Towards a helmet assessment metric capable of predicting diffuse brain injury while accounting for focal head injury

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Introduction

Due to the potential that helmets have to prevent brain injury in sport caused by impact, discussion centers on how helmet assessment methods might change to assess helmets relative to brain injury. Currently, certified helmets (e.g. CSA, ASTM) are considered to give adequate head protection if they limit peak headform acceleration during a drop test to less than 300g. Helmets meeting the 300g criterion are credited with all-but eliminating fatal focal head injury (e.g. hemorrhage, skull fracture). In many sports with mandated helmet use, however, diffuse brain injury (e.g. concussion) remains widespread. It is widely recognized that linear acceleration alone is a poor metric for predicting concussion, and studies have shown angular head kinematics to better predict concussive injury [1]. Therefore, debate is centered upon what kinematic measures should be included in a metric to certify helmets relative to diffuse injury, while also retaining linear acceleration measures that have led to helmets that effectively mitigate severe focal injuries.

Objective

Our objective is to develop a new helmet assessment metric capable of certifying helmets relative to kinematics relevant to both focal and diffuse brain injury.

Methods

We impacted a 50_{th} percentile Hybrid III head-neck equipped with an ice hockey helmet (Figure 1) and input the three-dimensional impact kinematics to a finite element brain model called the Simulated Injury Monitor (SIMon) (n=267) [2] to evaluate the relationship between impact kinematics and potential brain injury. Impact speeds ranged from 1.2m/s to 5.8m/s. To determine the most efficient set of linear and angular kinematics capable of predicting SIMon-computed brain strain measures, including the cumulative strain damage measure (specifically CSDM15) and maximum principal strain (MPS), we compared linear regression models using multiple regression techniques, calculating adjusted R_2 and the F-statistic.

Results

A model based on change in angular velocity ($\Delta\omega_R$) and peak g was the most efficient model that included both linear and angular kinematics and proved to be a better predictor for strain than peak g alone (Figure 2).

Discussion and Conclusions

This work shows that an assessment metric that correlates with brain strain measures, while including linear kinematics to account for focal injuries, can be achieved using as few as two variables. Through continued development and validation, a new metric form can be finalized that predicts diffuse injury while continuing to meet today's current linear acceleration criterion. Additionally, applying a maximum allowable threshold to the new metric would make it possible to use as a helmet certification tool certifying helmets relative to both focal and diffuse injury.

References

[1] Takhounts et al., STAPP V.57 (2013);

[2] Takhounts et al., STAPP v.43 (2003)

Figures

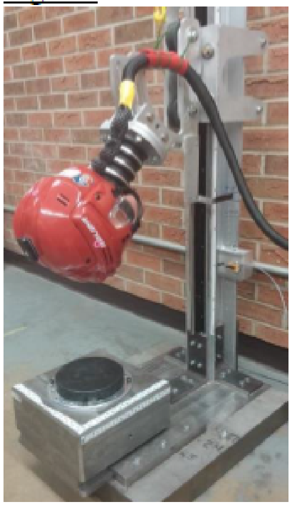

Figure 1: Impact test bed

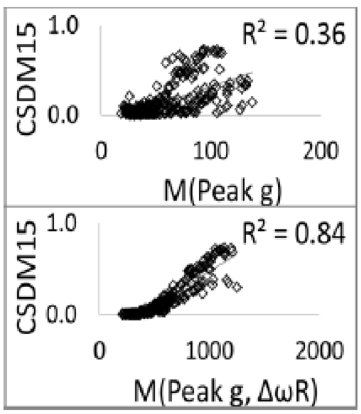

Figure 2: Regression model vs CSDM15 based on peak g (top) and both peak g and ΔωR (bottom). Similar results were found for MPS.