1040-5488/09/8607-0817/0 VOL. 86, NO. 7, PP. 817–825
OPTOMETRY AND VISION SCIENCE

ORIGINAL ARTICLE

Visual Impairment and Dysfunction in Combat-Injured Servicemembers With Traumatic Brain Injury

Karen D. Brahm*, Heidi M. Wilgenburg*, Jennine Kirby*, Shanida Ingalla*, Chea-Yo Chang†, and Gregory L. Goodrich‡

ABSTRACT

Purpose. The purpose of this study was to determine the frequencies of visual impairment and dysfunction among combat-injured Polytrauma Rehabilitation Center (PRC) inpatient and Polytrauma Network Site (PNS) outpatient military personnel with traumatic brain injury (TBI).

Methods. A retrospective analysis of data from vision screenings of 68 PRC-inpatients with moderate to severe levels of TBI and 124 PNS-outpatients with mild TBI at the VA Palo Alto Health Care System was conducted.

Results. Eighty-four percent of PRC-inpatients and 90% of PNS-outpatients had TBIs associated with a blast event. The majority of patients in both the PRC and PNS populations had visual acuities of 20/60 or better (77.8% PRC, 98.4% PNS). Visual dysfunctions (e.g., convergence, accommodative, and oculomotor dysfunction) were common in both PRC and PNS populations. In the PRC-inpatient population, acuity loss of 20/100 to no light perception (13%) and visual field defects (32.3%) were found. In the PNS-outpatient population, acuity loss of 20/100 to no light perception (1.6%) and visual field defects (3.2%) were infrequently found. In both the PRC and PNS populations, visual field defects were more often associated with blast than non-blast events.

Conclusions. Blast events were the most frequent mechanism of injury associated with TBI in combat-injured servicemembers. The vision findings suggest that combat troops exposed to blast with a resulting mild TBI are at risk for visual dysfunction, and combat troops with polytrauma injuries are at risk for visual dysfunction and/or visual impairment. The visual consequences of such injuries necessitate further study and support the need for appropriate evaluation and treatment in all severities of TBI.

(Optom Vis Sci 2009;86:817–825)

Key Words: traumatic brain injury, binocular vision, vision disorders, blast injuries, vision screening

Warfare has long produced injuries that result in vision loss and blindness. However, the vision-related injuries resulting from war have changed with the onset of hostilities in Iraq and Afghanistan.[1,2] The purpose of this study was to improve our understanding of vision-related impairments and dysfunctions occurring to military servicemembers in Iraq and Afghanistan. We present data on the effects of combat injuries on vision within two groups of patients whose injuries include traumatic brain injury (TBI). These patients were injured in conflicts referred to as Operation Iraqi Freedom (OIF), which began on March 19, 2003, and Operation Enduring Freedom (OEF), which began on October 7, 2001. Although our focus is on military servicemembers, it should be noted that similar mechanisms of injury may also affect the civilian population. Other causes of TBI include falls and motor vehicle accidents, which result in over 650,000 cases of TBI in the United States per year.[3] For the purpose of this article, we will confine our discussion to vision-related impairments and dysfunctions impacting military servicemembers.

It has been reported that approximately 90% of all U.S. military casualties in the current conflicts in Iraq and Afghanistan survive.[4] This is an improvement from a 70% survival rate in World War II, and a 76% survival rate in Vietnam and the first Gulf War.[4] The increased survival rate in the current conflicts is thought to be primarily due to improved medical response time and treatments

*OD
†OD, FAAO
‡PhD, FAAO
Western Blind Rehabilitation Center, VA Palo Alto Health Care System, Palo Alto, California.

as well as other technological advancements, such as Kevlar head and body armor.[4]

Despite improvements in head protection and protective eye wear, the incidence of eye injuries in OIF/OEF has been higher than reported in previous wars. In World War II, for example, the incidence of eye injuries was 2% and increased up to 9% during the Vietnam War.[5,6] A 13% incidence of eye injuries was reported during the first Gulf War.[1] In a study of soldiers who were evacuated from OIF/OEF between March 2003 and December 2004, it was determined that 15.8% of all medical evacuations were due to combat-related eye injuries.[6] Approximately 65% of all OIF/OEF casualties are the result of blast events.[7] These events include exposure to improvised explosive devices, rocket-propelled grenades, explosive formed projectiles, mortars, and vehicles constructed as mobile explosives. In addition to military servicemembers injured in blast events being at risk for concussive events and TBI, they are also at increased risk for direct injury to the eyes from airborne debris.[4,6] The most common cause of ocular injuries affecting OIF/OEF servicemembers was fragments from an explosive event.[2]

TBI may be caused by penetrating or non-penetrating injury to the head. In penetrating injury, the visual pathway, visual cortex, and/or other vision-related structures of the brain may sustain physical damage. In non-penetrating or closed-head injury, displacement, stretching, and shearing forces may damage areas of the brain, including those associated with vision.[8] The severity of TBI is diagnosed by the score on the Glasgow Coma Scale,[9,10] the duration of unconsciousness, and the length of posttraumatic amnesia.[11] The prevalence of TBI among military servicemembers has varied among studies. In a sample population of 155 injured OIF servicemembers, 62% of the injured servicemembers screened were identified as having sustained a TBI.[12] According to a recent report by the RAND Center for Military Health Policy Research, 19.5% of all U.S. servicemembers who have returned from Afghanistan and Iraq "report experiencing a probable TBI during deployment."[13]

METHODS

At VA Palo Alto Health Care System, TBI patients are evaluated within two established programs based on the severity of their injuries. These programs are referred to as the Polytrauma Rehabilitation Center (PRC) and the Polytrauma Network Site (PNS). The current standard of care at VA Palo Alto Health Care System is to provide vision examinations to all PRC and PNS patients.

In the PRC, patients were seen on an inpatient basis.[14] These individuals had moderate to severe TBI and were considered polytrauma, which is defined by the Department of Veteran Affairs (DVA) as "two or more injuries to physical regions or organ systems, one of which may be life-threatening, resulting in physical, cognitive, psychological, or psychosocial impairments, and functional disability."[15] Patients at the PRC are typically in the acute or sub-acute phases of rehabilitation. Some patients are emerging from coma status and are non-verbal at this stage. Injuries among PRC-inpatients included traumatic amputation, burns, hearing loss, cognitive impairment, infections, scarring, internal injuries, and injuries to the eyes and/or visual system. TBI due to blasts, motor vehicle accidents, falls, shrapnel, and other causes was also associated with visual impairment and dysfunction.

In the PNS, OIF/OEF servicemembers were seen as outpatients. These patients had screened positively for mild TBI using an expanded version of the 3-question Defense Veterans Brain Injury Center screening tool,[16] and did not have life-threatening injuries. PNS clinics were established by DVA to provide case management for patients with postacute rehabilitation needs. Although the majority of PNS-outpatients do not require urgent hospitalization, they often need specialized services for emotional, cognitive, and/or physical injuries they may have sustained. Most patients in this group are able to function independently in basic activities of daily living.

Data were collected from a retrospective review of electronic examination records of two populations of combat-injured patients. The inpatient group consisted of 68 consecutive polytrauma patients evaluated in the PRC between December 2004 and April 2008. The outpatient group consisted of 124 consecutive patients screened in the PNS clinic between August 2006 and December 2007. We examined the frequency of ocular injury, visual impairment, and visual dysfunction in these two groups.

Screening Protocols

Clinical examinations were conducted by several of the authors (K.B., J.K., H.W., and S.I.). The examiners used templates developed for each of the two clinics. These templates were modified over time to better capture relevant data and included tests specific to these populations. The major difference between the PRC examination and the PNS examination was the increased detail of the history and symptom questionnaire for the PNS-outpatient group compared with the PRC-inpatient group due to limited communication abilities in some PRC-inpatients. Variation in n-values reported reflect the fact that not all patients were able to respond to specific questions or screening procedures.

Initial vision screenings in the PRC were conducted at bedside and techniques were modified according to each patient's abilities. Depending on the patient's level of functioning, examinations progressed to standard optometric testing methods. If the patient was able to respond verbally, a series of questions was asked to obtain a brief history and symptoms. These questions were intended to gain information about the patient's refractive error, binocular functioning, sensitivity to light, visual field, and reading ability. Observations of the patient's physical status as well as eye and body alignment were made. A brief screening to assess the patient's orientation to his/her environment was done by having the patient point to specific objects around the room.

Visual Acuity

Visual acuities were usually assessed using the Feinbloom chart at a distance of 10 feet. If a patient was non-verbal, but able to respond to yes/no questions by head nodding or by indicating with fingers, acuity cards with single numbers were used. Teller acuity cards or an optokinetic nystagmus (OKN) drum were utilized in patients who were verbally non-responsive. Near acuities were taken using text, single words, triple digits, or single digits, depending on the patient's abilities. Visual acuity as reported in this study was based on best-corrected, pinhole, or retinoscopy/refraction of the better eye, depending on the level of cooperation and existing corrections provided by the patient.

Oculomotor Function

Fixation stability, saccades (reflexive and voluntary), pursuits, and extraocular motilities were assessed using various targets depending on the patient's abilities and/or acuity limits. Penlights, colored targets, and single letters down to 1.25 M letter size were used.

Binocular Function and Accommodation

Cover testing was performed in primary gaze at distance and near. Near point of convergence testing was performed. For the purpose of this screening, convergence insufficiency was diagnosed if the near point of convergence break point result was >7 centimeters. For patients under the age of 40, accommodation was tested monocularly using the pull-away method. We used the Hofstetter equation to calculate the minimum age-expected amplitude of accommodation.[17]

Reading Ability

To capture the attention of brain-injured patients, internally developed reading materials consisting of continuous text (10 point, Times New Roman font) were used to determine the patient's current reading status. Attention was paid to reading facility, speed, and comprehension.

Visual Fields

Confrontation visual fields were performed with simultaneous presentation of targets to assess for gross unilateral visuospatial neglect. Because of physical and attentional limitations in this population, confrontation fields were most commonly used. Goldmann visual fields were performed on patients capable of completing the test.

Ocular Injuries

Each patient was evaluated for ocular injuries by anterior and posterior segment examination as well as by imaging studies when indicated.

In this article, we refer to visual impairment as a loss of visual acuity or visual field. Visual impairment by visual acuity was classified as moderate visual acuity loss 20/70 to 20/100, legal blindness (visual acuity worse than 20/100), or total blindness (no light perception). Monocular visual status was defined as either no light perception or enucleation of one eye. Visual dysfunction was defined as disorders of vergence, accommodative, and/or oculomotor functions (pursuits and saccades).

RESULTS

Polytrauma Rehabilitation Center

Ninety-six percent of all PRC-inpatients examined (65/68) were male. The mean age of all PRC-inpatients was 28.6 years (median = 26.0). The mean age for patients with blast injury and non-blast injury was 28.6 years (median = 26.0) and 28.8 years (median = 27.0), respectively. Eighty-six percent (49/57) of blast-injured patients and 90.9% (10/11) of non-blast injured patients were <40 years of age. Eighty-four percent of patients (57/68) in the PRC-inpatient group had TBIs associated with a blast event. Sixteen percent (11/68) had TBIs associated with other mechanisms of injury (e.g., motor vehicle accidents, gunshot/shrapnel injuries, falls, or anoxia).

Table 1 summarizes the visual findings of blast and non-blast injured PRC-inpatients. As shown in Table 1, both groups reported frequent subjective visual complaints. More patients in the blast group had ocular injury and were monocular than in the non-blast group. The majority of PRC-inpatients had a

TABLE 1.
Visual findings by mechanism of injury in OIF/OEF polytrauma inpatients seen in the PRC by percent positive finding

		Mechanism of injury	
PRC findings	All injuries (N = 68)	Blast injury (N = 57)	Non-blast injury (N = 11)
Subjective visual complaint	75.4% (46/61)	77.4% (41/53)	62.5% (5/8)
Ocular injuries	38.2% (26/68)	43.9% (25/57)	9.1% (1/11)
Visual acuity of 20/60 or better	77.8% (49/63)	79.6% (43/54)	66.7% (6/9)
Visual impairment			
Moderate VA loss (20/70–20/100)	6.3% (4/63)	7.4% (4/54)	0
Legally blind (VA worse than 20/100)	12.7% (8/63)	9.3% (5/54)	33.3% (3/9)
No light perception in both eyes	3.2% (2/63)	3.7% (2/54)	0
Monocular	16.7% (11/66)	18.2% (10/55)	9.1% (1/11)
Visual dysfunctions			
Convergence insufficiency	42.6% (26/61)	42.3% (22/52)	44.4% (4/9)
Accommodative insufficiency (for subjects less than 40 years)	39.6% (21/53)	42.2% (19/45)	25.0% (2/8)
Pursuit/saccadic dysfunction	30.2% (19/63)	33.3% (18/54)	11.1% (1/9)
Fixation instability	9.5% (6/63)	9.3% (5/54)	11.1% (1/9)
Strabismus	25.0% (17/68)	24.6% (14/57)	27.3% (3/11)
Reading difficulties (observed or reported)	65.6% (40/61)	63.5% (33/52)	77.8% (7/9)

The number in parenthesis represents the number of positive findings and the total number of patients who were able to respond to testing (positive finding/total examined).

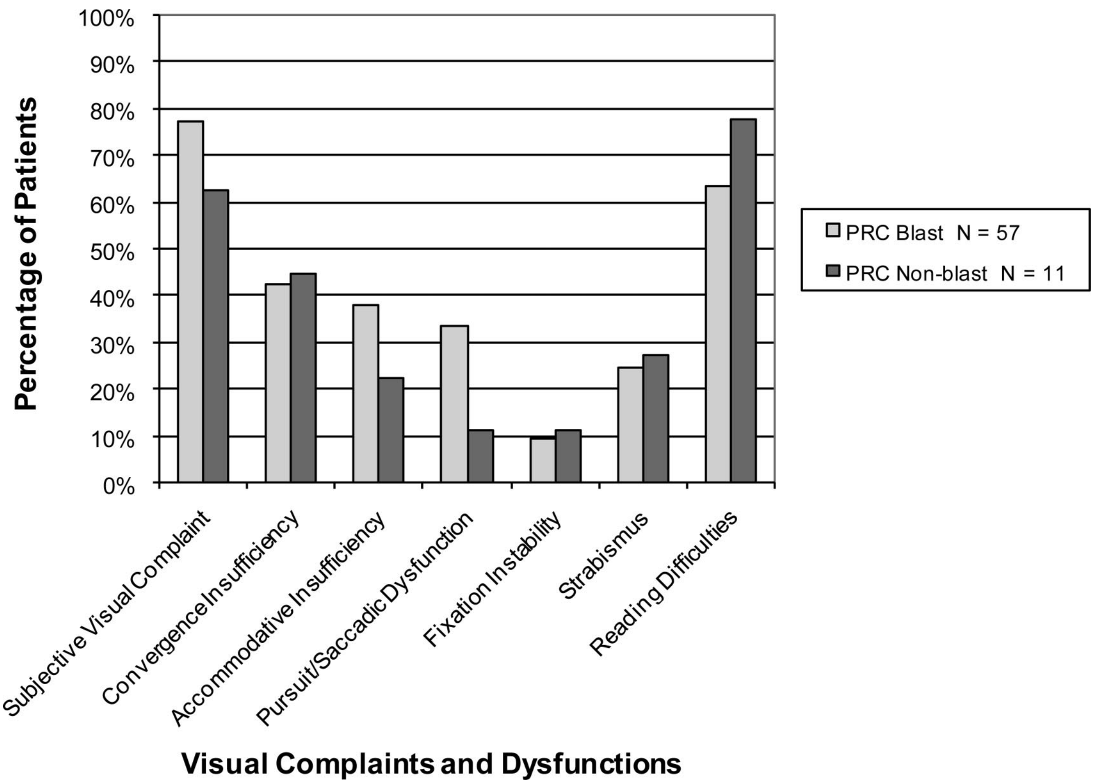

FIGURE 1.
Visual dysfunctions and visual complaints in PRC-inpatients.

visual acuity that was 20/60 or better. Blast events resulted in a visual acuity loss of 20/100 to no light perception in 13.0% of PRC in-patients, whereas non-blast events resulted in a visual acuity of 20/100 or worse in 33.3% of PRC-inpatients. Total blindness or no light perception in both eyes was infrequent and found only among patients with blast injury.

Fig. 1 highlights the visual complaints and dysfunctions of blast and non-blast injured PRC-inpatients. As shown in Table 1 and Fig. 1, blast and non-blast injured patients in the PRC had a nearly equal occurrence of convergence insufficiency. Higher frequencies of accommodative insufficiency and pursuit/saccadic dysfunction were found in the blast-injured group. Observed or reported reading difficulties were slightly higher in the non-blast group. Fixation instability and strabismus were approximately equal between the blast and non-blast injured groups.

Table 2 summarizes the visual field defects found among PRC-inpatients and PNS-outpatients. Visual field data was not available for 9 of 68 PRC-inpatients. Therefore, only 59 patients were included in the visual field analysis. Visual field defects were found in about one-third of PRC-inpatients. Of the total number of visual field defects seen in the PRC, the majority were found among patients who were injured by blast. Homonymous hemianopia was the most common type of visual field loss sustained in the PRC. Hemianopia in one eye was seen only in the blast-injured group. Two of these hemianopic patients were monocular and visual field testing was not possible in the other eye. Altitudinal visual field loss in one eye was seen in two blast-injured patients, one of whom was monocular. All other types of visual field loss (bitemporal hemianopia, homonymous quadrantanopia, quadrantanopia in one eye, central scotoma in one eye, paracentral scotoma in one eye, or other) were seen in only one patient.

Polytrauma Network Site

Ninety-six percent of all PNS-outpatients screened (119/124) examined were male. The mean age for all PNS-outpatients was 30.5 years (median = 26.0). The mean age for those reporting a blast-injury and non-blast injury was 29.7 years (median = 25.0) and 37.9 years (median = 37.5), respectively. This difference was statistically significant ($t = 2.265$, $p < 0.025$). Ninety percent of patients (112/124) self-reported having incurred their TBI as a result of a blast event compared with 9.7% (12/124) of patients who reported another mechanism of injury. Eighty-four percent (94/112) of blast-injured patients and 58.3% (7/12) of non-blast injured patients were <40 years of age.

Table 3 summarizes the visual findings of blast and non-blast injured PNS-outpatients. As shown in Table 3, three quarters of PNS-outpatients with both blast and non-blast injuries had a subjective visual complaint. Ocular injuries were found in 7.1% of patients with blast injury and in 16.7% of patients with non-blast injury. Two patients in the PNS clinic were monocular, and both were in the blast-injured group. Most patients had a visual acuity of 20/60 or better. Two patients in the PNS population had a visual acuity worse than 20/100 and both were in the blast-injured group.

Fig. 2 highlights the visual complaints and dysfunctions of blast and non-blast injured PNS-outpatients. As shown in Table 3 and Fig. 2, convergence insufficiency was found in 48.4% of the PNS population. Non-blast injured patients in the PNS had a higher

TABLE 2.
Visual field defects in PRC-inpatients and PNS-outpatients

Type of visual field defect by patient	Right eye	Left eye	Blast	Binocular with field loss in both eyes	Binocular with field loss in one eye	Monocular
Visual field defects present in 19 of 59 PRC—inpatients						
Bitemporal hemianopia	R hemi splitting	L hemi splitting	No	x		
Homonymous hemianopia	L hemi sparing	L hemi sparing	Yes	x		
	L hemi sparing	L hemi sparing	No	x		
	L hemi sparing	L hemi sparing	No	x		
	R hemi sparing	R hemi sparing	Yes	x		
Homonymous quadrantanopia	RI quad	RI quad	Yes	x		
Constricted in both eyes	Constricted	Constricted	Yes	x		
	Constricted	Constricted	No	x		
Hemianopia in one eye	NLP	L hemi sparing	Yes			x
	NLP	L hemi sparing	Yes			x
	R hemi sparing	No defect	Yes		x	
Quadrantanopia in one eye	LS quad	No defect	Yes		x	
Altitudinal defect in one eye	NLP	S altitudinal	Yes			x
Constricted in one eye	S altitudinal	No defect	Yes			x
	Constricted	No defect	Yes		x	
	NLP	Constricted	No			x
Central scotoma in one eye	Central scotoma	No defect	Yes		x	
Paracentral scotoma in one eye	NLP	Paracentral scotoma	Yes			x
Other	Constricted	RI quad	Yes	x		
Total			14	9	5	5
Visual field defects present in 4 of 124 PNS—outpatients						
Homonymous hemianopia	L hemi sparing	L hemi sparing	Yes	x		
Hemianopia in one eye	No defect	R hemi sparing	No		x	
Quadrantanopia in one eye	LS quad	NLP	Yes			x
Central scotoma in one eye	Central scotoma	NLP	Yes			x
Total			3	1	1	2

NLP includes no light perception and enucleated.

occurrence of convergence insufficiency than blast-injured patients. Non-blast injuries were also more frequently associated with accommodative insufficiency. Pursuit and/or saccadic dysfunctions were found in nearly one quarter of the PNS population, and were seen more frequently in patients with blast-related injuries. Fixation instability was found in 6.5% of the PNS population and was only seen in patients with blast-related injuries. Little difference in self-reported reading difficulties was seen between the blast and non-blast injured groups.

Visual field defects (Table 2) were found among four PNS-outpatients, and three of these four patients had blast-related injuries. One blast-injured patient had a homonymous hemianopia. Two monocular blast-injured patients had visual field defects in their remaining eye. One of these patients had a quadrantanopia and the other had a central scotoma. The single non-blast injured patient with a visual field defect was binocular and had a hemianopia in one eye.

DISCUSSION
Visual Acuity

PRC-inpatients with moderate and severe TBI had more frequent visual acuity loss compared with PNS-outpatients with mild TBI; hence, visual acuity loss was more common in patients with greater levels of injury. However, this study also found that the

TABLE 3.
Visual findings by mechanism of injury in OIF/OEF outpatients with presumed mild TBI seen in the PNS by percent positive finding

		Mechanism of injury	
PNS findings	All injuries (N = 124)	Blast injury (N = 112)	Non-blast injury (N = 12)
Subjective visual complaint	75.8% (94/124)	75.9% (85/112)	75.0% (9/12)
Ocular injuries	8.1% (10/124)	7.1% (8/112)	16.7% (2/12)
Visual acuity of 20/60 or better	98.4% (122/124)	98.2% (110/112)	100% (12/12)
Visual impairment			
Moderate VA loss (20/70–20/100)	0	0	0
Legally blind (VA worse than 20/100)	1.6% (2/124)	1.8% (2/112)	0
No light perception in both eyes	0	0	0
Monocular	1.6% (2/124)	1.8% (2/112)	0
Visual dysfunctions			
Convergence insufficiency	48.4% (59/122)	46.8% (52/111)	63.6% (7/11)
Accommodative insufficiency (for subjects less than 40 years)	47.5% (47/99)	45.7% (42/92)	71.4% (5/7)
Pursuit/saccadic dysfunction	23.4% (29/124)	24.1% (27/112)	16.7% (2/12)
Fixation instability	6.5% (8/124)	7.1% (8/112)	0
Strabismus	7.3% (9/124)	7.1% (8/112)	8.3% (1/12)
Reading difficulties (self-report)	87.1% (108/124)	87.5% (98/112)	83.3% (10/12)

The number in parenthesis represents the number of positive findings and the total number of patients who were able to respond to testing (positive finding/total examined).

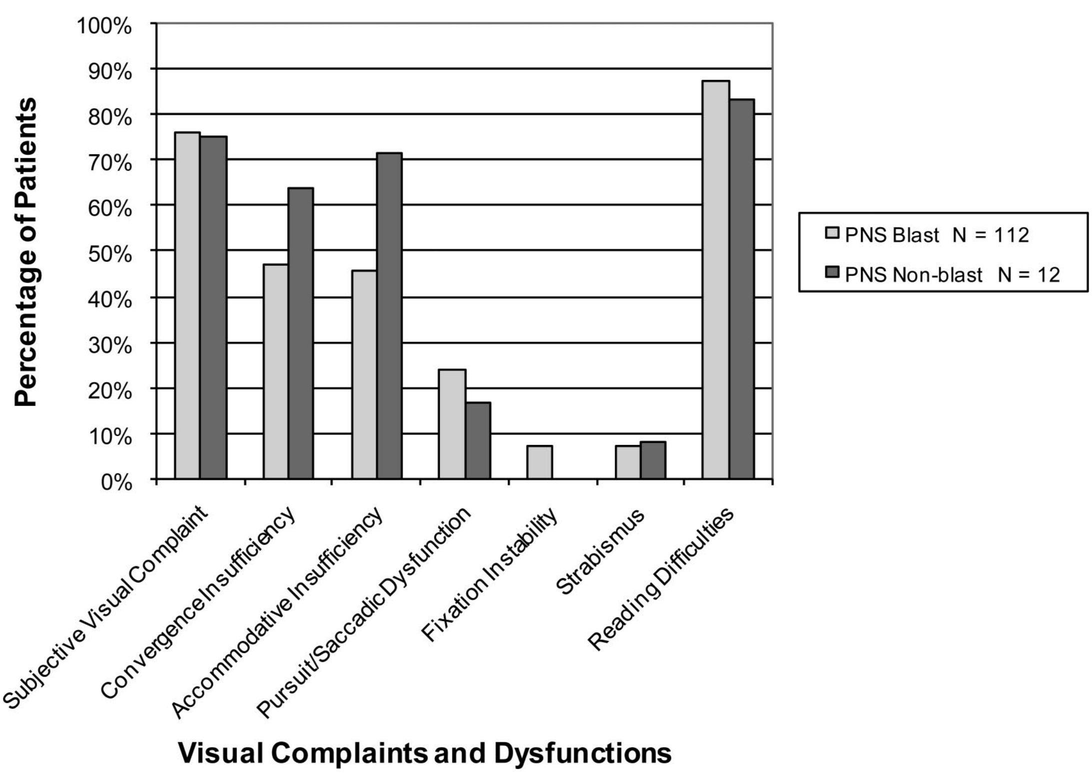

FIGURE 2.
Visual dysfunctions and visual complaints in PNS-outpatients.

majority of patients in both the PRC and PNS populations had normal to near-normal acuities.

Outside the realm of eye care providers, visual acuity is used to encapsulate a patient's overall visual function. Although visual acuity is a fundamental and prevalent element of eye examinations, this study suggests that it is not, in itself, an adequate representation of visual function in patients with TBI. Examinations that focus predominately on visual acuity findings risk overlooking other signs of visual deficits in patients with TBI.

Visual Dysfunctions

The most common visual dysfunctions in both the PRC and PNS populations were convergence insufficiency (42.6% PRC, 48.4% PNS) and accommodative insufficiency (39.6% PRC, 47.5% PNS). These findings were similar to the percentage of convergence insufficiency (42.5% of 160) and accommodative insufficiency (37.3% of 51) reported by Ciuffreda et al.[18] in a retrospective analysis of 160 ambulatory outpatients with TBI, the majority of whom were referred by rehabilitation professionals. Non-blast injuries had a higher occurrence of convergence insufficiency than blast injuries. The difference between non-blast and blast groups was greater in the PNS population than in the PRC population. Non-blast injuries were also more frequently associated with accommodative insufficiency in the PNS population (blast 42.2% PRC, 45.7% PNS; non-blast 25.0% PRC, 71.4% PNS). The difference in frequency of accommodative insufficiency between the PNS blast and non-blast groups may reflect age differences among the groups. For example, in our PNS population, more non-blast injured than blast-injured patients were age 40 years or older, and patients over the age of 40 years were not included in the calculation of accommodative insufficiency. Thus, the difference in frequency of accommodative insufficiency may be attributed to the small sample of patients aged 39 years or younger in the non-blast PNS group rather than actual differences in the rate of accommodative insufficiency for these two groups.

Pursuit and/or saccadic dysfunctions were found in 30.2% of the PRC population and 23.4% of the PNS population. Ciuffreda et al.[18] reported that 32.5% of TBI patients had pursuit dysfunction and that 38.9% had saccadic dysfunction. Blast injuries were more frequently associated with pursuit and/or saccadic dysfunction in both populations (blast 33.3% PRC, 24.1% PNS; non-blast 11.1% PRC, 16.7% PNS). The frequency of strabismus in the PRC population (25%) was similar to that reported by Ciuffreda et al.[18] (25.6%), although a lower frequency of strabismus was found in the PNS population (7.3%). Comparable percentages of patients with non-blast vs. blast injuries had strabismus in both the PRC and PNS populations (blast 24.6% PRC, 7.1% PNS; non-blast 27.3% PRC, 8.3% PNS).

The similar percentages of convergence insufficiency, accommodative insufficiency, oculomotor dysfunction, and strabismus in the PRC population and in the TBI population reported by Ciuffreda et al. suggest that the visual dysfunction findings detected in OIF/OEF servicemembers with TBI correspond to those seen in the civilian TBI population. Although blast-injured patients tended to have a higher occurrence of pursuit and/or saccadic dysfunction than non-blast injured patients both in the PRC and in the PNS populations, variation was seen in the occurrence of convergence and accommodative dysfunction in blast and non-blast injured patients in the PRC and PNS populations. This difference may reflect the disproportionate representation of (1) non-blast injured patients in the PRC compared to the PNS population (16.2% non-blast PRC vs. 9.7% non-blast PNS), and (2) the non-blast injured patients in both populations compared to blast-injured patients (83.8% blast vs. 16.2% non-blast PRC; 90.3% blast vs. 9.7% non-blast PNS).

Both blast and non-blast events were associated with impaired reading ability in PRC-inpatients and PNS-outpatients. Visual dysfunctions and visual acuity loss are known to reduce reading efficiency,[19] which negatively impacts educational, vocational, and recreational endeavors.[20,21] Reading difficulties (either measured and/or self-reported) in both the PRC and PNS populations were consistent with the acuity and visual dysfunction findings in this study. Other factors such as deficits in cognition, attention, and motivation can also influence reading ability.

Visual Fields

Visual field findings in the PRC population (32.2%) are similar to findings in a retrospective analysis of 160 ambulatory outpatients with TBI by Suchoff et al.,[22] in which 38.8% of patients had a visual field defect. The data from our PNS population showed lower frequencies (3.2%) of field loss than either the PRC population or findings from Suchoff et al. The majority of visual field defects were found in patients with blast-related injuries both in the PRC and PNS. Visual field testing in patients with a history of TBI is critical due to the adverse impact of visual field deficits on mobility and other visual tasks involving scanning.[23]

Conclusions

Our study documented vision loss and dysfunction in defined populations. As a retrospective study without a control group, we are unable to draw conclusions about the causative nature of these dysfunctions. It is also important to note that these results should not be generalized beyond the limits of this study. For example, although blast events were associated with a high number of visual findings in our populations, these findings may not apply to all servicemembers who have been exposed to a blast event. The discrepancy in numbers between blast and non-blast patients evaluated in this study makes it difficult to determine the validity of differences found between these two groups. Although PRC-inpatients received a comprehensive assessment and diagnosis of TBI, the categorization of mild TBI in PNS-outpatients was not a definitive diagnosis at the time these patients were examined and caution should therefore be exercised in comparing our PNS data with other published data on TBI and visual dysfunction. In addition, the potential impact of medication use on the visual system in these patients was not examined.

Despite these limitations, our data highlight the visual impairments and dysfunctions that may occur to combat-injured populations as well as the importance of multiple areas of research. For example, multi-center, controlled studies are needed to determine the extent to which these findings can be generalized. Imaging studies (e.g., magnetic resonance imaging utilizing functional and/or diffusion tensor imaging techniques) may reveal the underlying neurological pathways associated with TBI-related functional vision loss. Epidemiological studies are also needed to determine the incidence and prevalence as well as the social and economic costs of vision-related care after TBI. Such studies would be critical in defining the interventions necessary to treat and/or rehabilitate these visual impairments and dysfunctions. The differences in our findings for blast and non-blast injured patients point to the need for research regarding the impact that different mechanisms of injury may have on the visual consequences of TBI.

Visual impairments and dysfunctions in the populations we studied support the implementation of vision examinations in servicemembers who screen positively for TBI. Before our studies, binocular vision evaluations and vision rehabilitation therapies addressing visual impairment due to brain injury were not routinely performed at VA Palo Alto Health Care System. From this study, we found that the majority of patients in the PRC and PNS populations had normal to near normal visual acuity and/or visual fields. Eye care providers should be aware that assessment of visual acuity and visual field is not sufficient to uncover the visual dysfunctions found in these populations. In light of these and other findings,[14] the DVA has modified the standard of care for patients served at its four PRCs to include comprehensive vision assessments.[24]

Brain injury rehabilitation programs should include vision examination and treatment as a component of patient rehabilitative care. Expanding the role of eye care services into TBI may require eye care providers to gain a better understanding of brain injury and its rehabilitation. Other TBI rehabilitation providers should also consider the functional visual status of the patient in interpreting the results of their disciplinary assessments.[25] Vision examinations and treatment may facilitate TBI patient rehabilitation including reading, speech and language deficits, vestibular function, mobility, driving, and other activities in which the visual system plays a role.

In summary, blast events were the most frequent mechanism of injury in our study of OIF/OEF servicemembers with mild to severe levels of TBI. Other mechanisms of injury were also associated with TBI. This study suggests that combat-injured troops with TBI, regardless of mechanism of injury, are at risk for brain-related as well as eye-related vision loss and dysfunction. The functional visual consequences of these injuries necessitate further study and support the need for appropriate evaluation and treatment in all severities of TBI.

ACKNOWLEDGMENTS

We thank all members of the Palo Alto Eye & Vision Research Group (PAEVR) for their ongoing support of interdisciplinary eye and vision research and best clinical practices. We would also like to acknowledge Sandy Lai, MD, and the VA Palo Alto Health Care System PRC staff as well as Ms. Julianna Brooks and the VA Palo Alto Health Care System PNS staff for their continued support and cooperation.

This research was supported in part by a grant from VA Quality and Enhancement Research Initiative (QUERI Grant RRP 07-339) to Gregory Goodrich, PhD.

This research was approved by the VA Palo Alto Health Care System/Stanford University Institutional Review Board (Protocol ID 98285).

Received June 20, 2008; accepted February 5, 2009.

REFERENCES

1. Biehl JW, Valdez J, Hemady RK, Steidl SM, Bourke DL. Penetrating eye injury in war. Mil Med 1999;164:780–4.
2. Thach AB, Johnson AJ, Carroll RB, Huchun A, Ainbinder DJ, Stutzman RD, Blaydon SM, Demartelaere SL, Mader TH, Slade CS, George RK, Ritchey JP, Barnes SD, Fannin LA. Severe eye injuries in the war in Iraq, 2003–2005. Ophthalmology 2008;115:377–82.
3. Langlois JA, Rutland-Brown W, Thomas KE. Traumatic Brain Injury in the United States: Emergency Department Visits, Hospitalizations, and Deaths. Atlanta, GA: Centers for Disease Control and Prevention, National Center for Injury Prevention and Control; 2006. Available at: http://www.cdc.gov/ncipc/pub-res/tbi_in_us_04/tbi%20in%20the%20us_jan_2006.pdf. Accessed April 10, 2009.
4. Gawande A. Casualties of war—military care for the wounded from Iraq and Afghanistan. N Engl J Med 2004;351:2471–5.
5. La Piana FG, Ward TP. The development of eye armor for the American infantryman. Ophthalmol Clin North Am 1999;12:421–34.
6. Ari AB. Eye injuries on the battlefields of Iraq and Afghanistan: public health implications. Optometry 2006;77:329–39.
7. Department of Veterans Affairs, Veterans Health Administration. Polytrauma Rehabilitation Procedures. VHA Handbook 1172.1, Transmittal Sheet, September 22, 2005, part 2a. Available at: http://www1.va.gov/vhapublications/ViewPublication.asp?pub_ID=1317. Accessed April 10, 2009.
8. Taber KH, Warden DL, Hurley RA. Blast-related traumatic brain injury: what is known? J Neuropsychiatry Clin Neurosci 2006;18:141–5.
9. Bonnier C, Marique P, Van Hout A, Potelle D. Neurodevelopmental outcome after severe traumatic brain injury in very young children: role for subcortical lesions. J Child Neurol 2007;22:519–29.
10. Jennett B, Teasdale G, Braakman R, Minderhoud J, Knill-Jones R. Predicting outcome in individual patients after severe head injury. Lancet 1976;1:1031–4.
11. Department of Veterans Affairs, Veterans Health Initiative. Traumatic Brain Injury, Independent Study Course. Washington, DC: Department of Veterans Affairs; 2004.
12. Defense and Veterans Brain Injury Center (DVBIC). Home of Defense and Veterans Head Injury Program. 2007. Updated August 29, 2007. Available at: http://www.dvbic.org/. Accessed November 24, 2008.
13. Rand Corporation, Center for Military Health Policy Research. Invisible Wounds: Mental Health and Cognitive Care Needs of America's Returning Veterans. 2008. Available at: http://www.rand.org/pubs/research_briefs/2008/RAND_RB9336.pdf. Accessed April 10, 2009.
14. Goodrich GL, Kirby J, Cockerham G, Ingalla SP, Lew HL. Visual function in patients of a polytrauma rehabilitation center: a descriptive study. J Rehabil Res Dev 2007;44:929–36.
15. Lew HL, Poole JH, Vanderploeg RD, Goodrich GL, Dekelboum S, Guillory SB, Sigford B, Cifu DX. Program development and defining characteristics of returning military in a VA Polytrauma Network Site. J Rehabil Res Dev 2007;44:1027–34.
16. Schwab KA, Ivins B, Cramer G, Johnson W, Sluss-Tiller M, Kiley K, Lux W, Warden D. Screening for traumatic brain injury in troops returning from deployment in Afghanistan and Iraq: initial investigation of the usefulness of a short screening tool for traumatic brain injury. J Head Trauma Rehabil 2007;22:377–89.
17. Hofstetter HW. A comparison of Duane's and Donders' tables of the amplitude of accommodation. Am J Optom Arch Am Acad Optom 1944;21:345–63.
18. Ciuffreda KJ, Kapoor N, Rutner D, Suchoff IB, Han ME, Craig S. Occurrence of oculomotor dysfunctions in acquired brain injury: a retrospective analysis. Optometry 2007;78:155–61.
19. Waiss B, Cohen JM. Visual impairment and visual efficiency training. In: Cole RG, Rosenthal BP, eds. Remediation and Management of Low Vision. St. Louis, MO: Mosby; 1996:59–70.
20. Leonard R. Vision impairment in working-age adults. In: Silverstone B, Lang MA, Rosenthal BP, Faye EE, eds. The Lighthouse Handbook on Vision Impairment and Vision Rehabilitation, vol. 2. Vision Rehabilitation. New York: Oxford University Press; 2000:1201–18.

21. Whittaker SG, Lovie-Kitchin J. Visual requirements for reading. Optom Vis Sci 1993;70:54–65.
22. 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;79:259–65.
23. Freeman EE, Munoz B, Rubin G, West SK. Visual field loss increases the risk of falls in older adults: the Salisbury eye evaluation. Invest Ophthalmol Vis Sci 2007;48:4445–50.
24. Department of Veterans Affairs, Veterans Health Administration. Screening and Evaluation of Possible Traumatic Brain Injury in Operation Enduring Freedom (OEF) and Operation Iraqi Freedom (OIF) Veterans. VHA Directive 2007-013, April 13, 2007. Available at: http://www1.va.gov/optometry/docs/VHA_Directive_2007-013.pdf. Accessed April 10, 2009.
25. Bertone A, Bettinelli L, Faubert J. The impact of blurred vision on cognitive assessment. J Clin Exp Neuropsychol 2007;29:467–76.

Gregory L. Goodrich
Western Blind Rehabilitation Center (124)
VA Palo Alto Health Care System
3801 Miranda Ave.
Palo Alto, California 94086
e-mail: Gregory.Goodrich@va.gov