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A Study on the Influence of Directionality on Blast-Induced Brain Injury

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The growing use of Improvised Explosive Devices (IED) as well as the High Explosives (HE) in the battlefields has increased the risk of in-field and post-war blast induced traumatic brain injury (bTBI). In a study it has been reported that out of 1.6 million personnel deployed in the Iraq war, around 160,000 members have been recognized as suffering from blast-induced mild TBI [1]. Different parameters such as the blast wave orientation, head-neck directionality with respect to the waves, blast intensity, and the efficiency of the protective headgears prominently affect the level of bTBI by altering the dynamic and kinematical responses of the head under the blast assaults.

In this study, a computational finite element (FE) modelling of the interaction of an un/protected head-neck model with the blast-induced shockwaves at different blast orientations is presented. The main objective is to delineate the effect of directionality on the mechanical response of the brain at tissue level. Moreover, the influence of the current protective headgears in the military and police forces, especially the ballistic face shield, are evaluated under high-pressure blast waves to account for their efficacy with respect to the blast orientation.

The numerical formulation of the current problem is carried out through the arbitrary Eulerian-Lagrangian (ALE) technique to perform the coupling of fluid (blast waves) solid (un/protected head) interaction. Head-shockwave interaction mechanism is investigated for the blast scenarios from the front, back, top, bottom, and side. All simulations are performed using LS-DYNA, a nonlinear finite element code used for high-speed impact modelling.

As shown in Figure1(a), a 3D FE model of the human head-neck including most of the components such as dura and pia mater, scalp, skull, brain, falx, CSF, facial bone and skin as well as the neck muscle is employed for the current study. For the protective headgears, the ballistic Advanced Combat Helmet (ACH), foam padding system, and the NIJ-standard ballistic face shield are modelled using 3D image scanning, as shown in Figure 1(b).

To grasp a better understanding of the mitigation efficacy of the protective headgears the lung injury threshold of 520 kPa is chosen as the overpressure around the head.

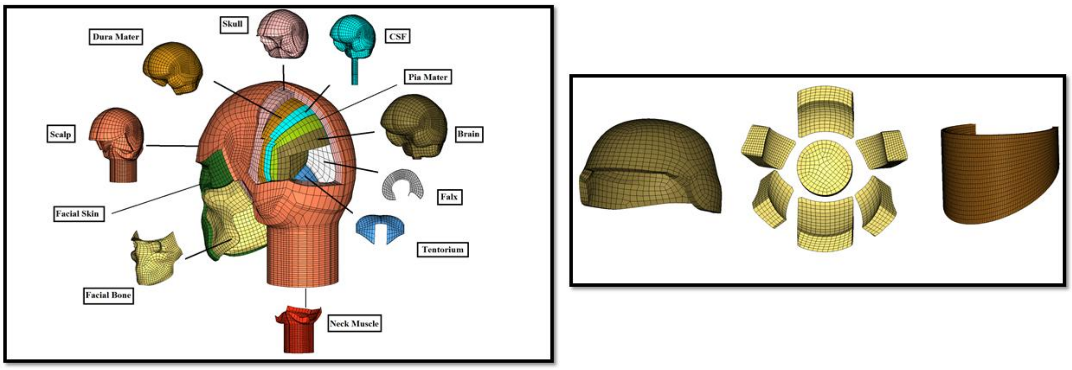

Figure 1. (a) FE model of head components; (b) Protective Headgears: Left to right: ACH Helmet, Padding System, Ballistic Face shield

Three different protection levels are defined for the current study: unprotected head, helmeted head, and the fully protected head (head-helmet-face shield assembly). The padding system is embedded inside the ACH helmet. The brain is modelled as a hyper-viscoelastic material in order to better replicate the brain tissue response under loading. The material properties for the brain are taken from [2].

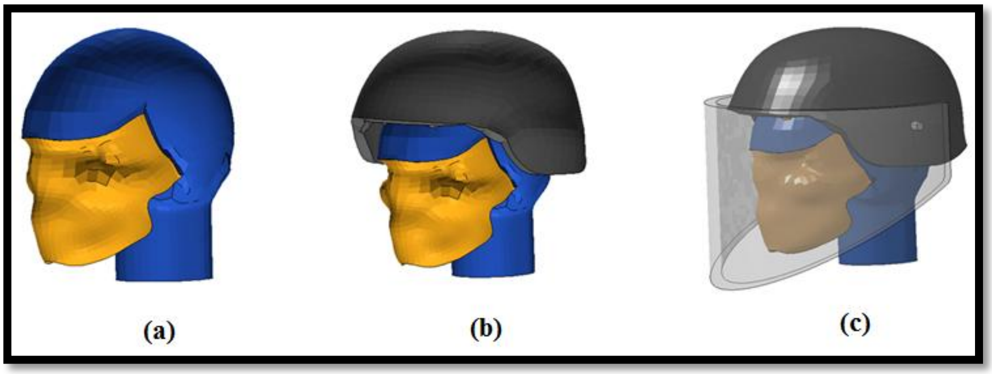

Figure 2. Different Protection Levels: (a) Unprotected, (b) Helmeted, and (c) Fully-Protected

It is observed that based on the head-neck-shockwave directionality, the mechanical response of the brain in terms of the kinematics as well as the dynamic response of the brain tissue is significantly altered. Accordingly, the mitigation efficacy of the protective headgears in attenuating the blast-induced injury on the brain is remarkably affected by the shockwave orientation. The scenario in which the blast waves approach the head from the bottom induce the highest risk of injury in terms of the biomechanical parameters of the brain. Higher shear stress, brain acceleration, and intracranial pressure due to the less protection and also great entrapment of the shockwaves in the head-helmet-face shield gap are observed for this scenario.

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