Increasing helmet friction as a novel avenue to achieving enhanced head health

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Introduction

Mild traumatic brain injury (mTBI) can cause long term cognitive problems **[1, 2]**. In the United States, as many as 3:8 million sports-related mTBIs occur each year, with American football presenting the highest injury incidence **[3]**, despite the mandated use of head protection. Helmet performance is now an area of significant innovation, with many brands bringing new technologies to market. Dissipating energy generated in the collision remains the greatest challenge, especially given the geometric constraints of a typical helmet. This is typically the function of the liner, a traditionally foam layer within the stiffer shell. This study now attempts to leverage greater energy dissipation via the *shell*, by varying the frictional coefficient.

Methods

This study evaluated the effect of shell friction by adopting the National Football League's (NFL) new assessment methodology. A helmeted head and neck is subjected to impacts by a pneumatic linear ram with a spherical compliant end cap **[4]**. The protocol comprises six impact locations and three speeds (9.3 m/s, 7.4 m/s and 5.5 m/s); for each, the head kinematic data is used to calculate two injury metrics: the Head Injury Criterion (HIC) and the Diffuse Axonal Multi-Axis General Evaluation (DAMAGE). HIC is based on the resultant translational acceleration time history of the head centre of gravity. DAMAGE is based on the maximum of the resultant displacement of a coupled three degree-of-freedom multibody model that uses the directionally dependent rotational acceleration time histories of the head as inputs **[5]**. Values for DAMAGE and HIC are used in a weighted linear combination to calculate the head acceleration response metric (HARM) for each impact condition. The Helmet Performance Score (HPS) is the sum of weighted HARM values calculated for each of the 18 impact conditions. Open-source finite element (LS-DYNA) models were adopted, designed to predict the HPS of a given design. The Riddell Speed Classic model was selected **[6]**, given its relatively high stiffness and was modified to include just a single grade of foam liner (VN740). The effect of the shell and facemask friction coefficient (cf) was assessed relative to HPS. Frictional coefficient was also considered against the relative volume of foam liner (volume fraction, ν_p), Fig 1.

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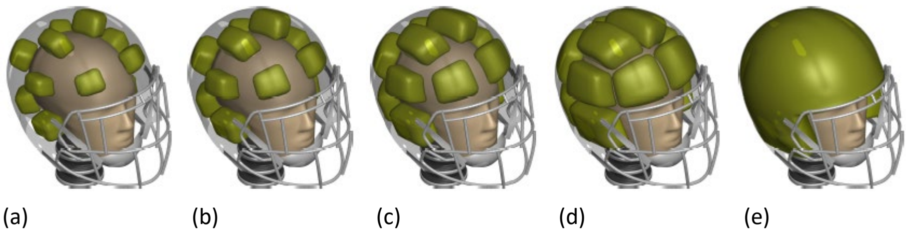

Fig 1: Range of padding volume (υ_p) considered. (a) $\upsilon_p = 0.179$; (b) $\upsilon_p = 0.275$; (c) $\upsilon_p = 0.423$; (d) $\upsilon_p = 0.650$; (e) $\upsilon_p = 1.000$

Results

Varying the frictional coefficient significantly influenced the HPS (Fig 2). Low friction coatings induced significant translational and rotational head accelerations, which produced high HPS scores. This was potentially because of the helmet being deflected off the pneumatic impactor. The higher friction surfaces appeared to achieve a greater contact time between the shell and impactor, so rotating and translating through a longer period. This, in turn, produced lower accelerations and so a lower HPS. Optimising the volume fraction of foam was also seen to influence HPS.

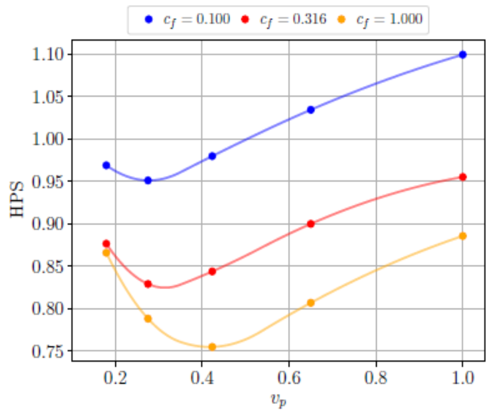

Fig 2: The effect of frictional coefficient and volume fraction on HPS

Discussion

Shell friction appears to have been disregarded in previous literature and helmet models. This computational analysis has demonstrated that a high frictional coefficient has the potential to achieve greater head protection, potentially by increasing the contact time and so reducing the associated accelerations. High friction surfaces can be achieved via routes including rough coatings.

References

[1] McAllister *et al.*, 2001; **[2]** Alves *et al.*, 1993; **[3]** Daneshvar *et al.*, 2011; **[4]** BioCore, 2019; **[5]** Gabler *et al.*, 2019; **[6]** BioCore FE models.

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