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Visual Dysfunctions at Different Stages after Blast and Non-blast Mild Traumatic Brain Injury

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ABSTRACT

Purpose. To assess the prevalence of visual dysfunctions and associated symptoms in war fighters at different stages after non–blast- or blast-induced mild traumatic brain injury (mTBI).

Methods. A comprehensive retrospective review of the electronic health records of 500 U.S. military personnel with a diagnosis of deployment-related mTBI who received eye care at the Landstuhl Regional Medical Center. For analysis, the data were grouped by mechanism of injury, and each group was further divided in three subgroups based on the number of days between injury and initial eye examination.

Results. The data showed a high frequency of visual symptoms and visual dysfunctions. However, the prevalence of visual symptoms and visual dysfunctions did not differ significantly between mechanism of injury and postinjury stage, except for eye pain and diplopia. Among visual symptoms, binocular dysfunctions were more common, including higher near vertical phoria, reduced negative fusional vergence break at near, receded near point of convergence, decreased stereoacuity, and reduced positive relative accommodation.

Conclusions. The lack of difference in terms of visual sequelae between subgroups (blast vs. nonblast) suggests that research addressing the assessment and management of mTBI visual sequelae resulting from civilian nonblast events is relevant to military personnel where combat injury results primarily from a blast event.

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Key Words: visual dysfunction, mild traumatic brain injury, mTBI, military, blast

Traumatic brain injury (TBI) has emerged as the major cause of morbidity during military operations in Iraq and Afghanistan, with mild TBI (mTBI) accounting for 82% of all cases.[1,2] War fighters suffer mTBI as the result of contact with enemy forces or weapons systems (e.g., improvised explosive devices, vehicle-borne improvised explosive devices, mortars, rocket-propelled grenades) as well as from head impacts from accidents caused by enemy action, equipment failure, or human factors. Although some deployment-related mTBI cases are associated with a blast event, a large number result from nonblast events.[3] In particular, garrison training operations such as combat and field exercises to prepare for military combat downrange reportedly result in more than 80% of all military TBI events.[1] Nonetheless, there is conflicting evidence regarding rate of injury from blast versus nonblast events.[4]

Regardless of the mechanism of brain injury, there is a reasonable probability that war fighters will experience visual consequences given the amount of visual sensory processing that occurs in the brain. Nearly 70% of sensory processing in the brain is vision related.[5] In addition, many brain structures that are most vulnerable to mTBI are vision related, that is, the frontal, occipital, temporal, and parietal lobes as well as the long axonal fibers connecting the midbrain to the cortex. Consequently, it comes as no surprise that the incidence of oculomotor dysfunctions resulting from a neurological event is very high.

Visual dysfunctions and symptoms are common in active duty military[6–8] and veteran populations after mTBI.[9–11] War fighters suffering from mTBI report a wide range of such vision-related symptoms, including headache, diplopia, vertigo, asthenopia, inability to focus, movement of print when reading, difficulty with

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tracking and fixations, and photophobia.[6,10] The ability of the visual system to coordinate precise alignment of both eyes, fixate, and track real-world objects is essential for forming a reliable three-dimensional percept of the world. The ability to effectively read, fuse images mediated by the two eyes, follow moving objects, detect targets, and determine depth all depends on intact oculomotor functions. War fighters with persistent visual problems can experience difficulty performing their military duties as well as reintegrating into civilian life. Consequently, visual dysfunction represents a significant challenge to the military readiness of the fighting force. Research that empowers clinicians with data regarding assessment of visual deficits and their etiology is a vital contribution to military medicine.

Many studies have reported the prevalence and treatment of visual deficits in the civilian population with mTBI and sport-related concussions; however, mTBI in the civilian population is mainly caused by nonblast events such as motor vehicle accidents, falls, and recreation/sport concussions.[12–15] Consequently, extrapolating research findings from the civilian nonblast mTBI population to the military blast-injured population must be done with caution, particularly given the possible exacerbating effects that environmental and combat-related stressors may have on the brain's response to mTBI. Despite the increased incidence of visual dysfunctions in war fighters with mTBI, to our knowledge, no study has compared visual deficits by mechanisms of injury (blast vs. nonblast) during different stages after the injury. Such information is important for the clinician caring for redeploying war fighters to streamline the visual assessment, expedite the diagnosis of mTBI sequelae, and prescribe the appropriate vision rehabilitation modality.

As the brain goes through its natural healing process, visual neurosensory sequelae associated with mTBI can be expected to improve across time after injury.[16,17] The identification of the differential prevalence of such visual neurosensory sequelae after injury may provide a basis for potentially important markers to determine return to duty and to monitor recovery of function in war fighters with mTBI. The aim of the present study was to assess the occurrence of visual dysfunctions and associated symptoms in war fighters at different stages after non–blast- or blast-induced mTBI.

METHODS

The Brooke Army Medical Center Institutional Review Board and U.S. Army Medical Research and Materiel Command Office of Research Protection approved the present study. Data for the present study were obtained from a comprehensive review of the electronic health records of 500 U.S. military personnel with a diagnosis of deployment-related mTBI. The diagnosis of mTBI was made by a neurologist based on the following criteria: loss of consciousness of no more than 30 min; posttraumatic amnesia of no more than 24 h; alteration of mental state; a Glasgow Coma Scale score from 13 to 15; and normal structural brain imaging.[1] All data included in the present study were from military personnel with a diagnosis of deployment-related mTBI who received eye care at the Landstuhl Regional Medical Center (LRMC) between January 2008 and February 2011.

In January 2008, the LRMC Optometry Clinic initiated a comprehensive eye examination and performance improvement program called "Polytrauma Vision Syndrome Screening" (PVSS). The PVSS program required that all patients with mTBI who were evaluated by the LRMC TBI Recover Team undergo a comprehensive neuro-optometric evaluation soon after arriving at LRMC, even in the absence of visual and ocular complaints. The TBI Recover Team used an interdisciplinary (i.e., neurology, optometry, ophthalmology, audiology, physical therapy, occupational therapy, and behavioral health) approach to screen, evaluate, and treat TBI patients. The mTBI patients evaluated by the TBI Recover Team were either medically evacuated from the combat zone or were individuals with deployment-related mTBI stationed in the vicinity of LRMC and referred by the primary care provider to the TBI Recover Team for further mTBI assessment.

The Armed Forces electronic health records were queried to generate a list of mTBI patients coded with the *International Classification of Disease, Ninth Revision,* codes used at LRMC to code for PVSS (i.e., V15.5_1 and V15.5_2). Data from 500 patients were included in the study after reviewing 549 records. All documented eye examinations for these patients before and after the mTBI available in the electronic health records were reviewed to rule out potential preexisting confounding conditions and to determine any subsequent diagnosis resulting potentially from the mTBI. Forty-nine records were excluded during the review because of patient duplication (N = 26), unconfirmed mTBI diagnosis (N = 9), incomplete oculomotor examination (N = 6), or diagnosed as moderate TBI (N = 2) or preexisting ophthalmic conditions such as amblyopia (N = 4) and optic neuritis (N = 2).

The PVSS files contained the postinjury comprehensive eye examination and the oculomotor assessment performed by one of two neuro-optometrists. Both optometrists followed the same protocol and used standard clinical procedures.[18] Manifest refraction with a phoropter measured refractive error. Best corrected distance and near visual acuities were measured with a high-contrast Snellen chart and reduced Snellen card, respectively. Color vision was assessed monocularly with Dvorine pseudoisochromatic plates. Pupil response was assessed with the swinging flashlight test. Confrontation visual fields and extraocular muscle assessment were performed on all patients. The patient's ocular health status was evaluated using ophthalmoscopy and biomicroscopy, and intraocular pressure was determined by noncontact tonometry. The prescription determined by manifest refraction was used during the oculomotor examination.

The documented oculomotor examination included stereopsis assessed by the Randot stereotest; near point of convergence; ocular alignment (lateral and vertical) at near and distance, as well as negative and positive fusional vergence break and its associated recovery at near, measured with the von Graefe technique; motor fusion with Worth-4-Dot test to assess diplopia and suppression; fixation disparity at near tested with a fixation card; accommodation using negative and positive relative accommodation behind the phoropter; saccadic and smooth pursuit eye movements assessed by the Northeastern State University College of Optometry Oculomotor Test.[18–20]

Statistical Analysis

For analysis, the data were grouped by the mechanism of injury (blast vs. nonblast), and each group was further divided into three

subgroups based on the number of days between injury and the initial eye examination. A possible confounder to this grouping was that injuries that were coded as blast related might also involve a vehicle rollover or expulsion from a vehicle and therefore may not be a purely blast-related event. The three subgroups were (1) *Acute/Subacute*, evaluated within 45 days after the injury; (2) *Chronic ≤ 1 year* (evaluated between 46 and 365 days after injury); (3) *Chronic > 1 year* (evaluated more than 365 days after the mTBI event). Although the exact number of days after injury has not been clearly defined in the literature to classify patients under a particular postinjury category, the literature commonly refers to the acute phase as within 72 h after the injury and subacute as up to several weeks after the injury.[17,21–25] Because of the less urgent level of care required by most war fighters with mTBI, the amount of time to be medically evacuated from the combat zone to LRMC for specialized evaluation often exceeded 72 h; therefore, the acute and subacute patients were grouped together for analysis.

Descriptive statistics (mean ± standard deviation [SD]) were calculated for most of the outcome measures. The Shapiro-Wilk test of normality was performed to determine if parametric or nonparametric analysis was required. A two-way analysis of variance (ANOVA) was used to compare visual functions producing normally distributed continuous data, and Kruskal-Wallis ANOVA was used to compare nonparametric continuous data resulting from oculomotor testing. Chi-square analyses were performed for visual dysfunctions and symptoms reported as categorical data. Fisher exact test was used to analyze ocular diagnoses with small sample size. All significance levels were $p < 0.05$. Statistical analyses were performed with Excel, Statistical Package for Social Sciences (IBM, SPSS), and GraphPad Prism (GraphPad Software Inc., San Diego, CA) software.

TABLE 1.
Study demographics

Characteristics	Blast (N = 343)	Non-blast (N = 157)	Total (N = 500)	p
Sex				
Male	334 (91)	121 (77)	456 (91)	0.035*
Female	9 (9)	36 (23)	44 (9)	0.050*
Race				
White	237 (69)	111 (71)	348 (70)	0.423
Black	53 (16)	29 (18)	82 (16)	0.462
Hispanic	46 (13)	13 (8)	59 (12)	0.455
Others	7 (2)	4 (3)	11 (2)	0.735
Status				
Active duty	307 (90)	135 (86)	442 (88)	0.882
National guard	24 (7)	11 (7)	35 (7)	0.822
Reserve	12 (3)	10 (6)	22 (4)	0.484
Civilian	0 (0)	1 (<1)	1 (<1)	1.000
Branch				
Army	287 (84)	133 (85)	420 (84)	0.895
Marine	43 (12)	6 (3)	49 (10)	0.002*
Air Force	7 (2)	14 (9)	21 (4)	0.045*
Navy	6 (2)	3 (2)	9 (2)	0.695
Civilian	0 (0)	1 (<1)	1 (<1)	1.000
Pay grade				
E1-E4	138 (40)	60 (38)	198 (40)	0.595
E5-E6	156 (45)	62 (39)	218 (44)	0.537
E7-E9	33 (10)	12 (8)	45 (9)	0.567
WO1-WO4	2 (1)	3 (2)	5 (1)	1.000
O1-O6	14 (4)	19 (12)	33 (6)	0.067
Civilian	0 (0)	1 (<1)	1 (<1)	1.000
Deployment				
Iraq	196 (57)	103 (66)	299 (60)	0.573
Afghanistan	147 (43)	54 (34)	201 (40)	0.620

Data shown as no. patients (%).

*Chi-square statistically significant ($p < 0.05$). Military pay grade preceded by the letters E, WO, and O indicates the pay grade in the U.S. Armed Forces for enlisted, warrant officer, and commissioned officer service member, respectively.

RESULTS

Demographic and Injury Characteristics

Tables 1 and 2 summarize the study population demographic and injury characteristics, respectively. The average patient was a young (29.33 ± 8.14 years), white (70%), active duty (88%), male (91%), enlisted below E-6 pay grade (84%), Army Soldier (84%) injured in Iraq (60%). Most injuries were combat related (75%) and blast related (69%) from an improvised explosive device (58%) sustained while performing mounted duties (61%). Fifty-four percent of the patients were evaluated by a medic close to the site of injury. In contrast, blunt force to the head (35%), falls (33%), and motor vehicle accident/rollover (26%) were the most common mechanisms of injury for nonblast mTBI. There was a higher frequency of loss of consciousness (69%) and alteration of mental state (75%) compared with posttraumatic amnesia (14%), but there was no difference between the blast and nonblast groups for any of these mTBI indicators. Most blast-induced mTBIs occurred while the war fighters were traveling in a vehicle (70%; $p = 0.023$), whereas most non–blast-associated mTBI resulted while performing dismounted duties (59%; $p = 0.045$). Overall, 70% of the patients were diagnosed as having posttraumatic stress disorder (PTSD), with a significantly higher frequency in the blast (78%) than the nonblast (55%) subgroup ($p < 0.001$).

There was no significant difference between the age of patients in the blast and nonblast groups, 28.54 ± 7.73 and 31.08 ± 8.76 years ($p = 0.06$), respectively. Similarly, both groups had completed, on average, a little more than 5 months ($p = 0.14$) of their deployment tour when the trauma occurred. However, the mean number of deployments was significantly greater for the blast group, with 1.99 and 1.71 deployments, respectively ($p = 0.02$). The nonblast group had a greater mean number of days between injury and postinjury eye examination (44.58 days) than the blast group (40.88 days) ($p = 0.002$). All patients had visual acuity correctable to 20/20 at distance and at near with mean spherical equivalent manifest refraction of −0.48 ± 1.86D and −0.63 ± 2.37D for the right eye and the left eye, respectively.

Visual Symptoms and Dysfunctions

Chi-square analyses compared the visual symptoms and diagnoses of patients with mTBI resulting from blast and nonblast mechanisms during different stages after the injury. The results are summarized in Table 3. The prevalence of visual symptoms did not differ significantly between injury mechanism and postinjury stage, except for eye pain and diplopia. Eye pain was higher during

the acute/subacute stage after a blast event ($\chi^2 = 6.41$; $p = 0.04$), and diplopia tended to be higher during the chronic ≤ 1-year period after a nonblast injury ($\chi^2 = 7.17$; $p = 0.03$). Overall, the data showed a very high frequency of visual symptoms and visual dysfunctions. The majority of the visual symptoms and deficits were related to oculomotor problems. The most common visual symptoms were subjective visual complaints (79%), blurred vision at near (66%), reading problems (62%), eye strain (53%), and light sensitivity (40%). The most common visual dysfunctions were posttrauma vision syndrome (37%), accommodative deficit (32%), vergence deficit (26%), vertical deviation (24%), version deficit (24%), visual field defect (22%), and diplopia (20%). Accommodative insufficiency, convergence insufficiency, and defective pursuit eye movements accounted for the majority of the accommodative (83%), vergence (88%), and version (57%) problems, respectively. In addition, we found a very high prevalence of headaches (87%) and dizziness (83%), which can result from visual and oculomotor deficits. Dizziness was more common

TABLE 2.
Injury characteristics

Characteristic	Blast (N = 343)	Non-blast (N = 157)	Total (N = 500)	p
Battle injury				
Yes	343 (100)	43 (27)	275 (75)	<0.001*
No	0 (0)	114 (73)	125 (25)	<0.001*
Injury mechanism				
IED	285 (83)	NA	285 (58)	NA
RPG/grenade	37 (11)	NA	37 (7)	NA
Mortar	21 (6)	NA	21 (4)	NA
Fall	NA	52 (33)	52 (10)	NA
MVA/rollover	NA	41 (26)	41 (8)	NA
Blunt force	NA	55 (35)	55 (11)	NA
Sport/recreation	NA	9 (6)	9 (2)	NA
Evaluated by medic				
Yes	191 (56)	79 (51)	270 (54)	0.885
No	152 (44)	78 (49)	230 (46)	0.872
mTBI indicator				
LOC	239 (70)	105 (67)	344 (69)	0.873
PTA	48 (14)	23 (15)	71 (14)	0.987
AMS	258 (75)	118 (75)	376 (75)	1.000
Mount status				
Mounted	241 (70)	65 (41)	306 (61)	0.023*
Dismounted	102 (30)	92 (59)	194 (39)	0.045*
Configuration				
In-vehicle	203 (59)	61 (39)	264 (53)	0.003*
Out-vehicle/gunner	46 (13)	17 (11)	63 (13)	0.785
Indoor	17 (5)	25 (16)	42 (8)	0.043*
Outdoor	77 (23)	54 (34)	131 (26)	0.055
Duty when injured				
Aircrew	1 (<1)	6 (4)	7 (1)	0.055
Driver	46 (13)	34 (22)	80 (16)	0.040*
Passenger	103 (30)	22 (14)	125 (25)	0.024*
Gunner	63 (18)	12 (8)	75 (15)	0.031*
Patrol	89 (26)	25 (16)	114 (23)	0.023*
Medic	13 (4)	10 (6)	23 (5)	0.533
Support	17 (5)	24 (15)	41 (8)	0.123
Other/NR	11 (3)	24 (15)	35 (7)	0.093
PTSD	266 (78)	86 (55)	352 (70)	<0.001*
	Mean (SD)	Mean (SD)	Mean (SD)	
Age	28.54 (7.73)	31.08 (8.76)	29.33 (8.14)	0.060
Days after injury	40.88 (361.9)	44.58 (297.6)	42.0 (343.0)	0.002†
Months deployed	5.36 (2.84)	5.57 (3.02)	5.35 (2.89)	0.140
No. deployments	1.99 (2.21)	1.71 (2.03)	2.03 (0.99)	0.020†

Data shown as no. patients (%).

*Chi-square statistically significant ($p < 0.05$); †ANOVA statistically significant ($p < 0.05$).

IED, improvised explosive device; RPG, rocket-propelled grenade; MVA, motor vehicle accident; LOC, loss of consciousness (no more than 30 min); PTA, posttraumatic amnesia (no more than 24 h); AMS, alteration of mental state (any); PTSD, posttraumatic stress disorder; NR, not reported. Mount status, if the service member was inside or outside a vehicle when injured; configuration, location of the service member at the time of the injury.

TABLE 3.
Frequency of visual symptoms and diagnoses in war fighters with mTBI

	Blast				Non-blast				Combined	
Characteristic	Acute/ subacute	Chronic ≤1 yr	Chronic >1 yr	Total	Acute/ subacute	Chronic ≤1 yr	Chronic >1 yr	Total	Total	p
Sample size (N)	140	88	115	343	53	57	47	157	500	
Visual symptom										
Subjective visual complaint	111 (79.3)	69 (78.4)	87 (75.7)	267 (77.8)	44 (83.0)	46 (80.7)	39 (83.0)	129 (82.2)	396 (79.2)	0.12
Blur near vision	80 (57.1)	58 (65.9)	73 (63.5)	211 (61.5)	39 (73.6)	42 (73.7)	37 (78.7)	118 (75.2)	329 (65.8)	0.31
Blur distance vision	48 (34.3)	24 (27.3)	33 (28.7)	105 (30.6)	19 (35.8)	21 (36.8)	12 (25.5)	52 (33.1)	157 (31.4)	0.07
Eye strain	79 (56.4)	44 (50.0)	61 (53.0)	184 (53.6)	27 (50.9)	27 (47.4)	29 (61.7)	83 (52.9)	267 (53.4)	0.20
Eye pain	15 (10.7)	1 (1.1)	2 (1.7)	18 (5.2)	4 (7.5)	4 (7.0)	2 (4.3)	10 (6.4)	28 (5.6)	0.04†
Reading issue	84 (60.0)	54 (61.4)	67 (58.3)	205 (59.8)	32 (60.4)	38 (66.7)	35 (74.5)	105 (66.9)	310 (62.0)	0.12
Light sensitivity	60 (42.9)	36 (40.9)	41 (35.7)	137 (39.9)	22 (41.5)	22 (38.6)	21 (44.7)	65 (41.4)	202 (40.0)	0.36
Glare sensitivity	22 (15.6)	13 (14.8)	13 (11.3)	48 (14.0)	12 (22.6)	9 (15.8)	13 (27.7)	34 (21.7)	82 (16.4)	0.52
Visual diagnosis										
Diplopia	25 (17.9)	18 (20.5)	25 (21.7)	68 (19.8)	9 (17.0)	17 (29.8)	6 (12.8)	32 (20.4)	100 (20.0)	0.03†
Strabismus	15 (10.7)	8 (9.1)	11 (9.6)	34 (9.9)	4 (7.5)	4 (7.0)	2 (4.3)	10 (6.4)	44 (8.8)	0.55
Accommodative issues*	47 (33.6)	33 (37.5)	30 (26.1)	110 (32.1)	20 (37.7)	14 (24.6)	16 (34.0)	50 (31.8)	160 (32.0)	0.83
Insufficiency	42 (30.0)	27 (30.7)	22 (19.1)	91 (26.5)	20 (37.7)	10 (17.5)	12 (25.5)	42 (26.8)	133 (26.6)	0.75
Infacility	3 (2.1)	4 (4.5)	3 (2.6)	10 (2.9)	0 (0.0)	1 (1.8)	0 (0.0)	1 (0.6)	11 (2.2)	0.52
Block	2 (1.4)	2 (2.3)	5 (4.3)	9 (2.6)	0 (0.0)	3 (5.3)	4 (8.5)	7 (4.5)	16 (3.2)	0.35
Version issue	26 (18.6)	16 (18.2)	30 (26.1)	72 (21.0)	14 (26.4)	16 (28.1)	17 (36.2)	47 (29.9)	119 (23.8)	0.36
Saccades	17 (12.1)	6 (6.8)	12 (10.4)	35 (10.2)	4 (7.5)	6 (10.5)	6 (12.8)	16 (10.2)	51 (10.2)	0.18
Pursuits	9 (6.4)	10 (11.4)	18 (15.7)	37 (10.8)	10 (18.9)	10 (17.5)	11 (23.4)	31 (19.7)	68 (13.6)	0.54
Fixation issue	21 (15.0)	6 (6.8)	14 (12.2)	41 (12.0)	6 (11.3)	8 (14.0)	5 (10.6)	19 (12.1)	60 (12.0)	0.06
Nystagmus	9 (6.4)	5 (5.7)	3 (2.6)	17 (5.0)	2 (3.8)	3 (5.3)	4 (8.4)	9 (5.7)	26 (5.2)	0.23
Vergence issue	39 (27.9)	21 (23.9)	23 (20.0)	83 (24.2)	14 (26.4)	19 (33.3)	14 (29.8)	47 (29.9)	130 (26.0)	0.11
Convergence insufficiency	36 (25.7)	17 (19.3)	22 (19.1)	75 (21.9)	12 (22.6)	15 (26.3)	13 (27.7)	40 (25.5)	115 (23.0)	0.12
Convergence excess	1 (0.7)	4 (4.5)	1 (0.9)	6 (1.7)	1 (1.9)	1 (1.8)	0 (0.0)	2 (1.3)	8 (1.6)	0.59
Divergence insufficiency	1 (0.7)	0 (0.0)	0 (0.0)	1 (0.3)	1 (1.9)	2 (3.5)	1 (2.1)	4 (2.5)	5 (1.0)	0.36
Divergence excess	2 (1.4)	0 (0.0)	0 (0.0)	2 (0.6)	0 (0.0)	1 (1.8)	0 (0.0)	1 (0.6)	3 (0.6)	0.71
Vertical deviation	32 (22.9)	20 (22.7)	27 (23.5)	79 (23.0)	12 (22.6)	15 (26.3)	16 (34.0)	43 (27.4)	122 (24.4)	0.34
Color vision deficit	7 (5.0)	2 (2.3)	2 (1.7)	11 (3.2)	2 (3.8)	2 (3.5)	1 (2.1)	5 (3.2)	16 (3.2)	0.61
Night vision issues	0 (0.0)	2 (2.3)	0 (0.0)	2 (0.6)	1 (1.9)	1 (1.8)	1 (2.1)	3 (1.9)	5 (1.0)	0.33
Pupil deficit	5 (3.6)	1 (1.1)	3 (2.6)	9 (2.6)	2 (3.8)	2 (3.5)	0 (0.0)	4 (2.5)	13 (2.6)	0.21
Visuospatial issues	9 (6.4)	2 (2.3)	3 (2.6)	14 (4.1)	6 (11.3)	2 (3.5)	3 (6.4)	11 (7.0)	25 (5.0)	0.89
Visual field defect	35 (25.0)	26 (29.5)	19 (16.5)	80 (23.3)	14 (26.4)	7 (12.3)	7 (14.9)	28 (17.8)	108 (21.6)	0.75
VMSS	10 (7.1)	1 (1.1)	5 (4.3)	16 (4.7)	2 (3.8)	1 (1.8)	2 (4.3)	5 (3.2)	21 (4.2)	0.11
Visual neglect	3 (2.1)	0 (0.0)	1 (0.9)	4 (1.2)	0 (0.0)	1 (1.8)	1 (2.1)	2 (1.3)	6 (1.2)	0.15
Posttrauma vision syndrome	57 (40.7)	38 (43.2)	32 (27.8)	127 (37.0)	21 (39.6)	21 (36.8)	17 (36.2)	59 (37.6)	186 (37.2)	0.49
Headaches	130 (92.9)	80 (90.9)	104 (90.4)	314 (91.5)	44 (83.0)	43 (75.4)	35 (74.5)	123 (78.3)	437 (87.4)	0.14
Dizziness	124 (88.6)	71 (80.7)	104 (90.4)	299 (87.2)	44 (83.0)	42 (73.7)	32 (68.1)	118 (75.2)	417 (83.4)	0.04†

Data shown as no. patients (%).
*Excluded patients older than 39 years of age; †χ^2 statistically significant ($p < 0.05$).
VMSS, visual midline shift syndrome.

in individuals who have experienced a blast-induced mTBI event (blast, 87.2% vs. nonblast, 75.9%; $\chi^2 = 6.27$; $p = 0.04$). Similarly, headaches were more common in individuals who have experienced a blast-induced mTBI event (blast, 91.5% vs. nonblast, 78.3%); however, this difference was not statistically significant.

Table 4 summarizes the mean (SD) of the oculomotor functions measured in the study. There were no statistically significant differences (ANOVA) for the measured oculomotor functions in terms of mechanism of injury and stage after injury. However, the data showed that, on average, relative to expected normative values,[18] there was higher near vertical phoria (0.50 ± 1.33 PD), reduced near negative fusional vergence break (15.66 ± 7.82 PD), receded near point of convergence (8.35 cm), decreased stereoacuity (52 sec arc), and reduced positive relative accommodation (−1.80 ± 0.87D).

Ocular Diagnosis

Table 5 summarizes the prevalence of ocular diagnoses during the initial eye examination after the mTBI event. The occurrence of ocular diagnoses in the mTBI sample was very low when compared with visual dysfunctions, regardless of the mechanism of injury. However, the blast group showed higher frequencies for dry eye ($p = 0.003$), retinopathies ($p = 0.014$), and optic neuropathies ($p = 0.018$) than the nonblast group. A total of 23 subjects had documented preexisting ocular diagnoses (i.e., anisocoria, ptosis, retinal breaks/detachments, visual field defect, and dry eyes), therefore were not included in the above analysis. However, these patients were included in the study because the ocular conditions do not affect the results of other visual functions.

DISCUSSION

The current study analyzed visual dysfunctions and symptoms of war fighters who experienced an mTBI event while conducting military operations in Iraq and Afghanistan. These visual deficits were documented during a comprehensive neuro-optometric examination at LRMC. The main objective of the study was to compare, at different stages after the injury, visual deficits and symptoms resulting from blast or nonblast mTBI events. Consistent with previous reports, we found a high frequency of visual dysfunctions and associated visual symptoms.[6,7,9–11,26] However, there were no significant differences in visual symptoms between any of the postinjury stages or injury mechanisms (blast vs. nonblast), except for diplopia and eye pain. Similarly, headaches

TABLE 4.

Frequency of binocular and accommodative visual functions

	Expected	Blast			
Function	Findings*	Acute/subacute	Chronic ≤1 yr	Chronic >1 yr	Total
Binocular					
Sample (N)		140	88	115	343
DLP, PD†	−1.0 (2.0)	−0.10 (4.92)	0.03 (4.35)	0.10 (3.17)	0.01 (4.24)
DVP, PD	0	0.43 (1.33)	0.43 (2.10)	0.24 (0.78)	0.37 (1.43)
NLP, PD†	−3.0 (3.0)	−5.54 (6.30)	−4.02 (5.74)	−3.88 (6.45)	−4.59 (6.24)
NVP, PD	0	0.53 (1.32)	0.55 (2.00)	0.35 (0.76)	0.47 (1.39)
NFV-B, PD	21.0 (6.0)	17.69 (8.40)	12.00 (6.98)	16.06 (8.13)	15.83 (8.23)
NFV- R, PD	11.0 (7.0)	10.49 (5.88)	7.65 (4.25)	11.34 (11.56)	10.14 (8.14)
PFV-B, PD	21.0 (4.0)	16.71 (10.24)	16.71 (8.77)	17.37 (9.73)	16.64 (9.65)
PFV-R, PD	13.0 (5.0)	7.20 (8.33)	8.35 (7.40)	9.14 (8.63)	8.15 (8.16)
NPC, cm	5.0 (2.50)	9.20 (7.19)	7.80 (6.27)	8.69 (7.26)	8.67 (6.99)
Stereo (SA)	≤40.0	53.71 (69.36)	44.32 (46.62)	52.57 (63.69)	50.92 (62.26)
Accommodation‡					
Sample (N)		108	64	93	265
NRA, D	2.50	2.15 (0.78)	2.04 (0.65)	2.11 (0.91)	2.11 (0.80)
PRA, D	−2.50	−1.77 (0.87)	−1.78 (0.90)	−1.70 (0.85)	−1.75 (0.87)

	Non-blast				Combined	
	Acute/subacute	Chronic ≤1 yr	Chronic >1 yr	Total	Total	
Binocular						
Sample (N)	53	57	47	157	500	p
DLP, PD†	0.11 (4.29)	−1.07 (3.35)	−0.45 (3.08)	−0.48 (3.63)	−0.14 (4.06)	0.337
DVP, PD	0.57 (1.67)	0.32 (0.66)	0.36 (0.57)	0.42 (1.10)	0.39 (1.33)	0.554
NLP, PD†	−4.87 (6.67)	−6.12 (5.80)	−5.45 (7.70)	−5.50 (6.68)	−4.88 (6.39)	0.124
NVP, PD	0.55 (1.51)	0.46 (0.69)	0.70 (1.32)	0.56 (1.21)	0.50 (1.33)	0.128
NFV-B, PD	16.00 (6.02)	13.22 (7.94)	16.38 (7.55)	15.41 (7.19)	15.66 (7.82)	0.096
NFV- R, PD	11.37 (4.62)	8.33 (4.80)	11.12 (5.330	10.44 (5.06)	10.26 (7.06)	0.118
PFV-B, PD	19.41 (9.95)	14.22 (9.51)	16.85 (7.88)	16.98 (9.25)	16.98 (9.44)	0.315
PFV-R, PD	10.41 (9.49)	7.50 (7.88)	9.12 (6.14)	9.11 (7.82)	8.55 (7.98)	0.516
NPC, cm	7.25 (4.91)	7.64 (4.88)	8.06 (5.26)	7.63 (4.98)	8.35 (6.44)	0.302
Stereo (SA)	60.19 (79.18)	55.26 (55.26)	46.70 (56.68)	54.36 (69.59)	52.00 (64.60)	0.781
Accommodation‡						
Sample (N)	38	43	36	117	382	
NRA, D	1.72 (0.74)	2.05 (0.77)	2.23 (0.71)	1.98 (0.76)	2.18 (0.74)	0.105
	−1.38 (0.76)	−1.65 (0.92)	−1.83 (0.94)	−1.62 (0.89)	−1.80 (0.87)	0.196

Data shown as mean (SD).

DLP, distance lateral phoria; DVP, distance vertical phoria; NLP, near lateral phoria; NVP, near vertical phoria; NFV-B, negative fusional vergence break; NFV-R, negative fusional vergence recovery; PFV-B, positive fusional vergence break; PFV-R, positive fusional vergence recovery; NPC, near point of convergence; SA, seconds of arc; PRA, positive relative accommodation; NRA, negative relative accommodation; PD, prism diopter; D, diopter.

*Expected findings (Carlson, 2004); †negative (−) sign denotes exophoria; ‡excluded patients 40 years and older.

and dizziness were more common in patients who experienced mTBI from a blast event. However, only dizziness was significantly higher in the blast-related group ($p = 0.04$). This is the first report describing visual sequelae exclusively in war fighters with mTBI and taking into account different injury mechanisms. Because no difference was found in terms of visual sequelae between the subgroups (blast vs. nonblast), this finding suggests that research addressing the assessment and management of mTBI visual sequelae resulting from civilian nonblast events may be relevant to military personnel in combat who sustain blast-induced mTBI.

The mean receded near point of convergence (8.35 cm) and decreased stereoacuity (52 sec arc) found here are consistent with the overall high frequency of convergence insufficiency. Similarly, the reduced positive relative accommodation (-1.80 ± 0.87D) is consistent with the high prevalence of accommodative insufficiency found in this population. There are only three studies quantifying oculomotor functions in patients with mTBI. Although two of these studies used the same mTBI criteria applied in the present study (i.e., loss of consciousness ≤30 min, posttraumatic amnesia ≤24 h, any alteration of mental state, Glasgow Coma Scale score from 13 to 15), the studies were conducted in relatively small samples of civilian nonblast ($N = 32$)[27] and military blast ($N = 40$)[7] mTBI patients. Consistent with the present study, the mean values for near point of convergence, stereoacuity, near exophoria, and vertical deviations were elevated, whereas the positive fusional vergence break was reduced in both of the previous studies. There

TABLE 5.
Frequency of ocular diagnoses

Diagnosis	Blast (N = 343)	Non-blast (N = 157)	Total (N = 500)	p
Eyelids				
Ptosis	3 (0.9)	4 (2.5)	7 (1.4)	0.414
Laceration	1 (0.3)	5 (3.2)	4 (1.2)	0.059
Bell palsy	1 (0.3)	0 (0.0)	1 (0.2)	1.000
Conjunctiva				
Pterygium	1 (0.3)	0 (0.0)	1 (0.2)	1.000
Subhemorrhages	1 (0.3)	1 (0.6)	2 (0.4)	1.000
Cornea				
Dry eye	24 (7.0)	3 (1.9)	28 (5.4)	0.003*
Endothelial defect	1 (0.3)	1 (0.6)	2 (0.4)	1.00
Foreign body	2 (0.6)	0 (0.0)	2 (0.4)	0.484
Scar	3 (0.9)	3 (1.9)	6 (1.2)	1.000
Iris/AC				
Uveitis	0 (0.0)	4 (2.5)	4 (0.8)	0.062
Lens				
Cataract	3 (0.9)	3 (1.9)	6 (1.2)	1.000
Exfoliation	1 (0.3)	0 (0.0)	1 (0.2)	1.000
Vitreous/retina				
Floaters/traction	2 (0.6)	1 (0.6)	3 (0.6)	1.00
Retinopathy	8 (2.3)	1 (0.6)	9 (1.8)	0.014*
Breaks	2 (0.6)	0 (0.0)	2 (0.4)	0.484
Optic nerve				
OHT	1 (0.3)	1 (0.6)	2 (0.4)	1.000
Glaucoma	3 (0.9)	1 (0.6)	4 (0.8)	0.494
Neuropathy	6 (1.7)	1 (0.6)	7 (1.4)	0.018*
Globe/orbit				
Exophthalmos	0 (0.0)	1 (0.6)	1 (0.2)	1.000
Floor fracture	0 (0.0)	4 (2.5)	4 (0.8)	0.276

Data shown as no. patients (%).
*Fisher exact test statistically significant ($p < 0.05$).
AC, anterior chamber; OHT, ocular hypertension.

were small discrepancies in the values compared with those two studies, which could be explained by the difference in sample size. However, the two prospective studies and the current study show a high frequency of light sensitivity and saccadic dysfunction. The third retrospective study conducted within the Department of Veterans Affairs (VA) used the same criteria for mTBI diagnosis but in a larger population.[28] This study, of 50 blast and 50 nonblast patient records, also found a high frequency of visual symptoms as well as saccadic, accommodative, and convergence dysfunction. In addition, the present study is in agreement with the results of a recent study describing chronic (>12 months) visual dysfunctions in veterans after blast-induced mTBI.[29] Magone et al.[29] found that the most common visual complaints were photophobia (55%) and reading difficulties (32%), which correlate with the 58% and 36%, respectively, found in the *Chronic > 1 year* subgroup of the current study.

We also found a large frequency of vertical deviation, corroborating an observation previously reported in samples of nonblast and blast mTBI patients.[7,27] An individual with a vertical deviation may tilt the head to help mechanically align the eyes, which, in turn, may disrupt the fluid of the inner ear, resulting in dizziness and balance disorders.[30,31] Furthermore, vertical deviation in TBI patients can be associated with lightheadedness, diplopia, poor depth perception, eye pain, headaches, reading difficulties, and blurred vision at near.[30,31] Consequently, the correction of vertical deviation with prisms before initiating any other rehabilitation modality can positively impact the mTBI patient's overall rehabilitation outcome and quality of life.

The period of natural recovery after mTBI is reported to be as long as 1 to 2 years after injury; however, symptoms may persist after therapy.[32] The fact that nearly one-third of all the patients in the present study sought care for postconcussion syndrome with visual sequelae more than a year after the injury emphasizes the importance of persistent visual sequelae and the continuous need for specialized vision rehabilitation care in the military and, subsequently, in VA medical treatment facilities.

The overall lack of significant differences between blast and nonblast mTBI groups in visual symptoms and dysfunctions is consistent with other studies that document that psychological and cognitive deficits in veterans with mTBI are not significantly different based on the injury mechanism.[33,34] Luethcke et al.[34] also found that, during the acute postinjury stage, there were no differences between injury mechanism (blast vs. nonblast) in the concussive and psychological symptoms, including vision, balance, memory, concentration, sleep, hearing, and irritability. Similarly, another study by Belanger et al.[4] showed that cognitive sequelae of mTBI were not different based on the injury mechanism with an average of 2 years after injury. In addition, they found a

marginally increased incidence of reported PTSD symptoms among blast-injured participants. This is in agreement with the finding of higher frequency of PTSD in the blast population documented in the present study. Behavioral data from this study will be reviewed in a separate manuscript currently in preparation.

The frequency of ocular diagnosis in this mTBI population was relatively small; however, dry eye was the most common diagnosis among these war fighters, with a higher frequency in the blast group ($p = 0.003$). The diagnosis of dry eye was recently reported by Cockerham et al.[35] in 32% of veterans with mTBI evaluated between 1 and 60 months after injury. Although in a lower frequency (7 vs. 32%), the present study is in agreement with findings of Cockerham et al.[35] that there is a threefold increase in the frequency of dry eye in individuals who sustained an mTBI from a blast injury when compared with a nonblast event. They also found that age and time after injury were not predictors of dry eye.

Recently, Goodrich et al.[36] completed a Delphi study with the intent of developing clinical guidelines and improving the consistency of visual examinations of veterans with mTBI. The Delphi study recommended a set of clinical guidelines composed of 17 history questions and an 11-item examination to diagnose mTBI. The procedures and associated methodology recommended in the Delphi study were the same used in the present study to assess oculomotor functions (i.e., accommodation, vergence, and version eye movements). Ten of the 11 recommended examination testing on the Delphi study overlap with the present study, including the distance and near cover test, pursuit and saccades testing, accommodation, near point of convergence, phorias, fixation, stereopsis, and light sensitivity/photophobia. In addition, 11 of the 17 Delphi-recommended history questions were included in the present study and proven significant to guide the assessment and to determine the accurate diagnosis (i.e., date of injury, loss of consciousness, alteration of mental state, eye pain, change in vision, light sensitivity, double vision, blur vision at distance or near, reading issues, headaches after near tasks). The results from the present study suggests that the Delphi study recommendations of clinical guidelines could be adopted by both the VA and the Department of Defense to ensure a continuum of care as war fighters transition their eye care between these federal treatment facilities.

The primary limitation of the current study is its retrospective nature. The data were not collected with the intention of further analysis; therefore, there is likely variation in the testing procedures and the history taken during the patient encounter. Second, the lack of a control cohort and the fact that not all subjects had a baseline eye examination with oculomotor assessment prevent the accurate estimation of visual deficits resulting from a deployment injury; therefore, the number of subjects who had preexisting oculomotor dysfunctions might lead to an overestimation of visual sequelae associated to the injury. Third, this study did not assess the cumulative effect of past mTBI/concussion since some of the patient histories indicated prior mild head injury.

Future research should investigate preinjury and postinjury oculomotor functions through predeployment baselines for a large number of war fighters. This should include a cohort of war fighters that deployed but did not sustain a head injury to assess if factors associated to the deployment contribute to visual deficits (e.g., stress, PTSD, environmental).

CONCLUSIONS

Consistent with previous reports, this study documents the high frequency of visual dysfunctions and associated visual symptoms in war fighters with mTBI. However, overall, there were no significant differences in visual sequelae and symptoms between stages after injury and the injury mechanism (i.e., blast vs. nonblast). The results of the current study, coupled with previous studies suggesting that there is no difference in symptoms based on time after injury or mechanism of combat injury (blast vs. nonblast), suggest that research addressing the assessment and management of mTBI visual sequelae resulting from civilian nonblast event may be relevant to military personnel in combat resulting primarily from a blast event.

The fact that nearly one-third of all patients in the present study had significant visual sequelae and complaints more than a year after the injury emphasizes the concern of persistent visual sequelae and the continuous need for specialized vision rehabilitation care by military and VA eye care providers. The findings of the present study correlate with the clinical guidelines (17 history questions and 11-item examination procedures) recommended in the Delphi study and highlight the need for these clinical guidelines to be adopted by both the VA and the Department of Defense to improve the consistency of visual examinations of military personnel with mTBI and ensure a continuum of care as war fighters transition their eye care between these treatment facilities.

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