Visual Dysfunction in Combat-related Mild Traumatic Brain Injury—A Review

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Abstract
Approximately half of all military personnel who have served in the conflicts in Iraq and Afghanistan are reported to have some degree of combat-related mild traumatic brain injury (TBI). Although in civilian concussion injuries symptoms typically resolve within several weeks, blast-induced mild TBI may be accompanied by prolonged symptoms and afferent and efferent visual dysfunction. Most commonly near vision problems and photophobia are the presenting symptoms. A complete eye exam including vision testing, oculomotor function, and near tasking, is highly recommended after blast-induced mild TBI to detect and improve symptoms in this young patient population. A review of the current literature is presented.

Keywords
Mild TBI, visual dysfunction, combat-related injuries, TBI

Blast Injury Mechanisms
There are several factors that can affect the degree of brain injury. At the time of the explosion a shock front is created followed by a blast wave, which expands until the pressure falls below atmospheric pressure.16,17 Initially, the primary blast wave passes through body armor and bone, and is able to disrupt underlying tissues through embedded shear and stress waves.18,22 Organ systems with high air content such as the pulmonary, gastrointestinal and auditory systems are the most susceptible, but overpressure also causes damage to the central nervous system, visual system, musculoskeletal and cardiovascular systems.25 Secondary damage occurs when debris or fragmentation from the explosive device or surrounding objects penetrate the body.24 Tertiary blast injury involves acceleration and deceleration forces, such as occur when a body is propelled and crashes into a fixed structure or the ground.25 Traumatic brain injury occurs...
Brain Trauma

Table 1: The Most Common Visual Symptoms after Mild Blast-induced Traumatic Brain Injury

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Time since TBI</td>
<td>Not reported</td>
<td>Not reported</td>
<td>Not reported</td>
<td>15–45 days</td>
<td>51±20 months (mean±SD)</td>
</tr>
<tr>
<td>Degree of TBI</td>
<td>Not reported</td>
<td>Only mild TBI subset reported here</td>
<td>Not reported (TBI only, no polytrauma patients reported here)</td>
<td>Mild</td>
<td>Mild</td>
</tr>
<tr>
<td>Mechanism of Injury</td>
<td>79 % blast</td>
<td>Non-blast</td>
<td>Blast</td>
<td>Not reported</td>
<td>Blast</td>
</tr>
<tr>
<td>Number of patients</td>
<td>62</td>
<td>12</td>
<td>112</td>
<td>36</td>
<td>20</td>
</tr>
<tr>
<td>Polytrauma</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Inpatient</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Outpatients</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Best corrected visual acuity</td>
<td>Normal to near-normal</td>
<td>12 patients 20/60 or better</td>
<td>110 patients 20/60 or better, 2 patients worse than 20/100</td>
<td>97 % 20/20</td>
<td>2 % Legally Blind</td>
</tr>
<tr>
<td>Total subjective visual symptoms</td>
<td>75 %</td>
<td>75 %</td>
<td>76 %</td>
<td>42 %</td>
<td>Not reported</td>
</tr>
<tr>
<td>Near vision/reading problems</td>
<td>70 %</td>
<td>83 %</td>
<td>88 %</td>
<td>50 %</td>
<td>65 %</td>
</tr>
<tr>
<td>Visual field deficits</td>
<td>0 %</td>
<td>3.2 %</td>
<td>14 %</td>
<td>0 %</td>
<td>0 %</td>
</tr>
<tr>
<td>Light sensitivity</td>
<td>59 %</td>
<td>Not reported</td>
<td>59 %</td>
<td>50 %</td>
<td>55 %</td>
</tr>
<tr>
<td>Accommodative insufficiency</td>
<td>21 %</td>
<td>71 %</td>
<td>46 %</td>
<td>47 %</td>
<td>35 %</td>
</tr>
<tr>
<td>Convergence insufficiency</td>
<td>46 %</td>
<td>64 %</td>
<td>47 %</td>
<td>28 %</td>
<td>45 %</td>
</tr>
</tbody>
</table>

TBI = traumatic brain injury.

from burns or any other damage. In addition, damage can occur from blast wave reflection off surrounding structures.21,23 If the explosion occurs in an enclosed space such as a vehicle or a building, then the reflected blast waves can exert potentiated damage.22,24 Finally, the distance to the explosion plays an important role in the severity of the injury.22,24

Binocular Vision Dysfunction after Blast-induced Mild Traumatic Brain Injury

Cranial nerves three through six are involved in the fine alignment of the extraocular muscles and therefore it is not surprising that oculomotor dysfunctions occur in approximately 90 % of individuals early after TBI.25 Capo'-Aponte studied in detail the near oculomotor functions in patients 15–45 days after blast-induced mild TBI and found that most patients had impaired reading abilities.25 Compared to control subjects without mild TBI affected subjects had a higher rate of near exophoria, abnormal near point of convergence, decreased amplitude of accommodation and abnormal pursuit.25 Magone found a much lower rate of convergence insufficiency 50 months after blast-induced mild TBI, which indicates possible improvement with time.26 However, the reported rate of 25 % for accommodative and convergence insufficiency remains at a 2.5-fold higher rate compared to mild TBI without a blast mechanism.27,28

Convergence insufficiency is common after TBI and is characterized by exophoria at near fixation, more than distance, and an abnormal near point of convergence.27,28 The rate of convergence insufficiency has been reported to be about 3–5 % in the general population and 9 % in civilian patients after TBI.27,28 In patients after blast-induced mild TBI it ranges between twenty-five to forty-seven percent.26,27,30-32 (see Table 1). Similarly, accommodative insufficiency ranged between 23–46 % in the previously mentioned studies.26,27,30,31 It is recommended that all patients after blast-induced mild TBI be assessed for near oculomotor functions. Ideally, an ophthalmic evaluation prior to deployment to the warzone would allow a more accurate post-injury dysfunction assessment.

Occult visual dysfunction can impact reading performance and the patient’s work performance and ultimately quality of life. In a recent retrospective study, 80 % of unemployed patients had accommodative and/or convergence insufficiency compared to only 31 % of employed.27 The majority of patients after combat-related TBI will re-enter the civilian workforce after discharge from the military and therefore it is important to evaluate patients after mild TBI to recognize and treat associated visual dysfunction. Treatment options are tailored to the individual patient, but include reading glasses, fusional prisms, large print texts, and vision therapy to assist the patient with visual processing techniques.23

Photophobia after Traumatic Brain Injury

Light sensitivity after TBI in the absence of ocular inflammation is a common complaint, affecting 40–50 % of patients early on.32-34 The
exact mechanism of persistent photophobia remains unknown.\textsuperscript{31-36} Although rods and cones are the primary light transmitters of the eye, other pathways exist for light to activate the pain circuit.\textsuperscript{37,38} Intrinsically photosensitive retinal ganglion cells were discovered in recent years and have multiple functions including pathways to pupil constriction and light avoidance.\textsuperscript{39} Melanopsin photoreceptors of the iris in mammals can bypass the optic nerve to activate nocioceptors outside the globe.\textsuperscript{40} Experimental studies also describe a light-induced sensitization of the trigeminal pathway independent of the central visual pathways.\textsuperscript{33,37-38}

Bohnen showed that tolerance to light and sound was decreased in patients 6 months after mild head injury compared to control subjects and suggested that the cause was a cortical and subcortical lack of inhibitory control.\textsuperscript{41} Abnormal responses to light conditions and nonuniform cortical excitability have been described in other brain disorders associated with photophobia such as migraines and epilepsy.\textsuperscript{31,42} A cortical hyperresponsivity could interfere with visual perception leading to photophobia.\textsuperscript{42} These findings indicate that photophobia is triggered by more complex pathways than previously assumed and future research will elucidate the exact mechanism of this condition after mild blast-induced TBI. The mainstay of therapy for photophobia after mild blast-induced TBI is the prescription of tinted lenses. Huang et al. found a reduction of cortical hyperactivation on functional magnetic resonance imaging in patients with migraine by using precision tinted lenses that block blue wavelengths compared to just grey lenses.\textsuperscript{43} Suppression of stimulatory high frequency wavelengths of light associated with photophobia may explain the symptom reduction in patients suffering from light sensitivity.\textsuperscript{44}

Table 1 summarizes the prevalence of visual dysfunction in outpatients diagnosed with TBI in the literature. Polytrauma and inpatient data from some articles are excluded as they typically have moderate to severe degrees of TBI and the emphasis of this review was to evaluate visual dysfunction after mild blast-related TBI (see Table 1).

Eye trauma associated with blast injuries is most commonly related to superficial or penetrating secondary blast injuries.\textsuperscript{45-47} Fortunately, combat-related eye injuries have significantly decreased over the last years, because of better compliance with eye protection wear.\textsuperscript{48-49} In polytrauma-associated TBI, closed globe injuries are more common than penetrating injuries.\textsuperscript{50} Forty-three percent of combat blast survivors in a VA Polytrauma Rehabilitation Center had closed-globe injury, often affecting multiple zones; injury occurred despite use of protective eyewear.\textsuperscript{50}

The first studies focusing on combat-related visual dysfunction in veterans who had been deployed to Iraq and/or Afghanistan were published in 2007. Goodrich and colleagues reported the incidence of visual injuries and dysfunction in 50 inpatients in a subacute rehabilitation setting after TBI.\textsuperscript{51} Half of the patients had suffered blast-induced TBI, however, the degree of TBI was not listed. Overall, 74 \% of patients complained of visual symptoms, and 20 \% had near vision problems. In addition, 24 \% of patients also had visual field abnormalities and 26 \% of non-visually impaired patients had damage to the eye, orbit, or cranial nerve.\textsuperscript{51} Cockeram described the early impact of blast-induced TBI on the visual system in an inpatient population without direct eye injury.\textsuperscript{52} Findings included visual field defects, decrease in contrast sensitivity, and occult ocular injuries from blunt trauma despite good visual acuity.\textsuperscript{52} Seventy percent of patients self reported vision problems and over 45 \% had accommodative and convergence insufficiency.

A retrospective study by Brahm and colleagues from a polytrauma rehabilitation center reported a similar visual complaint rate of 76 \% for blast-induced mild TBI and 75 \% percent for nonblast-induced mild TBI.\textsuperscript{53} Accommodation and convergence insufficiency were present in 46 and 47 \% respectively, and were even higher in nonblast-induced mild TBI. Unfortunately, the time since injury was not studied, although the institution mostly treats subacute stages of rehabilitation both in inpatients and outpatients. Stelmack and colleagues performed a retrospective study in a polytrauma rehabilitation center.\textsuperscript{54} Among 36 patients with TBI but without other injuries, half complained about reading problems. Twenty-eight percent of the TBI patients were diagnosed with a convergence insufficiency disorder and 47 \% percent had accommodative insufficiency. The authors did not specify the severity of TBI in their study.\textsuperscript{54}

A recent clinical study compared visual dysfunction in soldiers 15–45 days after blast mild TBI compared to deployed controls without TBI.\textsuperscript{55} This is so far the first study with matched controls, which deployed to the warzone but did not suffer TBI. The authors found significant early visual dysfunction in soldiers after blast induced mild TBI despite excellent visual acuity.\textsuperscript{55} Binocular vision problems, eye fatigue, and photophobia were the most commonly reported symptoms. Lew et al. reported persistent physical, vision and emotional problems in 38 patients up to 2 years after combat-related TBI, with the majority suffering a blast-related injury.\textsuperscript{56,57} In a retrospective study of routine eye exams in 31 veterans with blast-related mild TBI, Magone found significant visual dysfunction in 68 \% of patients almost 6 years after injury.\textsuperscript{58} Patients complained predominantly of photophobia and binocular function problems.\textsuperscript{58} Visual symptoms were more common after a dismounted mechanism of injury, where the patient was exposed directly to the blast wave. A subset of seventeen patients was not taking any systemic or topical medications and 59 \% reported vision problems 49 months after the injury. Forty-seven percent complained of photophobia, 35 \% had near vision problems, and 24 \% had accommodative and convergence insufficiency. Fortunately, the incidence of symptoms in Magone’s study decreased significantly with time, but the recovery was much longer than previously reported.\textsuperscript{58}

In conclusion, it is becoming evident that significant visual dysfunctions occur in blast-induced brain injuries, and can result in prolonged disability and symptoms compared to non-blast mild TBI. Eye care providers should be aware that combat veterans might have occult closed-globe injuries, visual symptoms and dysfunction related to blast-induced mild TBI despite excellent visual acuity. A complete eye exam including near oculomotor function is highly recommended to detect and improve visual symptoms in this predominately young patient population.
15. Magnuson J, Leonessa F, Ling GS, Neuropathology of explosive
14. Goldstein LE, Fisher AM, Tagge CA, et al., Chronic traumatic
12. French LM, Military TBI: An examination of important
19. Peskind ER, Petrie EC, Cross DJ, et al., Cerebrocerebellar
18. Du T, Ciuffreda KJ, Ludlam DP, Vergence dysfunction
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