Investigation of Intracranial Strains and Strain Rates in a 3D Human Head Model During Military Specification Impact Test

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INTRODUCTION

The Advanced Combat Helmet (ACH) performance specification requires a helmeted magnesium Department of Transportation (DOT) headform to be dropped vertically with an impact speed of 10 ft/s (3.1 m/s) onto a steel hemispherical target. The pass/fail criteria is based on a statistical calculation of peak headform acceleration holding below 150G for multiple impacts at a variety of locations and across low (14 °F) to high (130 °F) temperatures. Recent efforts seek to maintain the acceleration threshold while increasing the impact velocity from 10 to 14 or 17 ft/s, as shown in Table 1.

Table 1: Kinetic energy value and factor for target velocities 10, 14, and 17 ft/s.

Impact Velocity	Kinetic Energy (5 kg headform)	Kinetic Energy Factor
10.0 ft/s (3.05 m/s)	23.23 J	1x (Baseline)
14.1 ft/s (4.30 m/s)	46.18 J	2x
17.3 ft/s (5.27 m/s)	69.51 J	3x

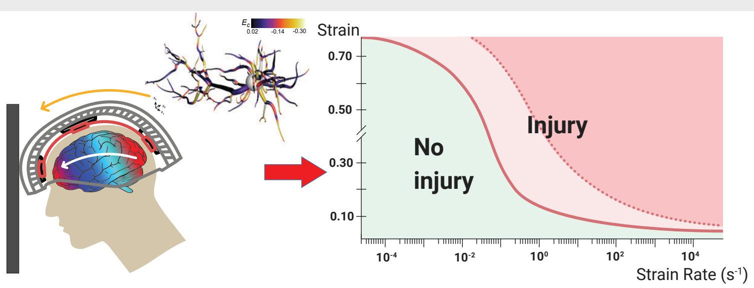

Figure 1: Cellular Injury Risk Curve prototype as a function of strain and strain rate.

An injury risk curve is urgently needed. The prototype in Figure 1 is based on only a few data points, and is not yet fully validated. There is strong evidence that strain and strain rate are the cause of cellular injury but they cannot be derived from testing with a magnesium headform. There is an urgent need to improve helmet testing, revising pass/fail criteria based on strain and strain rates cellular injury.

OBJECTIVES

1. Quantify the stresses, strains, and strain rates of brain tissue for a human surrogate subjected to the same impact requirement of current combat helmets, across a range of impact velocities.
2. Assess the sensitivity of cellular injury criteria to increasing impact velocity in a linearly constrained impact scenario, as currently specified for combat helmets.
3. Evaluate the potential injury risks represented by the current combat helmet impact specification, and whether it adequately addresses cellular-based mTBI.

METHODS

Unhelmeted Experiments. The experiments used a DOT headform assembly (5 kg) with a 10 ft/s crown impact onto a 1 inch target (MEP disk, 60 shore A elastomer), as shown in Figure 2. Twenty impacts were performed. A single-axis PCB accelerometer was used, with a 33 kHz acquisition rate. A channel frequency class 1,000 filter at 1,650 Hz was used (CFC, SAE J211 standard).

Helmeted Experiments. The experiments used the ACH mounted to a DOT C headform assembly (5 kg) with a 10 ft/s crown impact (AR/DP 10-02 standard, ambient temperature) onto a steel hemispherical target, as shown in Figure 3. Four impacts (two shells, two impacts each) were performed. Accelerometer and filter configurations were unchanged from the unhelmeted experiments.

Figure 2.

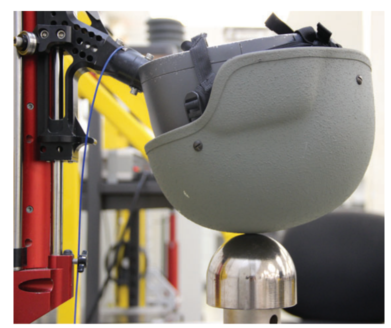

Figure 3.

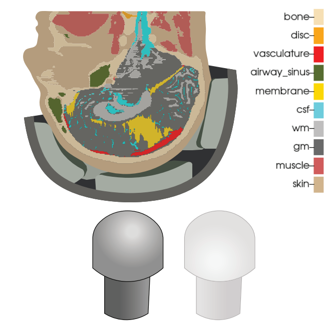

Figure 5.

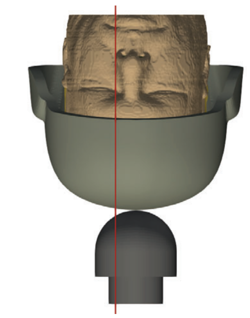

Figure 8.

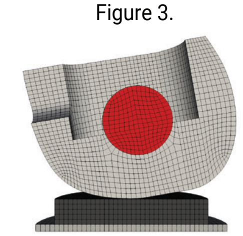

Figure 4.

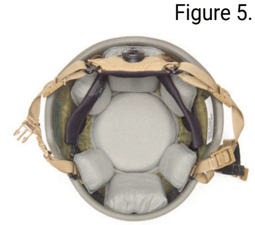

Figure 6.

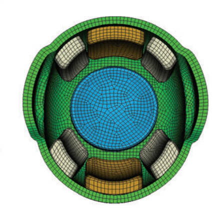

Figure 7.

Figure 9.

Unhelmeted Simulation. The simulation used a half-symmetry DOT headform (equivalently 5 kg) with a 10 ft/s crown impact onto a 1 inch target (MEP disk, 60 shore A elastomer), as shown in Figure 4. The headform acceleration was sampled at 50 kHz, and filtered with a 4-pole Butterworth low-pass filter at 1,650 Hz.

Helmeted Simulations. The simulations used a high-fidelity (1 mm resolution) human surrogate human head (5 kg) with crown (and 10 cm posterior to crown) impacts at speeds of 10, 14, and 17 ft/s onto a steel hemispherical target (Figures 5-9). Acceleration and filter configurations were unchanged from the unhelmeted simulation.

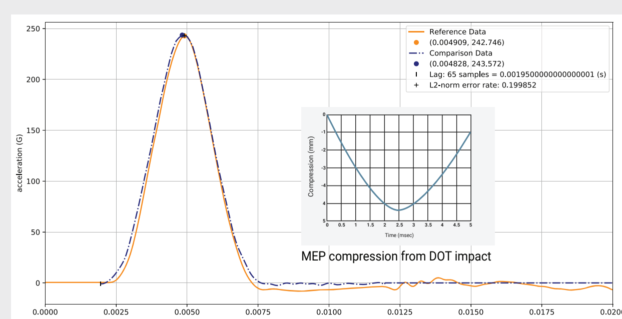

Figure 10. Unhelmeted DOT accelerations.

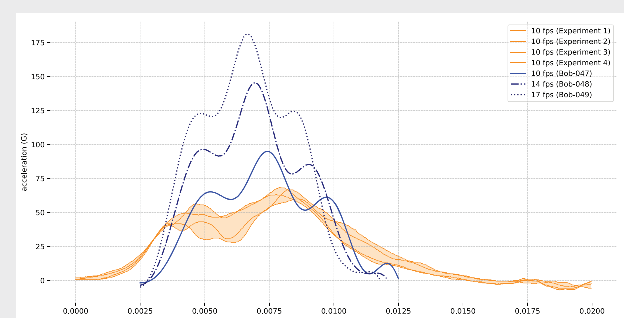

Figure 11. Helmeted DOT and head accelerations.

RESULTS

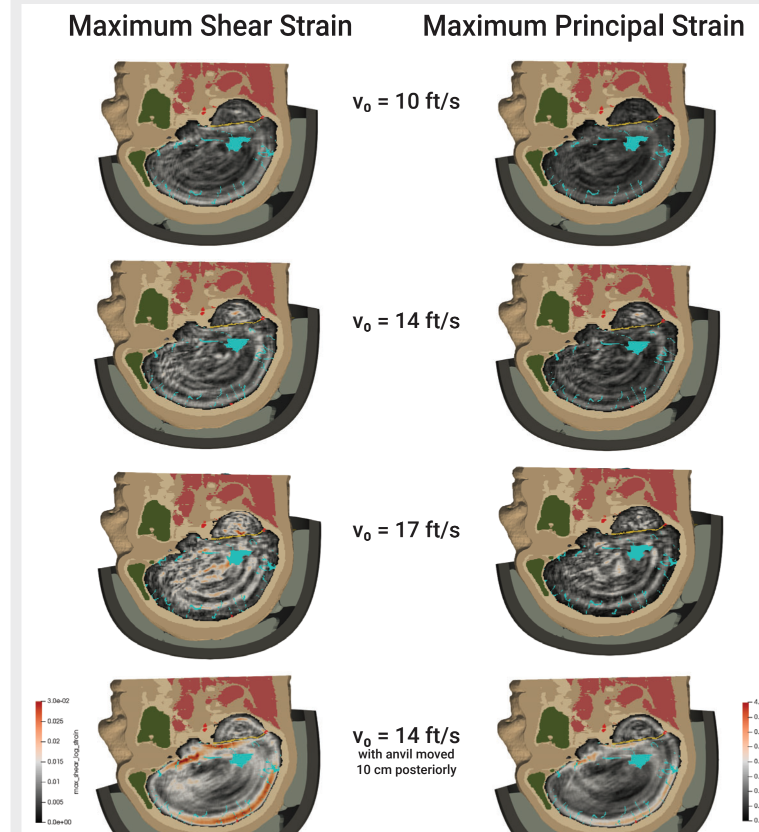

Figure 12.

CONCLUSIONS

1. Head accelerations (a) from the 10 ft/s impact speed exceeded the DOT accelerations, and (b) increased for the 14 and 17 ft/s cases. (Figure 11).
2. Increased impact speeds led to increased strain (Figure 12).
3. At the 14 ft/s impact speed, the off-axis impact caused head rotation and produced significantly more strain than the on-axis impact (Figure 12).
4. The current ACH performance specification may not adequately address the potential for brain injury caused by head impact (Figures 11, 12).

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