Contribution of Energy-absorbing Structures to Head Kinematics in Football Helmet Impacts

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I. INTRODUCTION

Protective helmets have a demonstrated ability to reduce head kinematics resulting from an impact, thereby reducing or preventing head injury [1]. Although experimental testing has led to new advances in protective helmets, future advances will require additional insight that may be enabled by advanced methods, including computational modeling. Importantly, finite element (FE) models must be validated using relevant experimental test data in order to evaluate the predictive capability to assess real-world events. Confidence in FE model predictions (such as the head kinematics resulting from an impact) is stronger for models that are validated against numerous cases, capturing a wider range of possible loading scenarios.

A detailed FE model of a current protective football helmet (Xenith X2E) has been developed and validated using 68 impact scenarios [2]. The resulting head kinematics were assessed using cross-correlation with ratings considered Good to Excellent (0.65 to 0.86) [3]. The model development philosophy included measurement of the mechanical properties of each material in the helmet, development and validation of FE models for each helmet component, and assembly and validation of the full helmet system. For the helmet investigated in this study, the components included: helmet shell; shock bonnet suspension system containing compression shocks; comfort pads; strap system; and face mask (Fig. 1(a)).

An important role for FE models is the ability to assess the effects of material or geometric changes to components, and ultimately to optimise for performance and protection in impact scenarios. Initial investigations of the Xenith X2E helmet model indicated that, out of all the energy-absorbing components in the helmet, the compression shock (Fig. 1(b)) had the strongest influence on the resulting kinematics. Accordingly, the compression shock was investigated in the current study by varying the material properties and assessing the resulting head kinematics, as a first step towards optimisation of helmet protection.

II. METHODS

The FE models were simulated in a side-impact scenario with the Hybrid III headform and neck at impact velocities of 3.0 m/s, 4.6 m/s and 6.1 m/s, corresponding to the experimental test data. The impact was created with a pendulum impact apparatus (14 kg effective mass) and different impact velocities were achieved by varying the pendulum drop height. The helmet was fit onto the Hybrid III headform and neck, which were connected to a mass and carriage, allowing for translation of the system (Fig. 1(c)). The head translational and rotational kinematics were determined from the simulations, and the effect of varying the compression shock material properties was assessed. The material properties of the compression shocks, made from Thermoplastic Polyurethane (TPU), were scaled by factors of 0.5 and 2.0.

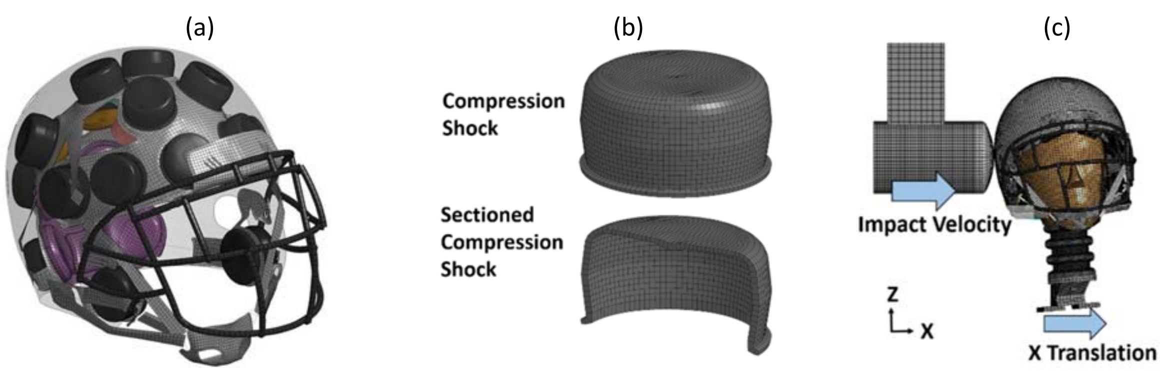

Fig. 1. (a) Helmet model, (b) compression shock geometry, (c) pendulum test setup.

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III. INITIAL FINDINGS

The response for a lateral 3.0 m/s impact (Fig. 2) demonstrated an increase in both acceleration and rotational velocity of the head centre of gravity (CG) for the stiffer TPU material, and a decrease for the compliant TPU, relative to the baseline model. Interestingly, the 6.1 m/s data (Fig. 3) demonstrated the opposite effect, and also exhibited larger variations in response.

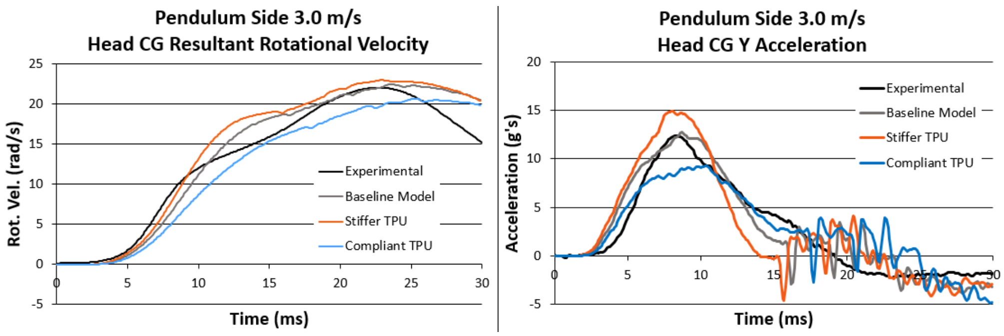

Fig. 2. Response of the Helmet/Hybrid III head to pendulum side impact at 3.0 m/s.

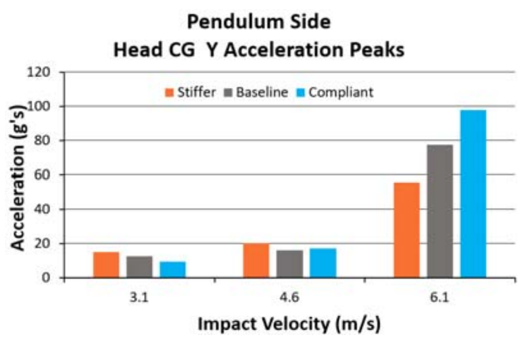

Fig. 3. Change in response for varying impact velocities and material properties.

IV. DISCUSSION

The higher compliance TPU material resulted in lower peak accelerations at low impact velocities, but also reduced the total energy to consolidation of the shock. For the highest impact velocity, the higher compliance material properties resulted in full consolidation of the shock prior to absorbing all of the energy from the impact, leading to higher maximum head acceleration.

The maximum accelerations were similar for all three material properties at the 4.6 m/s impact velocity, identifying a transition in helmet response at this velocity where the shock was not consolidated during the impact and provided similar energy absorption for the different material properties. However, it was noted that the acceleration peak for the compliant TPU occurred later in time, relative to the baseline case, due to attenuation from the higher compliance material. The peak head rotational acceleration and velocity followed a similar trend, although the rotational velocity was less sensitive to changes in the shock material properties.

The results of this study highlight the importance of considering a range of impact velocities to assess helmet protection, and the benefit of using FE models to evaluate impact response in detail. The varying responses across a range of impact velocities suggest that a progressive stiffness shock could address a range of impact conditions, or could be optimised for player position-specific impact conditions.

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VI. REFERENCES

[1] Viano, D. C., *et al.*, *Ann Biomed Eng,* 2012. [2] http://biocorellc.com. [3] CORA Release 3.6 User's Manual.