Protective Equipment

Assessment of the Effectiveness of Eyewear against Blast-induced Eye Injury

Blast-induced ocular injuries were responsible for nearly 80 percent of all ocular injuries during Operation Iraqi Freedom (OIF).[1] Ocular injuries from explosive devices, such as improvised explosive devices (IEDs), can result from the interaction of a blast wave with the eye (primary blast ocular injury), penetrating trauma to the eye (secondary blast ocular injury), blunt trauma to the eye (tertiary blast ocular injury), and thermal burns (quaternary blast ocular injury).[2] In fact, exposures to IEDs were responsible for 51 percent of blast-related ocular injuries.[1] To prevent eye injury from shrapnel and other ballistic fragments during combat operations, Service Members are mandated to wear spectacles or goggles from the Authorized Protective Eyewear List.[3] Even though the use of protective eyewear reduced the incidence of ocular injury,[4] 8,323 such events were reported at military treatment facilities (MTFs) in theater between 2005 and 2010.[5] An epidemiological study correlated the use of eyewear with a reduction in penetrating eye injuries (often associated with secondary blast ocular injury). However, no such correlation was reported for closed eye injury (associated with both primary and secondary modes of blast ocular injury).[6] This lack of correlation between the use of eyewear and closed eye injury may be attributed to the inability of the eyewear to protect the eye from a blast wave. In addition, various blast overpressure (BOP) studies ranging from 120 to 210 kilopascals have reported ocular injury in animals, such as a decrease in retinal ganglion cell response in mice,[7] corneal edema and photoreceptor cell loss in mice,[8] and damage to

1 Mader, T. H., Carroll, R. D., Slade, C. S., George, R. K., Ritchey, J. P., & Neville, S. P. (2006). Ocular war injuries of the Iraqi Insurgency, January-September 2004. Ophthalmology, 113(1), 97–104. https://doi.org/10.1016/j.ophtha.2005.07.018

2 Scott, R. (2010). The injured eye. Philosophical Transactions of the Royal Society B: Biological Sciences, 366(1562), 251. https://doi.org/10.1098/rstb.2010.0234

3 Adams, G. L. (2004). Combat Eye Protection, the FY 2005 Rapid Fielding Initiative (RFI), and the Approved Product LIst (APL). United States Army Medical Department.

4 Gondusky, J. S., & Reiter, M. P. (2005). Protecting military convoys in Iraq: an examination of battle injuries sustained by a mechanized battalion during Operation Iraqi Freedom II. Military Medicine, 170(6), 546–549.

5 Hilber, D. J. (2011). Eye injuries, active component, U.S. Armed Forces, 2000-2010. MSMR, 18(5), 2–7.

6 Cockerham, G. C., Rice, T. A., Hewes, E. H., Cockerham, K. P., Lemke, S., Wang, G., … Zumhagen, L. (2011). Closed-eye ocular injuries in the Iraq and Afghanistan wars. The New England Journal of Medicine, 364(22), 2172–2173. https://doi.org/10.1056/NEJMc1010683

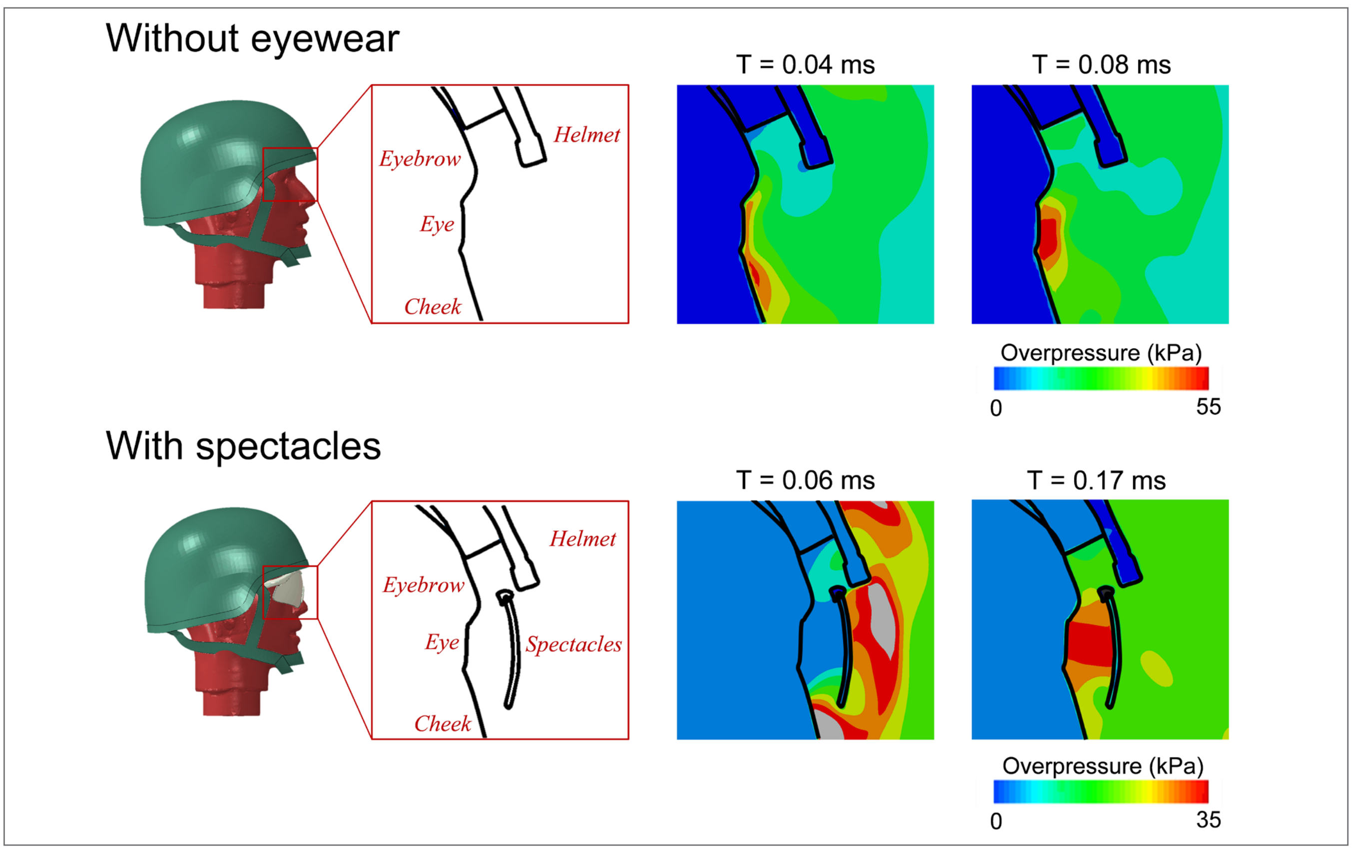
7 Mohan, K., Kecova, H., Hernandez-Merino, E., Kardon, R. H., & Harper, M. M. (2013). Retinal ganglion cell damage in an experimental rodent model of blast-mediated traumatic brain injury. Investigative Ophthalmology & Visual Science, 54(5), 3440–3450. https://doi.org/10.1167/iovs.12-11522

8 Hines-Beard, J., Marchetta, J., Gordon, S., Chaum, E., Geisert, E. E., & Rex, T. S. (2012). A mouse model of ocular blast injury that induces closed globe anterior and posterior pole damage. Experimental Eye Research, 99, 63–70. https://doi.org/10.1016/j.exer.2012.03.013

cells of the optic nerves in rats.[9] Therefore, to better characterize the pressure loading to the eye due to blast wave exposure and the benefits of protective gear, in collaboration with the US Army Aeromedical Research Laboratory (USAARL), the Biotechnical High Performance Computing Software Applications Institute (BHSAI), a subordinate organization of the Telemedicine and Advanced Technology Research Center (TATRC) of the US Army Medical Research and Materiel Command (USAMRMC), Fort Detrick, Maryland, investigated how eyewear interacts with BOP.

To this end, in collaboration with USAARL, BHSAI developed three-dimensional finite element models (FEMs) of a headform fitted with an advanced combat helmet (ACH) and Revision Sawfly Tactical spectacles, as well as a FEM of a shock tube.[10] BHSAI researchers performed computer simulations

FIGURE 1: Comparison of Blast-wave Induced Pressure Loading to the Eye With and Without Spectacles



9 Wang, H.-C. H., Choi, J.-H., Greene, W. A., Plamper, M. L., Cortez, H. E., Chavko, M., … Johnson, A. J. (2014). Pathophysiology of blast-induced ocular trauma with apoptosis in the retina and optic nerve. Military Medicine, 179(8 Suppl), 34–40. https://doi.org/10.7205/MILMED-D-13-00504

10 Sundaramurthy, A. G., Unnikrishnan, G., Mao, H., Williams, T. H., & Reifman, J. (2016). Assessment of the effectiveness of eyewear against blast-induced eye injury. Presented at the Personal Armour Systems Symposium, Amsterdam, Netherlands.

with the head facing the blast wave (0°) and with the head rotated at 60° and 90° relative to the direction of the propagation of the blast wave, with and without spectacles and then validated the model by comparing the results with experimental data. At 0° orientation, the maximum pressure on the left eye without spectacles was 2.75 times the incident blast pressure, and with spectacles it was 1.75 times the incident blast pressure (Figure 1).[10] This was in agreement with experimental observations (2.76 and 1.93, respectively). Without spectacles, at 0° orientation, the blast wave loading to the eye was primarily a combination of reflected pressures from the eye, forehead, and cheek. At 60° and 90° orientations, in agreement with experimental data, BHSAI researchers observed an intense secondary loading on the left eye. With spectacles, the blast wave reached the eye through the gap between the spectacles and the face and was amplified due to reflections from the inside of the spectacles. However, the spectacles prevented secondary loading to the left eye at 60° and 90° orientations. From the computer simulations, BHSAI quantitatively characterized the protective effectiveness of spectacles in reducing the blast pressure to the eye and determined how the blast wave loading mechanisms to the eye were modified by the eyewear.[10]

The results from the simulations and USAARL experiments demonstrated that the use of spectacles reduced the intensity of BOP on the eye during a head-on blast wave exposure. However, at other orientations, the protective effectiveness of spectacles in reducing the blast pressure to the eye is significantly diminished because the blast wave enters into the confined space between the eyewear and the eye through the gap between the spectacles and the face and is amplified. The quantification and improved understanding of the protective effectiveness of spectacles against blast wave exposure can help guide the design of future eye-protective gear.