The Influence of Headform Geometry on the Dynamic Impact Response of a Hybrid III Headform

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SUMMARY
Research has reported that impact location and direction play an important role in predicting head injuries [6][5][2][3]. The limited biofidelity of the Hybrid III headform is a concern for researchers who perform head impact reconstructions that use accelerometers to measure and calculate the dynamic response of the head form. The dynamic impact response is interpreted as the interaction between a material (the skull) that is attached to other material bodies (neck, impactor and brain) and their related responses during a direct impact [7,8].

INTRODUCTION
Head injuries are sensitive to impact direction and related to the magnitude of linear (g) and rotational (rad/s^2) accelerations [1, 2]. Current head injury thresholds for recreational sport helmet testing are not location specific and do not represent the three-dimensional dynamic response of the head [3]. The Hybrid III headform used for direct head impact reconstructions was originally designed for impulsive automotive reconstructions. The steel skull of the Hybrid III does not deform or provide a dynamic response similar to the human head during direct head impact. This results in increased reliability but decreased biofidelity and validity [4].

The dynamic response of the Hybrid III headform may be the result of the unique elliptical geometry of the head. The moment of inertia (I = mk^2) of the headform due to its elliptical geometry varies with how the mass is distributed and its distance from the center of gravity [10]. A decrease in moment of inertia would be the result of a concentrated mass closer to the center of gravity of the head. As a result, the contribution of geometry to the dynamic impact response of the Hybrid III headform remains unknown. Use of a Hybrid III neckform coupled to the Hybrid III headform for dynamic testing provides improved dynamic impact response and allows data collection of three-dimensional linear and rotational acceleration data. The effect of head geometry on the dynamic response has not yet been quantified. This study documented the influence of headform geometry on the dynamic impact response of a Hybrid III headform.

METHODS
A 50th percentile Hybrid III head, with a mass of 4.54±0.01 kg was impacted for this study (Figure 1). Accelerometers were fixed in an orthogonal position near the center of gravity of the headform using the “3-2-2-2” array developed to measure and calculate three-dimensional motion during impact [9].

RESULTS AND DISCUSSION
The elliptical shape of the Hybrid III headform that distinguishes the different impact locations may help explain the significant differences in the peak resultant linear acceleration and peak resultant rotational acceleration of the dynamic response between the three impact locations. The front impact location (Front to COG = 0.05588m) has a higher perpendicular distance from the center of gravity than the side impact location (Side to COG = 0.04826m). The main effects of impact location on peak resultant linear (F(2, 107) = 65.295, p<0.001) and peak resultant rotational (F(2,107) =
202.822, p<0.001) accelerations were significantly different across all conditions for impact location. The influence of the Hybrid III headform’s geometry on the dynamic impact response where an identical Forward 0° neck orientation with reference to the impactor is maintained across all three impact locations (Figure 3&4).

Figure 3: Linear acceleration (g) at three impact locations with identical neckform orientation.

Decreases in the time to peak of the curves for linear and rotational accelerations where the side k distance is the least, reflect the effect of radius of gyration.

Figure 4: Rotational acceleration (rad/s^2) at three impact locations with identical neckform orientations.

As previously reported the side impact location was at greater risk of head injuries [2,3,6]. Regardless of neck orientation, the side impact location revealed greater risk of injury due to greater peak linear and rotational accelerations than other impact locations. A shift to the left (Figures 3&4) represents a decrease in the k distance, decreasing the moment of inertia, therefore; increasing head acceleration. The geometry of the Hybrid III headform affects the dynamic response of the head to impacts and therefore is important to understand when interpreting impact data from different location of the head and injury risk. [2,3,6].

The Hybrid III headform equipped with the rubber butyl skin is also designed with facial landmarks like a nose, lips and eye sockets (Figure 5). These landmarks are crucial to the Hybrid III headform’s geometry to provide a realistic appearance and an appropriate dynamic response of the headform. Facial bones provide energy attenuation properties due to their decreased mechanical impedance unlike the increased mechanical impedance of skull bone [11].

Figure 5: Side by side comparison of the Hybrid III head- and neckform with and without the rubber butyl skin showcasing facial landmarks.

This characteristic of the Hybrid III headform at the front impact location resulted in lower peak resultant linear acceleration and peak resultant rotational accelerations than other impact locations regardless of the neck orientation. Attributed to the decreased magnitude of the dynamic response of the Hybrid III headform at the front location was the increased volume and thickness of rubber butyl skin simulating soft tissue often found on the anterior side of the human head that are the Hybrid III headform’s landmarks that act to attenuate energy during direct impacts.

Impact locations of the Hybrid III headform influence the dynamic impact response. Understanding this interaction is important for developing a three-dimensional head injury protocol to advance helmet technology with the goal of reducing the risk of head and brain injuries.

CONCLUSIONS

This study provides important data and information concerning the dynamic response of the Hybrid III headform. Understanding the influence of headform geometry and physical neckform characteristics when undertaking impact reconstructions is very important when interpreting data. The results of this study can be used for further development of more accurate three-dimensional head injury thresholds.

REFERENCES