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Visual Dysfunctions and Symptoms During the Subacute Stage of Blast-Induced Mild Traumatic Brain Injury

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ABSTRACT The purpose of the present study was to assess the occurrence of visual dysfunctions and associated symptoms in active duty warfighters during the subacute stage of blast-induced mild traumatic brain injury (mTBI). A comprehensive visual and oculomotor function evaluation was performed on 40 U.S. military personnel, 20 with blast-induced mTBI and 20 without. In addition, a comprehensive symptom questionnaire was used to assess the frequency of visual, vestibular, and neuropsychiatric-associated symptoms. The most common mTBI-induced visual dysfunctions were associated with near oculomotor deficits, particularly large exophoria, decreased fusion ranges, receded near point of convergence, defective pursuit and saccadic eye movements, decreased amplitude of accommodation, and monocular accommodative facility. These were associated with reduced reading speed and comprehension and an increased Convergence Insufficiency Symptom Survey score. Photosensitivity was a common visual dysfunction along with hearing, balance, and neuropsychiatric symptoms. The oculomotor testing for warfighters suspected of blast-induced mTBI should include, at a minimum, the assessment of near lateral and vertical phorias, positive fusional vergence, stereoacuity, near point of convergence, amplitude of accommodation, monocular accommodative facility, saccades, and pursuit eye movements. A reading test should be included in all routine exams as a functional assessment of the integration of oculomotor functions.

INTRODUCTION

Traumatic brain injury (TBI) is the most prevalent injury among warfighters during Operation Enduring Freedom (OEF), Operation Iraqi Freedom (OIF), and Operation New Dawn (OND). The Defense Centers of Excellence for Psychological Health & Traumatic Brain Injury reported the prevalence of TBI in the U.S. military to be 202,281 between 2000 and 2010 for OEF, OIF, and OND combined, with the majority classified as mild TBI (mTBI).[1] Several studies have revealed that most TBI cases are associated with a blast event. For example, a survey of 225 veterans found that of the mTBI patients ($n = 134$), blast accounted for 67%, motor vehicle accident for 25%, and 7% were caused by other mechanisms.[2] Similar prevalence of blast-induced TBI was previously reported by Hoge et al.[3] These data clearly show that explosive devices have become the primary mechanism of injury on the modern battlefield and that warfighters are particularly at risk of TBI resulting from combat blast exposure.[3,4] Explosive devices are likely to remain a serious challenge for the military in the future.

Since the beginning of the war, the prevalence of blast-induced ocular injury caused by fragments or blunt trauma and requiring evacuation from theater has decreased, mainly because of the increased use of military combat eye protection.[5,6] Although the use of military-issue combat eye protection decreases the prevalence of ballistic ocular trauma, a new constellation of occult eye injury and visual deficits can be expected in warfighters who have suffered blast-induced mTBI but have no obvious physical injuries.[5,7] Since many cases of mTBI have a subtle presentation, the associated visual problems may go undiagnosed, leading to continued degraded visual abilities. Visual problems can be crucial for military personnel in combat since their lives and safety depend on accurate and rapid situational awareness and perception of the environment. Furthermore, premature return to combat duty after mTBI places warfighters at greater risk of disability if they receive additional concussive trauma.[8]

In light of the extent to which vision depends upon the integrity of the brain and the many ways in which blast can disrupt brain function, blast trauma should be expected to disrupt vision even in the absence of obvious ocular trauma. Table I summarizes the prevalence of overall TBI-associated ocular and visual deficits in OIF and OEF veterans reported in the literature. The first study describing the prevalence of visual dysfunctions in OEF and OIF veterans was conducted by Goodrich et al[9] at the Palo Alto Veterans Affairs (VA) Polytrauma Rehabilitation Center (PRC). They found 74% of the subjects self-reported visual complaints and 38% had a visual impairment. Even though they grouped subjects with visual dysfunctions by the mechanism of injury (blast versus nonblast), the exact proportion of mTBI patients was not identified. Since the population of this retrospective study included polytrauma patients, it is likely that most subjects experienced either moderate or severe TBI.

A follow-on retrospective study by Brahm et al described the prevalence of visual impairment and dysfunctions of

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TABLE I. Summary of TBI-Associated Visual and Ocular Dysfunctions in OIF/OEF Veterans Reported in the Literature

	Study:	Goodrich (2007)		Brahm (2009)				Stelmack (2009)	
	Trauma Care Level:	PRC TBI[a,b]		PRC Moderate/Severe TBI[b]		PNS mTBI[c]		*Polytrauma/TBI*	*TBI*
	Injury Mechanism:	Non-Blast[d]	Blast[e]	Non-Blast	Blast	Non-Blast	Blast	Mixed	Mixed
	Sample Size:	*n* = 25	*n* = 25	*n* = 11	*n* = 57	*n* = 12	*n* = 112	*n* = 103	*n* = 88
Visual Dysfunction	Accommodation	24	20	25	42	71	46	30	47
	Convergence	34	36	44	42	64	47	13	28
	Pursuit/Saccades	5	32	11	33	17	24	9	6
	Fixation/Nystagmus	0	4	11	9	0	7	6	0
	Diplopia	0	12	NR	NR	NR	NR	15	8
	Suppression	14	16	NR	NR	NR	NR	0	0
	Neglect	10	8	NR	NR	NR	NR	NR	NR
	Visual Spatial	29	32	NR	NR	NR	NR	NR	NR
	Reading	62	60	78	63	83	88	60	50
	Ocular Injury	16	36	9	44	17	7	21	6
	Strabismus	NR	NR	27	25	8	7	4	8
	Visual Complaints	78		78	64	75	76	76	75
	Vision Loss	52		33	20	0	2	4	3
	Visual Field	24				3		23	14

PNS, Polytrauma Network Site; NR, Not reported. Note: [a]41% were noncombat related. [b]Inpatient care. [c]Outpatient care. [d]16% produced penetrating head injury. [e]44% produced penetrating head injury.

192 combat-injured veterans with TBI. Although this study separates the prevalence by mechanism of injury (blast versus nonblast) and TBI severity (mild versus moderate/severe), there is no indication of the stage (i.e., acute, subacute, or chronic) following the injury during which the vision problems were present. Based on the studied veteran population, it is likely that the diagnoses were during the chronic stage following the injury.

The most recent retrospective study was conducted in 2009 by Stelmack et al who describe visual deficits noted in the medical records of 194 patients with polytrauma and/or TBI who were examined at the Illinois VA Polytrauma Network Site. This study also showed a high prevalence of accommodation, vergence, and version eye movement problems, but did not specify the TBI severity between the groups.[10]

The abovementioned studies show different estimates of the prevalence of vision problems in veterans with TBI from current combat operations. These retrospective record reviews are hard to compare because they used differing methodologies for the assessment of visual functions, did not consistently separate the prevalence of visual dysfunctions by the severity of TBI (i.e., mild, moderate, or severe), level of trauma care (single sensory, dual sensory or polytrauma), or mechanism of injury (blast versus nonblast). More importantly, these studies describe visual dysfunctions in veterans receiving polytrauma care in the VA Healthcare System so that their relevance to the active duty warfighter population is limited. Injured warriors are usually transferred to the VA Healthcare System after being medically discharged from the military, which is months or years after the injury (i.e., chronic stage).[5]

The neurosensory sequelae of mTBI are expected to change as the brain goes through its natural healing process.[11,12] It is important to identify those visual dysfunctions that occur during the acute and subacute phase of the blast-induced mTBI since they may provide potential markers to expedite the diagnosis and proper management of warfighters with suspected mTBI in the battlefield. It is also important to recognize that during the chronic stage after the injury there are several possible confounders to consider when interpreting the type and frequency of visual deficits. For instance, any interpretation must take into account the natural recovery from the brain injury and the chronic effect of other comorbid injuries (e.g., vestibular) on the visual system. Moreover, studies describing the prevalence of visual dysfunctions during the chronic stage can be influenced by ocular side effects of medications prescribed for the management of comorbid neuropsychiatric symptoms such as depression and anxiety, as well as post-traumatic stress disorder (PTSD) and sleep disorders.[11,13,14] It should be emphasized that the prevalence estimates reported in the literature are based on samples of veterans and civilians; the literature reporting the prevalence of such mTBI-associated visual complaints in active duty military is virtually nonexistent. The aim of the present study was to assess the occurrence of visual dysfunctions and associated symptoms on active duty warfighters during the subacute stage following blast-induced mTBI.

METHODS

Participants

Two groups of U.S. military personnel participated in this study designed to determine the prevalence of visual dysfunctions and symptoms present during the subacute stage (i.e., between 15 and 45 days) following blast-induced mTBI.[12] For this study, "blast-induced mTBI" included mTBI caused by improvised explosive devices (IEDs), rocket propelled grenades and mortars. One group consisted of 20 ambulatory subjects recruited from the TBI clinic who had suffered blast-induced mTBI within the previous 45 days. These individuals were receiving medical care at Walter Reed Army Medical Center in Washington, DC. The other group of 20, the control group, who had deployed, but had no history of TBI, head concussion, or blast exposure and were recruited and evaluated at the U.S. Army Aeromedical Research Laboratory located at Fort Rucker, AL. Subjects were age-matched with ages ranging from 20 to 43 years (mean ± standard deviation [SD], 31.2 ± 7.36). The study approvals were obtained from the Walter Reed Army Medical Center Department of Clinical Investigation and the U.S. Army Medical Research and Materiel Command Institutional Review Board, respectively. All volunteers freely gave informed consent to participate in the study while receiving no compensation, monetary or otherwise, for their participation in the study.

Comprehensive Symptoms Questionnaire

All subjects underwent a comprehensive ophthalmic and oculomotor examination. Before initiating the examination, a comprehensive ocular and systemic history was obtained using a paper-and-pencil questionnaire. This questionnaire captured demographic information regarding subjects' military and combat experience, blast exposure, post-deployment problems regarding ocular, visual, reading, hearing, and balance as well as behavioral, psychological, and neurological problems. An electronic medical record review was also conducted to confirm comorbid problems reported by the subjects and to rule out pre-existing visual problems.

Visual and Ocular Health Assessment

The comprehensive eye examination and the oculomotor assessment were conducted by one of two optometrists (co-authors J.E.C. and T.G.U) using standard clinical procedures to determine manifest refraction error, distance high contrast best corrected visual acuity measured with a Snellen projector chart, color vision function measured with Dvorine pseudoisochromatic plates, confrontation visual fields, ocular health status evaluated using ophthalmoscopy and biomicroscopy, pupil responses assessed with the swinging flash-light test, and intraocular pressure.[15] The prescription determined by manifest refraction was used during the oculomotor examination.

Oculomotor Assessment

The oculomotor examination included stereopsis using the Randot stereotest, near point of convergence (NPC), ocular alignment at distance and near determined by cover test, near and distance phoria (lateral and vertical), and gradient accommodative convergence/accommodation (AC/A) ratio using the von Graefe technique, maximum near negative (i.e., base in [BI]) and positive (i.e., base out [BO]) fusional vergence with its associated recovery measured with the von Graefe technique, motor fusion with Worth 4 Dot test, fixation disparity tested with the Borish near point card, amplitude of accommodation (AoA) measured by phorometry using the minus lens to blur method, monocular accommodative facility measured with +2.00/−2.00 D lenses flippers, saccadic, and smooth pursuit eye movements assessed by the Northeastern State University College of Optometry Oculomotor Test.[15–17]

Reading Fluency Assessment

The computerized Reading Level Test from the ADR iNet Dynamic Reader was used to assess reading fluency (i.e., speed and comprehension). All subjects were tested with materials designed to assess a seventh-grade reading level. The test consisted of the subject reading a short story displayed in 12-point font on the computer screen positioned at 16 inches from the subject. After reading the story, the subject answered 10 questions about the story content to determine reading comprehension. The outcome measure was a pass or fail score based on the number of words per minute (wpm) read by the subject and the score of the reading comprehension test (0 to 100). The expected reading speed and reading comprehension score at the seventh-grade reading level are ≥197 wpm and ≥80%, respectively.

Convergence Insufficiency Symptoms Survey

At the end of the examination, all subjects completed the 15-question Convergence Insufficiency Symptoms Survey (CISS). The CISS was validated and standardized for randomized clinical trials (i.e., Convergence Insufficiency Treatment Trial Study Group) to subjectively measure the recovery of

TABLE II. Demographics and Injury Characteristics

Characteristics	mTBI, No. (%)	Non-TBI, No. (%)
Gender		
Male	18 (90)	14 (70)
Female	2 (10)	6 (30)
Status		
Active Duty	15 (75)	17 (85)
National Guard	2 (10)	3 (15)
Reserve	3 (15)	0 (0)
Branch		
Army	18 (90)	20 (100)
Marine	2 (10)	0 (0)
Rank		
Enlisted	18 (90)	16 (80)
Officers	2 (10)	4 (20)
Deployment		
OIF	5 (25)	14 (70)
OEF	15 (75)	6 (30)
Mechanism of Blast Injury		
IED	17 (85)	N/A
RPG	2 (10)	N/A
Mortar	1 (5)	N/A

RPG, rocket propelled grenade; N/A, nonapplicable.

TABLE III. Oculomotor Functions Measurements

Function	mTBI, Mean (SD)	Non-TBI, Mean (SD)	p
Distance Cover Test (PD)	−0.50 (2.24)[a]	0.20 (1.06)	0.2133
Near Cover Test (PD)	−0.60 (1.85)[a]	0.15 (1.18)	0.1344
Distance Lateral Phoria (PD)	−0.65 (3.28)[a]	0.45 (2.98)	0.2742
Distance Vertical Phoria (PD)	0.25 (0.62)	0.15 (0.49)	0.5919
Near Lateral Phoria (PD)	−6.75 (3.73)[a]	−0.65 (1.33)[a]	0.0203*
Near Vertical Phoria (PD)	0.65 (1.05)	0.15 (0.33)	0.0496*
Near BI Break (PD)	20.45 (4.90)	22.30 (5,81)	0.1595
Near BI Recover (PD)	17.15 (5.21)	21.35 (4.96)	0.1982
Near BO Break (PD)	19.30 (15.30)	28.35 (7.00)	0.0348*
Near BO Recover (PD)	13.00 (17.00)	22.15 (7.39)	0.0377*
Stereo (sec of arc)	47.50 (27.59)	34.50 (9.99)	0.6620
NPC (mm)	99.45 (74.28)	29.00 (24.26)	0.0003*
AC/A Ratio (__/1)	2.80 (0.70)	3.10 (0.85)	0.2344
Monocular AoA (D)	6.09 (2.59)	9.49 (3.63)	0.0168*
Mono Acc Fac (cpm)	12.10 (4.10)	14.08 (2.14)	0.0634

PD, prism diopter; D, diopters; Acc, accommodation; Mono Acc Fac, monocular accommodative facility; cpm, cycles per minute. [a]Negative (–) sign denotes exophoria. *Statistically significant ($p < 0.05$).

near vision symptoms.[18–20] Each of the symptom questions had five possible answers with an associated value: always (4), frequently (3), sometimes (2), rarely (1), and never (0). The expected CISS score for normal adult is ≤20.

Statistical Analysis

Descriptive statistics (mean ± SD) were calculated for most of the outcome measures. Student's paired t-test was used to examine between-group visual functions producing continuous data. Fisher's exact test was used to examine between-group comparisons of oculomotor functions producing categorical data. All significance levels were $p < 0.05$. Statistical analyses were performed with Statistical Package for Social Sciences and GraphPad Prism (GraphPad Software, San Diego, California) software.

RESULTS

Vision and Ocular Health

The current study compared the visual dysfunctions and symptoms of warfighters diagnosed with mTBI during the subacute stage of the blast injury to the visual dysfunctions and symptoms of age-matched controls who had deployed in support of OIF and OEF but who had neither experienced an mTBI nor been exposed to a blast event. The median interval from blast-induced mTBI and the examination date was 30.5 days (range, 16–45 days). Table II summarizes the demographics of both groups as well as the injury characteristics for the blast-induced mTBI group. Most of the blast injured warfighters were active duty (75%), Army (90%), enlisted (90%) males (90%), and deployed in support of OEF (75%). IEDs were the most frequent (85%) mechanism of blast injury. No subject reported previous eye injury.

The comprehensive eye examination revealed that all subjects, in both groups, were correctable to 20/20 and had healthy eyes with normal color vision and visual fields. Neither manifest refraction (right eye: mTBI, −0.48 ± 2.00 D; non-TBI, + 0.12 ± 0.95 D; $p = 0.2466$; left eye: mTBI, −0.50 ± 2.19 D; non-TBI, −0.01 ± 1.04 D; $p = 0.3649$) nor intraocular pressure (right eye: mTBI, 13.85 ± 2.46 mmHg; non-TBI, 12.35 ± 2.39 mmHg; $p = 0.1413$; left eye: mTBI, 13.80 ± 2.65 mmHg; non-TBI, 12.95 ± 2.19 mmHg; $p = 0.3589$) was statistically different between the groups.

Oculomotor Functions

Table III shows the summary of the mean (±SD) of oculomotor functions for each group with outcome measures scored on a ratio scale. Based on paired t-test analysis, the oculomotor functions that presented statistically significant difference between the blast-induced mTBI and the control groups were near lateral phoria ($p = 0.0203$), near vertical phoria ($p = 0.0496$), near BO vergence break ($p = 0.0348$) and recovery ($p = 0.0377$), NPC ($p = 0.0003$), and AoA ($p = 0.0168$).

Fisher's exact test analysis showed that pursuit ($p < 0.001$) and saccadic ($p = 0.0202$) eye movements were significantly more defective in the mTBI group than controls. In contrast, there was no significant difference for fixation disparity and flat fusion (i.e., Worth 4 Dot) between the groups (Table IV). Vergence, version, accommodative, and reading deficit were the most common visual dysfunctions. Note that the prevalence of defective monocular accommodative facility was significantly higher for the mTBI group despite the findings that the mean differences of cycles per minute were not significantly different between the two groups as shown in Table III.

TABLE IV. Prevalence of Visual Dysfunctions

Visual Dysfunction	mTBI, No. (%)	Non-TBI, No. (%)	p
Distance Lateral Phoria	1 (5)	1 (5)	1.0000
Distance Vertical Phoria	2 (10)	1 (5)	1.0000
Near Lateral Phoria	9 (45)	1 (5)	0.0084*
Near Vertical Phoria	11 (55)	1 (5)	0.0012*
Near BI Break	5 (25)	5 (25)	1.0000
Near BI Recover	3 (15)	2 (10)	1.0000
Near BO Break	7 (35)	1 (5)	0.0436*
Near BO Recover	7 (35)	1 (5)	0.0436*
Diplopia/Suppression (W4D)	2 (10)	0 (0)	0.4872
Stereo	6 (30)	1 (5)	0.0915
NPC	11 (55)	1 (5)	0.0012*
AC/A Ratio	3 (15)	3 (15)	1.0000
AoA	13 (65)	3 (15)	0.0031*
Accommodative Facility	7 (35)	2 (10)	0.0031*
Pursuit	12 (60)	0 (0)	<0.0001*
Saccades	6 (30)	0 (0)	0.0202*
Fixation	2 (10)	0 (0)	0.4872
Reading	13 (65)	3 (15)	0.0031*

W4D, Worth 4 Dot test. *Statistically significant ($p < 0.05$).

Reading Fluency

There was a statistically significant decrease in reading speed (mTBI, 189.80 ± 70.89 wpm; non-TBI, 268.10 ± 67.95 wpm; $p = 0.0019$) and reading comprehension score (mTBI, 83.50 ± 17.30; non-TBI, 95.00 ± 8.27; $p = 0.0106$) in the mTBI group when tested at the seventh-grade reading level. Sixty five percent of the mTBI subjects failed the reading test compared to 15% of the controls.

Convergence Insufficiency Symptoms Survey

The total CISS scores showed a statistically significant difference (paired t-test, $p = 0.0326$) between the mTBI (20.45 ± 14.88) and the non-TBI (12.15 ± 7.66) groups. Analysis of the individual symptoms is summarized in Table V. Six of the 15 CISS individual symptoms showed a statistically significant score increase for the mTBI group when reading or doing close work. These symptoms include uncomfortable eyes ($p = 0.0092$), headaches ($p = 0.0003$), sore eyes ($p = 0.0017$), "pulling" feeling around the eyes ($p = 0.0191$), words blurring or coming in and out of focus ($p = 0.0396$), and lose place while reading ($p = 0.0343$).

Figure 1 shows the scatter diagram of the individual CISS scores plotted against the reading speed. CISS scores had a moderately strong negative correlation with reading speed (Pearson's $r = -0.65$), indicating higher CISS score for subjects with lower reading speed. Although the regression for the two groups of subjects was not statistically significantly different, both groups showed this strong inverse relationship, and the mTBI group has a much larger range of CISS scores.

Associated Symptoms

The difference of the prevalence of blast-induced mTBI-associated symptoms between the two groups was analyzed by Fisher's exact test. Among the surveyed visual symptoms, we found that light sensitivity ($p = 0.0138$) and eye strain ($p = 0.0471$) were the only symptoms showing statistical difference between the groups (Table VI). Table VII shows that the prevalence of reading-associated symptoms were significantly higher in the mTBI group for blurred vision ($p = 0.0471$), losing place or skipping words while reading ($p = 0.0225$), reduced or inefficient reading ($p = 0.0407$), words running together ($p = 0.0033$), and decreased reading comprehension ($p = 0.0197$).

Hearing and balance problems are expected after blast exposure because of the physical effect of the blast overpressure on air- and fluid-filled organs. The only hearing and balance symptoms with a significantly higher prevalence for the mTBI group were noise sensitivity ($p = 0.0084$), hearing loss ($p = 0.0484$), ringing in the ears ($p = 0.0225$), and balance problems ($p = 0.0012$) (Table VIII).

A large number of warfighters returning from the combat duty experience a myriad of behavioral, psychological, and neurological symptoms.[11] Among the symptoms with significant higher incidence in the mTBI group were periods of confusion or disorientation ($p = 0.0083$), anxiety ($p = 0.0187$), sleep disturbances ($p = 0.0248$), memory or language difficulties ($p = 0.0187$), delayed reaction time ($p = 0.0471$), forgetful or poor memory ($p = 0.0003$), comprehension problems ($p = 0.0033$), attention or concentration difficulties ($p = 0.0022$), dizziness ($p = 0.0004$), and chronic headaches ($p < 0.0001$) (Table IX).

Because of the concomitant diagnosis of insomnia, seizures, depression, PTSD, and other psychological problems, most of mTBI subjects were taking a combination of prescription

TABLE V. Convergence Insufficiency Symptom Survey score

Symptoms	Score Mean (SD) mTBI	Non-TBI	p
Eyes Feel Tired	1.75 (1.33)	1.20 (0.89)	0.1337
Eyes Feel Uncomfortable	1.80 (1.47)	0.80 (0.70)	0.0092*
Headaches	1.60 (1.27)	0.35 (0.59)	0.0003*
Feel Sleepy	1.25 (1.02)	1.30 (1.13)	0.8839
Lose Concentration	1.75 (1.45)	1.15 (0.81)	0.1141
Trouble Remembering What was Read	1.50 (1.15)	1.10 (0.91)	0.2297
Double Vision	0.50 (0.89)	0.35 (0.67)	0.5504
Words Move, Jump, or Appear to Float on the Page	0.15 (0.49)	0.30 (0.57)	0.3781
Feel Read Slowly	2.05 (1.64)	1.45 (1.23)	0.1986
Eyes Hurt	1.20 (1.28)	0.65 (0.99)	0.1368
Eyes Feel Sore	1.25 (1.25)	0.25 (0.44)	0.0017*
Feel "Pulling" Around the Eyes	0.85 (1.23)	0.15 (0.37)	0.0191*
Words Blurring or Coming In and Out of Focus	1.30 (1.22)	0.60 (0.82)	0.0396*
Lose Place While Reading	1.90 (1.25)	1.15 (0.88)	0.0343*
Need to Re-read the Same Line of Words	1.60 (1.19)	1.35 (0.88)	0.4532
Total Score	20.45 (14.88)	12.15 (7.66)	0.0326*

*Statistically significant ($p < 0.05$).

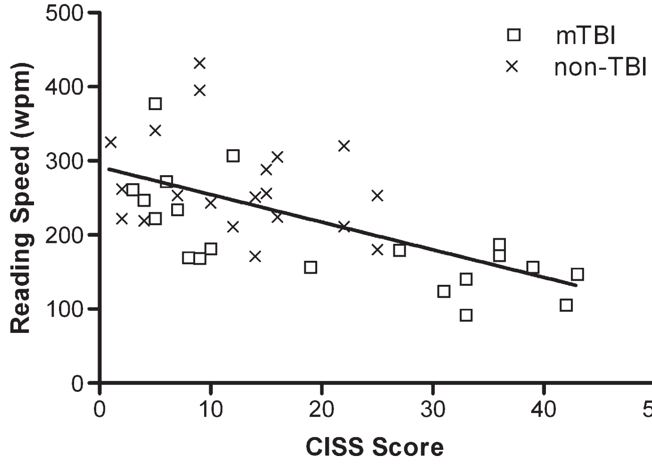

FIGURE 1. Scatter diagram of the individual CISS score plotted against the reading speed for mTBI (□) and non-TBI (×) subjects. For completeness, the regression line is presented.

TABLE VI. Prevalence of Visual Symptoms

Symptoms	mTBI, No. (%)	Non-TBI, No. (%)	*p*
Blur Vision at Distance	3 (15)	4 (20)	1.0000
Double Vision	2 (10)	0 (0)	0.4872
Vision Worse at the End of Day	1 (5)	1 (5)	1.0000
Light Sensitivity	10 (50)	2 (10)	0.0138*
Glare Sensitivity	6 (30)	2 (10)	0.2351
Missing Part of Visual Field	0 (0)	0 (0)	1.0000
Bumping into Objects/Walls	1 (5)	0 (0)	1.0000
Color Vision Problem	1 (5)	0 (0)	1.0000
Depth Perception Problem	3 (15)	1 (5)	0.6050
Visual Motion Sensitivity	5 (25)	0 (0)	0.2308
Eye Strain	7 (35)	3 (15)	0.0471*
Aching Eyes	2 (10)	1 (5)	1.0000
Visual Fatigue	7 (35)	3 (15)	0.2733
Difficulty Scanning/Navigating	6 (30)	1 (5)	0.0915
Problem With Spatial Relation Among Objects	1 (5)	0 (0)	1.0000
Objects Appear to Move When Not Moving	1 (5)	0 (0)	1.0000
Seeing Floor Tilted	2 (10)	0 (0)	0.4872
Unable to See Entire Picture or Its Parts	1 (5)	0 (0)	1.0000
Poor Eye–Hand Coordination	3 (15)	0 (0)	0.2308
Clumsy or Knocks Things Over	3 (15)	1 (5)	0.6050
Other Visual Symptoms	0 (0)	0 (0)	1.0000

*Statistically significant ($p < 0.05$).

TABLE VII. Prevalence of Reading-Associated Symptoms

Symptoms	mTBI, No. (%)	Non-TBI, No. (%)	*p*
Blur Vision When Reading	7 (35)	3 (15)	0.0471*
Loss of Place, Skipping, or Re-reading Words	12 (60)	4 (20)	0.0225*
Reduced or Inefficient Reading Speed	10 (50)	3 (15)	0.0407*
Words Run Together	8 (40)	0 (0)	0.0033*
Burn, Itchy, Watery Eyes	2 (10)	1 (5)	1.0000
Fall Asleep When Reading	6 (30)	6 (30)	1.0000
Dizzy/Nauseas When Reading	2 (10)	1 (5)	1.0000
Head Tilt/Close One Eye When Reading	1 (5)	0 (0)	1.0000
Decreased Reading Comprehension	8 (40)	1 (5)	0.0197*
Trouble Keeping Attention on Reading	10 (50)	4 (20)	0.0958
Unable to Read Continuous Text Comfortably	8 (40)	3 (15)	0.1552
Unable to Understand What You Read	0 (0)	0 (0)	1.0000
Unable to Attend While Reading in Quite Place	1 (5)	0 (0)	1.0000
Unable to Attend While Reading in Noisy Place	3 (15)	0 (0)	0.2308
Other Symptoms	0 (0)	0 (0)	1.0000

*Statistically significant ($p < 0.05$).

drugs for the treatment of these conditions for ranging from 7 to 14 days before the time of the study. These medications have well-known side effects on the ocular structures and/or the part of the brain responsible for vision and oculomotor function. Table X summarizes a list of medications prescribed to the study mTBI population and the potential side effects to the neurosensory systems. Subjects on the non-mTBI groups (i.e., control) were not taking any systemic medications at the time of the study. It is also important to survey the use of illicit/recreational drugs since they may influence oculomotor and visual functions.

DISCUSSION

Over three-quarters of all TBI cases reported during current combat operations in Iraq and Afghanistan are classified as mTBI with explosive devices as the main mechanism of injury.[21] Despite the astonishing prevalence of blast-related mTBI, the literature reporting the prevalence of visual deficits and symptoms of active duty warfighters is virtually nonexistent. Warfighters with blast-induced mTBI who present with no obvious physical injuries usually go undiagnosed or misdiagnosed. Unfortunately, there are no specific clinical practice guidelines with a functional test battery for the assessment of visual dysfunctions of returning warfighters with suspected mTBI, particularly for those dysfunctions resulting from blast exposure.

Similar to a previous study by Brahm et al,[22] all subjects in the present study had normal high contrast visual acuity, color vision, and overall ocular health, indicating that these clinical characteristics are poor indicators of the overall visual function status of warfighters with suspected mTBI caused by blast in the absence of ocular trauma. However, the most common blast-induced visual dysfunctions were associated with near oculomotor deficits (i.e., vergence, version, and accommodation). Vergence problems were indicated by the large exophoria, decreased fusional ranges, and receded NPC. Even though both pursuit and saccadic (i.e., version) eye movements were affected, there was a higher prevalence of pursuit deficits. We found that reduced monocular AoA was more common than reduced monocular accommodative facility, even after excluding two subjects from each group who were early presbyopes.

TABLE VIII. Prevalence of Hearing and Balance Symptoms

Symptoms	mTBI, No. (%)	Non-TBI, No. (%)	*p*
Noise Sensitivity	9 (45)	1 (5)	0.0084*
Hearing Loss	11 (55)	4 (20)	0.0484*
Ringing in Ears	12 (60)	4 (20)	0.0225*
Vertigo	8 (40)	3 (15)	0.1552
Balance Problems	11 (55)	1 (5)	0.0012*
Abnormal Posture	4 (20)	1 (5)	0.3416
Leaning Forward/ Backward	3 (15)	2 (10)	1.0000
Leaning to One Side	2 (10)	1 (5)	1.0000
Other Symptoms	1 (5)	0 (0)	1.0000

*Statistically significant ($p < 0.05$).

TABLE IX. Prevalence of Behavior, Psychological, and Neurological Symptoms

Symptoms	mTBI n (%)	Non-TBI n (%)	p
Agitation	9 (45)	4 (20)	0.1760
Excessive Fatigue	6 (30)	3 (15)	0.4506
Confusion/Disorientation	7 (35)	0 (0)	0.0083*
Anxiety	11 (55)	3 (15)	0.0187*
Depression	4 (20)	1 (5)	0.3416
Sleep Disturbances	13 (65)	5 (25)	0.0248*
Irritability	9 (45)	5 (25)	0.3203
Mood Swings	6 (30)	2 (10)	0.2351
Personality Changes	3 (15)	1 (5)	0.6050
Emotional Outburst	3 (15)	0 (0)	0.2308
Confusion	4 (20)	0 (0)	0.1060
Social Withdrawal	4 (20)	1 (5)	0.3416
Interpersonal Difficulty	4 (20)	1 (5)	0.3416
Poor Motivation	3 (15)	3 (15)	1.0000
Car Motion Sickness	4 (20)	1 (5)	0.3416
Motion Sensitivity	3 (15)	2 (10)	1.0000
Memory or Language Difficulty	11 (55)	3 (15)	0.0187*
Delayed Reaction Time	5 (25)	0 (0)	0.0471*
Forgetful or Poor Memory	15 (75)	3 (15)	0.0003*
Comprehension Problem	8 (40)	0 (0)	0.0033*
Attention/Concentration Difficulty	12 (60)	2 (10)	0.0022*
Spatial Disorientation	1 (5)	1 (5)	1.0000
Loss of Appetite	2 (10)	4 (20)	0.6614
Seizures	0 (0)	0 (0)	1.0000
Dizziness	10 (50)	0 (0)	0.0004*
Chronic Headaches	16 (80)	1 (5)	<0.0001*
Other Symptoms	1 (5)	0 (0)	1.0000

*Statistically significant ($p < 0.05$).

Although the types of visual deficits were similar to those previously reported for nonblast mTBI in the civilian[23–26] and veteran[9,10,22] populations, we found slightly different occurrences of visual dysfunctions and symptoms. These differences may reflect the fact that previous reports did not consistently differentiate the prevalences of visual dysfunctions by the mechanism of injury (i.e., blast versus nonblast), the severity of the TBI (i.e., mild, moderate, or severe), or the stage following the trauma at the time of the examination (i.e., acute, subacute, or chronic). We also found a large prevalence of hyperphoria that has not been previously described in a military population. A hyperphoria can account for some of the perceptual and vestibular problems typically reported by mTBI patients in that an individual with a vertical misalignment of the eyes may tilt the head to help mechanically align the eyes, a maneuver that, in turn, may cause disorders in the fluid of the inner ear and resultant dizziness and balance disorders.[27] A significant difference between the mTBI resulting from blast and nonblast mechanism found in the present study is the lack of strabismus, visual field defects, and vision loss previously reported in veterans with nonblast mTBI.[22] Our results suggest that the ophthalmic clinical test battery administered to warfighters with a suspected or confirmed diagnosis of mTBI resulting from a blast event, in the absence of polytrauma or ocular injury, should include functional near oculomotor testing.

Reading is a complex task requiring the integration of vergence, version, and accommodative functions as well as attention and cognitive functions.[23] Similar to previous studies describing visual sequelae associated to mTBI in civilians[25] and veterans,[9,22] we found that most warfighters with blast-induced mTBI have impaired reading abilities characterized by decreased reading speed and reading comprehension. We also found a strong negative correlation between reading speed and the CISS scores. Taken together, these results suggest that CISS and reading assessment should be performed routinely by military clinicians to establish predeployment baseline for symptoms associated with the performance of near visual tasks as well as predeployment level of reading speed and comprehension. Such information is valuable for deployed clinicians when making a retun-to-duty or evacuation determination for warfighters suspected of having mTBI. In addition, these simple and quick assessment tools can be used to monitor the improvement of visual functions as warfighters progress through the rehabilitative process, as previously shown in individuals with convergence insufficiency.[18–20,28]

In many instances, the presence of mTBI can be suspected if specific symptoms present. For example, warfighters reporting visual symptoms when performing sustained near tasks such as reading can be suspect for mTBI-associated visual dysfunctions. In addition, the high prevalence of idiopathic photosensitivity found in our study stresses the need for the development of objective clinical instrumentation and methodology to assess and monitor the level of photosensitivity reported by warfighters. A similar prevalence of photosensitivity was also described in a veteran population with TBI.[10,29]

Since blast affects fluid- and air-filled organs, it was not surprising that subjects with blast-induced mTBI had significant symptoms associated with noise sensitivity, hearing loss, tinnitus, and balance problems. In fact, hearing loss, tinnitus, and other auditory complaints are the major disabilities for veterans.[30] This raises concerns regarding the importance of dual sensory impairment (vision and hearing) on military performance, rehabilitative process, and quality of life.[31,32]

The presence of comorbid neuropsychiatric sequelae is important for eye care providers since patients taking systemic medication for the treatment of such disorders or associated symptoms may present with visual dysfunctions and symptoms similar to those commonly seen in patients with mTBI. The current study showed that even as early as 2 weeks following the injury, mTBI patients were taking a significant number of systemic medications for the treatment of neuropsychiatric sequelae with known ophthalmic side effects.

A potential study limitation was the relatively small sample size. However, based on the similar demographic characteristics (e.g., gender, age, rank, and mechanism of injury) compared to other studies describing the prevalence

TABLE X. Summary of Prescription Medications Taking by mTBI Subjects in the Current Study and Associated Neurosensory Side Effects

		Neurosensory Side Effects																			
Generic Name	Primary Treatment	Distance Blur Vision	Near Blur Vision	Mydriasis	Increased IOP	Photophobia	Acc Problems	Dry Eye	Conjunctivitis	Cataracts	Diplopia	Iritis	Eye Irritation	Eye Hemorrhage	Nystagmus	Eye Pruritus	Eye Swelling	Eye Pain	ION	Balance Problems	Tinnitus
Amitriptyline	Depression	x			x			x												x	
Trazodone	Depression	x																			
Eszopiclone	Insomnia			x		x		x	x			x								x	
Lexapro	Depression	x		x				x	x				x							x	
Esomeprazole	GERD	x	x						x											x	
Oxycodone	Fibromyalgia													x						x	x
Topiramate	Epilepsy		x		x		x	x			x										
Sumatriptan	Migraine	x												x				x	x		
Cyclobenzaprine	Muscle Spasms	x																		x	
Verapamil	Hypertension	x													x						
Prazosin	PTSD/Nightmares															x	x				
Citalopram	Anxiety/Panic			x		x	x		x	x	x				x			x			
Pregabalin	Neuropathy	x	x			x	x	x	x		x		x	x			x				x
Fluoxetine	Depression/Panic				x																
Bupropion HCL	Depression	x		x	x		x	x			x										
Zolpidem	Insomnia																			x	
Meloxicam	Pain/Inflammation																				x
Nortriptyline	Depression																			x	
Gabapentin	Epilepsy/Neuropathy	x	x			x	x	x	x	x	x		x	x		x		x			
Doxicycline	Antimicrobial										x						x				
Lisinopril/HCTZ	Hypertension		x		x																
Chlorhexidine	Chemical Antiseptic								x								x	x			
Excedrin	Migraine																x				
Methylphenidate	ADHD	x		x			x				x										

HCTZ, hydrochlorothiazide; GERD, Gastro-Esophageal Reflux Disease; ADHD, Attention Deficit Hyperactivity Disorder; IOP, intraocular pressure; Acc, accommodation; ION, ischemic optic neuropathy.

of TBI in large populations, we feel that our study population was representative of a blast-induced mTBI population.[3,21,33] In addition, based on the marked difference in the frequency of oculomotor dysfunctions and associated symptoms when compared to age-matched controls, the results suggest that the present findings can be generalized to wounded warriors with blast-induced mTBI.

CONCLUSIONS

The frequency of visual dysfunctions and symptoms associated with blast-induced mTBI among warfighters resulting from combat operations in the Middle East is very high. The results from this study suggest that all warfighters exposed to blast or diagnosed with blast-induced mTBI should have a complete TBI functional vision examination by an eye care provider, with emphasis on near oculomotor functions. The near oculomotor assessment should include at minimum: near lateral and vertical phorias, BO break and recovery, NPC, AoA, monocular accommodative facility, saccades, and pursuit eye movements. In addition, a reading fluency test should be included as a functional assessment tool to evaluate the integration of the accommodative, version, and vergence functions in parallel with cognition and attention. Since near oculomotor functions appear to be among the more affected by mTBI, the administration of the CISS will help to identify individuals with near oculomotor problems. Furthermore, the presence of comorbid neuropsychiatric problems should be surveyed since the treatment of such conditions and their associated symptoms includes the administration of medications with significant ocular side effects. Of particular importance is the assessment of photosensitivity since this can be debilitating for warfighters. Given the significant number of oculomotor deficits and associated symptoms associated with blast-induced mTBI/concussion, it is highly recommended that all service members receive a comprehensive oculomotor assessment by an eye care provider during the predeployment medical assessment so that oculomotor and visual deficits can be accurately diagnosed during a postdeployment evaluation.

The knowledge of visual deficits that are prevalent within the subacute stage of mTBI, as reported here, can (1) help deployed clinicians make important decisions regarding recommendations for treatment or return-to-duty disposition after blast exposure, particularly in cases with no obvious physical injuries and (2) improve patient care by providing recommendations regarding the optimal, sensitive functional visual test battery for early identification and management of blast-induced visual dysfunctions.

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