higher perceived handicap after participation in VBRT. Again, it is possible that the individuals without vision disorders had additional central disorders hindering improvement with standard VBRT, or that additional time in rehabilitation was needed. When we grouped patients according to vision disorders, significant differences were noted in functional balance performance and perceived handicap after VBRT; however, if we grouped the participants according to different diagnostic categories the outcomes may have been different. To our knowledge, this is the first report exploring the VBRT outcomes in blast exposed soldiers with history of dizziness, when categorized by the presence of vision disorders. Therefore, the effect of VBRT should be further explored prospectively in blast exposed soldiers and in a larger sample to determine the clinical relevance of our findings.

DVA and SOT of computerized dynamic posturography are common functional outcome measures in blast rehabilitation programs[32]. Gottshall et al.[35] found that DVA scores improved within 4 weeks post VBRT in individuals with vestibular deficits, whereas GST scores did not show significant improvements until 12 weeks after initial therapy. Our results indicated that standard VBRT was ineffective for improving GST results for those soldiers with vision disorders; in fact a slight decrease in performance was noted after VBRT. There has been some speculation in the recent literature that while DVA and GST are moderately correlated with one another, the tests may be measuring different mechanisms[36]. It is difficult to understand based on this retrospective review if the difficulties with GST performance was truly due to VOR dysfunction or central mechanisms. It is possible that soldiers with dizziness and vision problems also had substantial difficulty with cervical range of motion, leading to the unchanged head velocity after VBRT. This is the aim of future work to explore differences in DVA and GST performance after head injury.

It was also evident from this current study that soldiers with a complaint of dizziness secondary to mTBI had an increased likelihood of co-morbid conditions such as PTSD, depression and anxiety which is consistent with reports in other studies[6,37,38]. The common use of subjective measurements (e.g. self-reported questionnaires) to investigate the relationship between mTBI and/or blast exposure and the presence of vestibular disorders may be mediated by symptoms of PTSD, and anxiety/depression as suggested by Hoge et al.[37]. It seems likely that subjective measures of dizziness are more influenced by PTSD, anxiety, and depression than objective measures of vestibular function due to the greater impact of these psychological stress symptoms over physical function[37,39].

In summary, soldiers with dizziness and vision problems may not benefit from VBRT at that same rate as soldiers without vision problems. Therefore, additional time in therapy is suggested. The use of vision therapy may also play an important role in the rehabilitation of the mTBI patients, specifically for those that have dual sensory disorders. Vision therapy is a clinical approach to treat a variety of visual disorders including convergence and divergence insufficiency, saccadic disorders, and accommodative dysfunction. Exercises designed to enhance the visual system and adaptive processes are incorporated into the visual therapy program[40,41]. In a study by Hudac et al.[42], it was found that adjusting visual processing with corrective prisms impacted neural processing. This intervention appeared to facilitate the appropriate integration of information between the visual pathways and improved processing across proprioceptive, kinesthetic, vestibular, cognitive, and language domains[42]. Additional work with visuospatial training[41] show some promise for improving visual performance post-TBI. Continued support of vision rehabilitation efforts is necessary to address best-practice care for blast-injured military. A multi-disciplinary approach for evaluation and remediation of these patients is necessary to review and modify individual treatment goals as traditional rehabilitation methods may be not sufficient for reducing symptoms complaints and improving functional performance.

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