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Visual dysfunction following blast-related traumatic brain injury from the battlefield

AMBER L. DOUGHERTY, ANDREW J. MACGREGOR, PEGGY P. HAN, KEVIN J. HELTEMES, & MICHAEL R. GALARNEAU

Department of Medical Modeling, Simulation, and Mission Support, Naval Health Research Center, San Diego, CA, USA

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Abstract

Primary objective: To assess the occurrence of ocular and visual disorders following blast-related traumatic brain injury (TBI) in Operation Iraqi Freedom.

Research design: Retrospective cohort study.

Methods and procedures: A total of 2254 US service members with blast-related combat injuries were identified for analysis from the Expeditionary Medical Encounter Database. Medical record information near the point of injury was used to assess factors associated with the diagnosis of ocular/visual disorder within 12 months after injury, including severity of TBI.

Main outcomes and results: Of 2254 service members, 837 (37.1%) suffered a blast-related TBI and 1417 (62.9%) had other blast-related injuries. Two-hundred and one (8.9%) were diagnosed with an ocular or visual disorder within 12 months after blast injury. Compared with service members with other injuries, odds of ocular/visual disorder were significantly higher for service members with moderate TBI (odds ratio (OR) = 1.58, 95% confidence interval (CI) = 1.02–2.45) and serious to critical TBI (OR = 14.26, 95% CI = 7.00–29.07).

Conclusions: Blast-related TBI is strongly associated with visual dysfunction within 1 year after injury and the odds of disorder appears to increase with severity of brain injury. Comprehensive vision examinations following TBI in theatre may be necessary.

Keywords: *TBI, ocular and visual disorder, combat injury, military*

Introduction

Changes in the nature of warfare during the current military conflicts in Iraq and Afghanistan have led to an increase in traumatic brain injuries (TBIs) not experienced in previous wars [1–3]. These injuries are often associated with explosive weaponry, such as improvised explosive devices, that can cause a wide range of penetrating and non-penetrating injuries [4, 5]. Blasts have been responsible for ~75% of all combat casualties in Iraq and Afghanistan [6] and for more than 85% of all head, face and neck injuries [5]. Improvements in protective equipment have reduced the frequency and severity of penetrating injuries, but they provide limited protection for non-penetrating injuries, such as concussion resulting from the blast wave of a high-energy explosion [7]. In addition, advances in battlefield medicine and medical response times have improved the survivability of wounds that were fatal in previous wars [8]. Together, these changes have resulted in a new pattern of injuries among survivors. TBI has emerged as a preponderant injury of Operations Enduring Freedom and Iraqi Freedom [9].

Survivors of TBI experience a wide range of physical, cognitive and emotional symptoms and

Correspondence: Amber L. Dougherty, Naval Health Research Center, 140 Sylvester Road, San Diego, CA 92106, USA. Tel: +1 (619) 368 6853. Fax: +1 (619) 553 8378. E-mail: amber.dougherty@med.navy.mil

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often require a complex and integrative approach to rehabilitative care [10, 11]. Visual problems are among the most common physical sequelae following a TBI [12, 13]. The occurrence of TBI-related ocular and visual disorders is varied, depending on the diagnostic criteria, condition and patient population, but has primarily been studied in civilian settings where blunt force trauma is often cited as the cause of injury [12, 14–16]. Visual dysfunction following TBI in a combat setting has not been widely examined, nor have the effects of blast-related TBI on vision. The aim of the present study was to assess the occurrence of visual dysfunction following blast-related TBI among US service members injured during combat deployment in Operation Iraqi Freedom.

Methods

Study sample

The study sample was identified from the Expeditionary Medical Encounter Database (EMED), formerly the Navy-Marine Corps Combat Trauma Registry, which is maintained by the Naval Health Research Center in San Diego, CA. The EMED contains information abstracted from US service members' medical records completed by military providers at forward-deployed treatment facilities in the combat zone, nearest to the point of injury, and is merged with inpatient and outpatient medical record information obtained from other US Department of Defense databases [17].

From the EMED, US service members who met the following criteria were included in this study: (a) having survived injury due to an explosion (or blast) in Operation Iraqi Freedom between 1 March 2004 and 28 February 2007, (b) having only one recorded injury event and (c) having not received a diagnosis of ocular or visual disorder prior to the injury event. Those who sustained eye injury were excluded from analysis in order to minimize confounding. This research was conducted in compliance with all applicable US federal regulations governing the protection of human subjects.

Measures

Demographic information included age and military rank (enlisted or officer) at the time of injury and gender. The cause of injury was indicated on service members' clinical records from theatre and was categorized as improvised explosive device, landmine, mortar, rocket-propelled grenade and blast, other/unspecified. Traumatic brain injury, the exposure of interest, was defined according to criteria established by the Centers for Disease Control and Prevention as indicated by any one of the following *International Classification of Diseases, Ninth Revision, Clinical Modification* (ICD-9-CM) codes: 800.0–801.9, 803.0–804.9 or 850.0–854.1 [18]. The Abbreviated Injury Scale (AIS) 2005 was used to describe severity of brain injury [19]. The AIS details the severity of each injury in nine body regions and ranges from 0 (no injury) to 6 (unsurvivable injury). Due to a small number of TBI observations with scores of 4 (severe injury) and 5 (critical injury) in the present study, TBI severity was categorized as follows: 0 = no TBI, 1 = minor, 2 = moderate and 3–5 = serious to critical. Service members with AIS scores of 6 were not eligible for inclusion in this study.

The main outcome measure, ocular/visual disorder, was indicated by the ICD-9-CM diagnostic codes for 'disorders of the eye and adnexa' (360.0–379.9) obtained from electronic outpatient medical records (Standard Ambulatory Data Record) and diagnosed within 12 months after blast-related combat injury.

Statistical analysis

Descriptive and univariate analyses were performed using SPSS software, v. 17.0 (SPSS Inc., Chicago, IL). The prevalence of ocular/visual disorder was calculated for the sample. Differences in demographic and injury characteristics between groups with and without TBI were assessed with the Mann-Whitney U-test for non-normally distributed, continuous data (i.e. age) and with chi-square (χ^2) tests for categorical data. Simple logistic regression was performed to ascertain odds ratios and 95% confidence intervals for characteristics associated with diagnosis of ocular/visual disorder. The StatCalc program in Epi Info software version 6 was used to perform the Mantel extension of chi-square test for trend (χ_{trend}) to assess a dose-dependent relationship between severity of TBI and diagnosis of ocular/visual disorder. An alpha level of 0.05 was used to determine statistical significance for all tests.

Results

The study sample consisted of 2254 US service members injured by an explosive weapon during a 3-year period of Operation Iraqi Freedom. Median age at the time of injury was 23 years and ranged from 18–59 years. The majority of service members were male (99.0%) and were enlisted (95.9%). Approximately 8.9% (201 of 2254) were diagnosed with ocular/visual disorder within 12 months after injury in a blast event.

Thirty-seven per cent of the sample ($n = 837$) were diagnosed with a blast-related TBI during

Table I. Demographic and injury characteristics of blast-injured US service members from Operation Iraqi Freedom by TBI status.

Characteristic	Total ($n = 2254$)	TBI ($n = 837$)	Other injury ($n = 1417$)	p
Ocular/visual disorder, no. (%)				0.01
Yes	201 (8.9)	91 (10.9)	110 (7.8)	
No	2053 (91.1)	746 (89.1)	1307 (92.2)	
Median age (range), years	23 (18–59)	22 (19–53)	23 (18–59)	0.19
Gender, no. (%)				0.13
Male	2231 (99.0)	832 (99.4)	1399 (98.7)	
Female	23 (1.0)	5 (0.6)	18 (1.3)	
Military rank, no. (%)				0.04
Enlisted	2162 (95.9)	812 (97.0)	1350 (95.3)	
Officer	92 (4.1)	25 (3.0)	67 (4.7)	
Blast mechanism, no. (%)				<0.001
Improvised explosive device	1563 (69.3)	703 (84.0)	860 (60.7)	
Mortar	188 (8.3)	19 (2.3)	169 (11.9)	
Rocket-propelled grenade	113 (5.0)	26 (3.1)	87 (6.1)	
Landmine	111 (4.9)	47 (5.6)	64 (4.5)	
Other/unspecified	279 (12.4)	42 (5.0)	237 (16.7)	

the study period. The characteristics of service members with TBI and with other injury are compared in Table I. Median age and gender did not statistically differ by TBI status. Traumatic brain injury status differed, however, by military rank, injury mechanism and ocular/visual disorder outcome. Compared with service members without TBI, higher proportions of those with TBI were enlisted (97.0% vs 95.3%, $p = 0.04$) and were injured by an improvised explosive device (84.0% vs 60.7%, $p < 0.001$). Ocular/visual disorder diagnosis was more common among those with TBI than service members with other injuries (10.9% vs 7.8%, $p = 0.01$).

Ocular/visual disorder diagnoses by TBI status, based on the ICD-9-CM category descriptions, are shown in Table II. Overall, the most common disorders were 'disorders of refraction and accommodation' and 'visual disturbances' (see Appendix for a detailed list of diagnoses within these categories). Although 'disorders of refraction and accommodation' were proportionally higher among service members with TBI than those without (7.3% vs 5.8%), the difference was not statistically significant. 'Visual disturbance' disorders and 'disorders of conjunctiva', however, were statistically more common in the TBI than the other injury group (1.9% vs 0.6%, $p = 0.003$, and 1.6% vs 0.6%, $p = 0.03$, respectively).

In Table III, simple logistic regression (univariate) analyses show the odds of new-onset ocular/visual disorder following blast-related injury by sample characteristics. Age, gender, military rank and blast mechanism were not associated with diagnosis of ocular/visual disorder. In order to assess for difference in odds by severity of brain injury, service members were categorized as no TBI, minor, moderate and serious-to-critical. Compared with service members without TBI, those with minor TBI did not have statistically different odds of new-onset ocular/visual disorder ($p = 0.88$). The odds of new-onset ocular/visual disorder were statistically higher, however, among service members with moderate TBI (odds ratio (OR) = 1.58, 95% confidence interval (CI) = 1.02–2.45) and serious-to-critical TBI (OR = 14.26, 95% CI = 7.00–29.07). Figure 1 demonstrates the upward trend in odds of ocular/visual disorder by increasing brain injury severity (Mantel $\chi_{\text{trend}} = 28.063$, $p < 0.001$).

Discussion

In the present study, 37% of service members sustained a blast-related TBI during combat deployment. These personnel were significantly more likely to be diagnosed with an ocular or visual disorder than service members with other blast-related injuries. Furthermore, the findings demonstrate a dose-dependent effect of brain injury severity on visual dysfunction, in that the odds of ocular or visual disorder diagnosis increases with brain injury severity. This finding is not altogether surprising as injury severity is known to be linearly associated with morbidity, mortality, hospitalization and other measures of severity [19–21].

Previous literature has demonstrated an occurrence of visual dysfunction in 30–85% of civilian and military samples with occult TBI [7, 12, 22]. In the present study, only 11% of those with TBI, overall, were diagnosed with visual dysfunction within 1 year of blast-related combat injury. This discrepancy in the occurrence of visual dysfunction following TBI

Table II. Number and percentage of US service members in each ocular/visual disorder diagnostic category by TBI status.

ICD-9-CM code and category[a]		TBI ($n=837$)		Other injury ($n=1417$)	
360	Disorders of the globe	0		1	<0.1%
361	Retinal detachments and defects	0		1	<0.1%
362	Other retinal disorders	2	0.2%	4	0.3%
363	Chorioretinal inflammations, scars and other disorders of choroid	1	0.1%	0	
364	Disorders of iris and ciliary body	1	0.1%	3	0.2%
365	Glaucoma	3	0.4%	2	0.1%
366	Cataract	1	0.1%	1	<0.1%
367	Disorders of refraction and accommodation	61	7.3%	82	5.8%
368	Visual disturbances*	16	1.9%	8	0.6%
369	Blindness and low vision	3	0.4%	2	0.1%
370	Keratitis	3	0.4%	3	0.2%
371	Corneal opacity and other disorders of cornea	2	0.2%	5	0.4%
372	Disorders of conjunctiva**	13	1.6%	9	0.6%
373	Inflammation of eyelids	1	0.1%	1	<0.1%
374	Other disorders of eyelids	3	0.4%	5	0.4%
375	Disorders of lacrimal system	1	0.1%	4	0.3%
376	Disorders of orbit	1	0.1%	0	
377	Disorders of optic nerve and visual pathways	1	0.1%	4	0.3%
378	Strabismus and other disorders of binocular eye movements	5	0.6%	5	0.4%
379	Other disorders of eye	5	0.6%	5	0.4%

Individuals may be represented in multiple diagnostic categories.
[a]Each category is calculated as a separate variable.
*$\chi^2=9.063$, $p=0.003$. **$\chi^2=4.585$, $p=0.03$.

Table III. Descriptive and univariate analyses of ocular/visual disorder outcome among blast-injured US service members from Operation Iraqi Freedom ($n=2254$).

Variable	Ocular/visual disorder ($n=201$)		No disorder ($n=2053$)		Odds ratio	95% CI	p
Traumatic brain injury, no. (%)							<0.001
No	110	(54.7)	1307	(63.7)	Ref		
Minor	45	(22.4)	520	(25.3)	1.03	0.72–1.48	0.88
Moderate	28	(13.9)	211	(10.3)	1.58	1.02–2.45	0.04
Serious-to-critical	18	(9.0)	15	(0.7)	14.26	7.00–29.07	<0.001
Median age[a] (range), years	22	(19–53)	23	(18–59)	1.38	0.66–2.87	0.39
Gender, no. (%)							0.49
Male	193	(98.5)	2033	(99.0)	Ref		
Female	3	(1.5)	20	(1.0)	1.54	0.45–5.23	
Military rank, no. (%)							0.30
Enlisted	190	(94.5)	1972	(96.1)	Ref		
Officer	11	(5.5)	81	(3.9)	1.41	0.74–2.69	
Blast mechanism, no. (%)							0.47
Improvised explosive device	140	(69.7)	1423	(69.3)	Ref		
Mortar	15	(7.5)	173	(8.4)	0.88	0.51–1.54	0.66
Rocket-propelled grenade	9	(4.5)	104	(5.1)	0.88	0.44–1.78	0.72
Landmine	15	(7.5)	96	(4.7)	1.59	0.90–2.81	0.11
Other/unspecified	22	(10.9)	257	(12.5)	0.87	0.55–1.39	0.56

CI, confidence interval; Ref, reference group.
[a]Age was log transformed for univariate analysis due to non-normal distribution.

may be explained by the difference in assessment of outcome. Generally, previous studies used prospective visual screening, clinical evaluation measures or self-report data to identify visual problems, whereas, in the present study, the occurrence of dysfunction was retrospectively assessed by the presence of an ocular or visual disorder diagnosis in the service members' existing medical record. Without thoroughly evaluating all patients, one is likely underestimating the occurrence of ocular and visual problems among service members with blast-related combat injury.

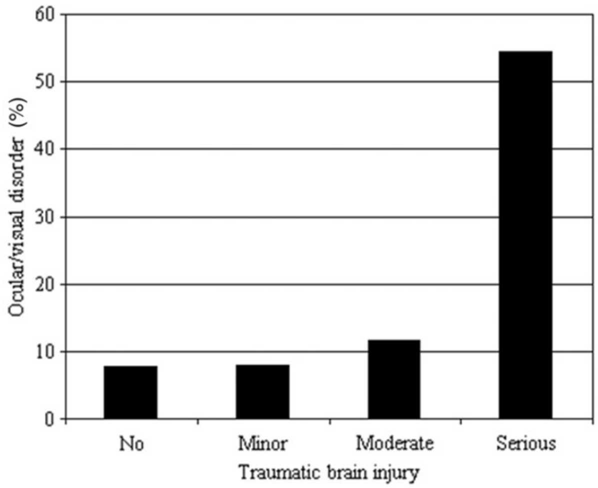

Figure 1. Percentage of US service members with ocular/visual disorder by traumatic brain injury status.
Note: Mantel $\chi_{\text{trend}} = 28.063$, $p < 0.001$.

The primary finding of the present study was the strong dose-dependent relationship between severity of TBI and the occurrence of visual dysfunction. These disorders should be considered common sequelae of moderate and serious-to-critical TBI among blast-injured combat veterans and clinical interventions should be applied appropriately. Although the association between minor TBI and ocular/visual disorder did not achieve statistical significance, those with minor blast-related TBI (or concussions) may still be at risk for developing vision problems. In a recent study of combat-injured service members with self-reported mild TBI, the majority reported visual complaints and presented with visual dysfunctions, such as accommodative insufficiency [22]. Many patients with minor injuries, including mild TBI, are immediately returned to duty following treatment in theatre [5, 23]. Because visual problems reduce the ability to perform daily activities (e.g. reading) [12] and might further affect one's abilities to perform duties required during combat deployment, administration of comprehensive visual examinations in theatre following any severity of TBI and especially blast-induced injury should be considered.

The primary limitation of this study was the retrospective nature of the analysis; data were not collected for the purpose of this study. Further, in order to minimize confounding, the analysis included only those without eye injury. Future research should assess the potential cumulative effects blast-related eye injury and TBI may have on the short- and long-term visual outcomes among combat veterans. As mentioned previously, because the outcome data were diagnoses of patients who presented for care rather than a vision assessment of all patients in the sample, this analysis may underestimate the true prevalence of impairment.

Despite these limitations, this study is unique because it examined new-onset visual dysfunction in a large cohort of blast-injured veterans and assessed the outcome in US service members with all types of injuries, ranging from minor to severe. Furthermore, it is the first to identify a statistical relationship between severity of TBI and subsequent diagnosis of ocular/visual disorder in a blast-injured population. As blast mechanisms, such as improvised explosive devices, continue to cause the majority of injuries among military personnel serving in Operations Enduring Freedom and Iraqi Freedom, further research of the effects of blast-related brain injury will be needed.

Conclusion

Given the occurrence of vision problems in the growing population of service members with blast-related TBI, strategies for diagnosis and management of these conditions are needed and should be included in TBI treatment protocols. Comprehensive vision examinations after TBI in theatre may be necessary in order to identify undiagnosed cases of ocular/visual disorder. For veterans with undiagnosed TBI, Post-Deployment Health Assessments, which contain questions about exposure to blasts and brain injury experience (e.g. losing consciousness), may be used to identify service members who may require vision assessments and/or rehabilitation. Future research should include population-based studies and screening among returning service members to elucidate specific ocular and visual conditions associated with blast-related TBI, in order to develop appropriate rehabilitation guidelines.

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References

1. Reister FA. Medical Statistics in World War II. Washington, DC: Department of the Army, Office of the Surgeon General; 1975. p 21.
2. Reister FA. Battle casualties and medical statistics: US army experience in the Korean War. Washington, DC: Department of the Army, Office of the Surgeon General; 1973. Chapter 3.
3. Okie S. Traumatic brain injury in the war zone. New England Journal of Medicine 2005;352:2043–2047.
4. Xydakis MS, Fravell MD, Nasser KE, Casler JD. Analysis of battlefield head and neck injuries in Iraq and Afghanistan. Otolaryngology—Head and Neck Surgery 2005;133: 497–504.
5. Wade AL, Dye JL, Mohrle CR, Galarneau MR. Head, face, and neck injuries during Operation Iraqi Freedom II: Results from the US Navy-Marine Corps Combat Trauma Registry. Journal of Trauma 2007;63:836–840.
6. IOM (Institute of medicine). Gulf War and health. Vol. 7: Long-term consequences of traumatic brain injury. Washington, DC: the National Academies press; 2009.
7. Lew HL, Poole JH, Alvarez S, Moore W. Soldiers with occult traumatic brain injury. American Journal of Physical Medicine & Rehabilitation 2005;84:393–398.
8. Champion HR, Bellamy RF, Roberts P, Leppaniemi A. A profile of combat injury. Journal of Trauma 2003;54: S13–S19.
9. Department of Defense Task Force on Mental Health. An achievable vision: Report of the Department of Defense Task Force on mental health. Falls Church, VA: Defense Health Board; 2007.
10. Lew HL, Poole JH, Guillory SB, Salerno RM, Leskin G, Sigford B. Persistent problems after traumatic brain injury: The need for long-term follow-up and coordinated care. Journal of Rehabilitation Research and Development 2006;43:vii–x.
11. Hoge CW, McGurk D, Thomas JL, Cox AL, Engel CC, Castro CA. Mild traumatic brain injury in U.S. soldiers returning from Iraq. New England Journal of Medicine 2008;358:453–463.
12. Kapoor N, Ciuffreda KJ. Vision disturbances following traumatic brain injury. Current Treatment Options in Neurology 2002;4:271–280.
13. Suchoff IB, Kapoor N, Ciuffreda KJ, Rutner D, Han E, Craig S. The frequency of occurrence, types, and characteristics of visual field defects in acquired brain injury: A retrospective analysis. Optometry 2008;79:259–265.
14. Poggi G, Calori G, Mancarella G, Colombo E, Profice P, Martinelli F, Triscari C, Castelli E. Visual disorders after traumatic brain injury in developmental age. Brain Injury 2000;14:833–845.
15. Schlageter K, Gray B, Hall K, Shaw R, Sammet R. Incidence and treatment of visual dysfunction in traumatic brain injury. Brain Injury 1993;7:439–448.
16. McKenna K, Cooke DM, Fleming J, Jefferson A, Ogden S. The incidence of visual perceptual impairment in patients with severe traumatic brain injury. Brain Injury 2006;20:507–518.
17. Galarneau M, Hancock WC, Konoske P, Melcer T, Vickers RR, Walker GJ, Zouris JM. The Navy-Marine Corps Combat Trauma Registry. Military Medicine 2006;171:691–697.
18. Thurman DJ, Sniezek JE, Johnson D, Greenspan A, Smith SM. Guidelines for surveillance of central nervous system injury. Atlanta, GA: Centers for Disease Control and Prevention; 1995.
19. Gennarelli T, Wodzin E. The Abbreviated Injury Scale-2005. Des Plaines, IL: Association for the Advancement of Automotive Medicine; 2005.
20. Baker SP, O'Neill B, Haddon W, Long WB. The Injury Severity Score: A method for describing patients with multiple injuries and evaluating emergency care. Journal of Trauma 1974;14:187–196.
21. Copes WS, Champion HR, Sacco WJ, Lawnick MM, Keast SL, Bain LW. The Injury Severity Score revisited. Journal of Trauma 1988;28:69–76.
22. Brahm KD, Wilgenburg HM, Kirby J, Ingalla S, Chang C-Y, Goodrich GL. Visual impairment and dysfunction in combat-injured service members with traumatic brain injury. Optometry and Vision Science 2009;86:817–825.
23. Dougherty AL, Mohrle CR, Galarneau MR, Woodruff SI, Dye JL, Quinn KH. Battlefield extremity injuries in Operation Iraqi Freedom. Injury 2009;40:772–777.

Appendix: ICD-9-CM codes and diagnoses for 'disorders of refraction and accommodation' and 'visual disturbances'

Disorders of refraction and accommodation
367.0 Hypermetropia (farsightedness, hyperopia)
367.1 Myopia (nearsightedness)
367.2 Astigmatism
367.3 Anisometropia and aniseikonia
367.4 Presbyopia
367.5 Disorders of accommodation
367.8 Other disorders of refraction and accommodation
367.9 Unspecified disorder of refraction and accommodation
Visual disturbances
368.0 Amblyopia ex anopsia
368.1 Subjective visual disturbances
368.2 Diplopia (double vision)
368.3 Other disorder of binocular vision
368.4 Visual field deficits
368.5 Colour vision deficiencies (colour blindness)
368.6 Night blindness (nyctalopia)
368.8 Other specified visual disturbance
368.9 Unspecified visual disturbance

ICD-9-CM, International Classification of Diseases, Ninth Revision, Clinical Modification [18].