# Effect of Initial Positioning of the Hybrid III Head-Neck in Frontal and Oblique Bare Head Impact

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## I. INTRODUCTION

Helmet impact testing is fundamental to American football helmet design and regulation. As our understanding of the role of angular head kinematics on traumatic brain injury (TBI) risk has improved [1], the field has shifted toward assessing helmets using headforms mounted on deformable necks, which allow for more biofidelic head rotation. The most widely used neck for football helmet assessment is the Hybrid-III (HIII) 50$^{th}$ percentile male neck, which is used with the HIII headform. There are two impact conditions using this setup to assess the performance of football helmets available in the market: a rigid pendulum impact [2]; and a compliant linear impact [3]. There is a need for a platform of validated computational tools for simulating these impact test conditions *in silico* during the helmet design process. The objective of this study was to develop HIII head-neck (HIII H-N) and impactor models of the aforementioned evaluation cases, and to investigate the sensitivity of the HIII H-N kinematic and injury criteria outputs to variations in initial position in frontal and oblique impacts.

## II. METHODS

The HIII H-N model geometry was obtained from technical drawings provided by the U.S. Department of Transportation. Overall, the model consisted of the head skin rubber, rigid inner skull, head mount and OC pin, neck rubber and metal discs, neck cable and neck mount (Fig. 1). To account for the simplified geometry of the head, mass and inertial properties were defined for the rigid skull to match technical specifications. A hyperelastic constitutive model was used to represent the head skin rubber properties, and the NHTSA head drop certification test [4] was simulated to validate the head model (Fig. 2). The neck rubber was modeled using a viscoelastic constitutive model that consisted of a nonlinear spring in parallel to a viscous damper. The neck cable was comprised of a series of truss elements. A zero-length discrete beam joined the head and neck at the centre of the OC pin, and the y-axis of the beam was assigned properties of the nodding block. The NHTSA neck flexion and extension certification tests [4] were simulated to assess the combined response of the HIII H-N model (Fig. 2).

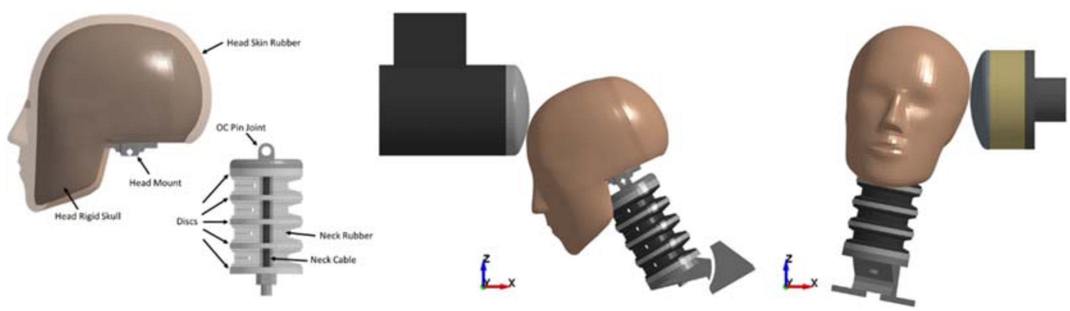


Fig. 1. Overview of the HIII H-N model (left), front pendulum impact (middle), and side-oblique linear impact (right).

The pendulum impactor was meshed from technical drawings of the test apparatus and the mass (15.5 kg) and inertial properties ($I_y$ = 72 kg-m$^2$) were explicitly defined [2]. Elastic properties were assigned to the nylon striking face. The linear impactor included a vinyl nitrile (VN600) foam puck sandwiched between the nylon striking face and the ram [3]. A series of compression tests at quasi-static and dynamic strain rates were performed to characterise the foam material response. The VN600 foam was modeled using a strain-rate dependent foam constitutive model with a lookup table defining the response over the range of strain rates.

Frontal and side-oblique pendulum and linear impacts were simulated with initial velocities of 3.0 m/s and 5.5 m/s, respectively (Fig. 1). Positioning specified in the experimental protocols was used to validate the HIII and impactor models. The CORA objective rating method was used to compare the model and experimental responses [5]. To assess sensitivity in the frontal impacts, the ATD position was varied by ± 5 mm in the global z- and y-directions and ± 3° in global y-rotation. In the oblique impacts, the ATD position was varied by ± 5 mm in the global y- and z-directions and ± 3° in global y- and z-rotation. The global coordinate system is shown in Fig. 1. A total of 30 simulations were conducted.

Peak head kinematics and injury criteria were calculated to assess model sensitivity. These included peak

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resultant linear velocity and acceleration and peak resultant angular velocity and acceleration. The injury criteria calculated were the Head Injury Criterion (HIC15, [6]) and the Universal Brain Injury Criteria (UBrIC, [7]). For each case, the mean and standard deviation of each evaluation metric was computed. Sensitivity was categorised by the standard deviation of the metric as a percentage of the mean (Table I).

## III. RESULTS

Overall, the HIII H-N model demonstrated accurate behaviour compared to the physical dummy. The model passed certification (Fig. 2), and the CORA scores for the pendulum and linear impactor cases were 0.79 and 0.82, respectively. Head model response was most sensitive to variations in position for the frontal impact cases (Table I). The most pronounced variations were observed in the frontal pendulum cases where the head was positioned -5 mm in the z-direction and +3° in y-rotation. Similar results were observed in the frontal linear impactor case. The variability of the head response was relatively small in both oblique loading cases.

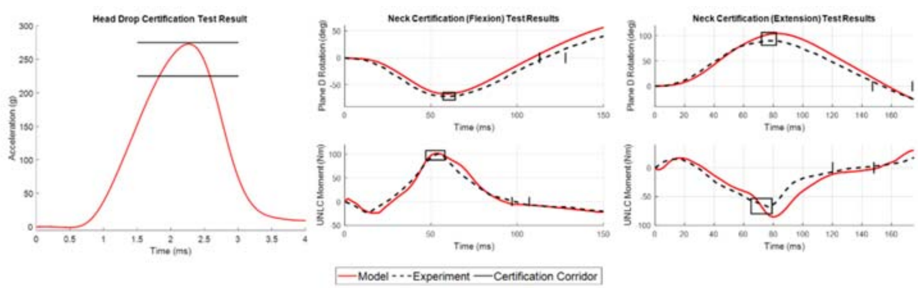


Fig. 2. Results of the head drop (left), neck flexion (middle), and neck extension (right) certification tests.

TABLE I
AVERAGE AND STANDARD DEVIATIONS OF EACH EVALUATION METRIC INVESTIGATED IN THE SENSITIVITY STUDY

| Impact Cae | | HIC | UBrIC | Peak Vel. (m/s) | Peak Accel. (m/s$^2$) | Peak Ang. Vel. (rad/s) | Peak Ang. Accel. (rad/s$^2$) |
|---|---|---|---|---|---|---|---|
| **Pendulum** | **Front** | 680 ± 28.0 | 0.09 ± 0.02 | 3.0 ± 0.04 | 246 ± 5.6 | 15.8 ± 3.6 | 9110 ± 470 |
| **Linear** | **Front** | 157 ± 12.0 | 0.13 ±0.01 | 4.7 ± 0 .05 | 66.8 ± 3.6 | 21.8 ± 3.4 | 4040 ± 565 |
| **Pendulum** | **Oblq.** | 479 ± 4.2 | 0.18 ± 0.002 | 2.8 ± 0.01 | 216 ± 0.98 | 25.6 ± 0.13 | 19170 ± 234 |
| **Linear** | **Oblq.** | 262 ± 4.3 | 0.21 ± 0.009 | 4.6 ± 0.04 | 96.4 ± 1.0 | 30.7 ± 0.48 | 7120 ± 207 |

| | | |
|---|---|---|
| Std. Dev < 5% of Mean | 5% of Mean < Std. Dev < 10% of Mean | Std. Dev > 10% of Mean |

## IV. DISCUSSION

In this study, a suite of HIII H-N and impactor models were developed, validated and used to investigate the sensitivity of the model outputs to variation in initial positioning of the HIII H-N model. The greatest sensitivity in model response was observed in the frontal pendulum impact cases. In the -5 mm (z) and +3° (y) cases, the model response was substantially different from the baseline case, because the impactor remained adhered to the head skin following impact, greatly reducing +y-rotation, angular velocity and, subsequently, UBrIC. This highlights the importance of replicating the effective initial positioning of the HIII H-N when simulating impact, considering that in these tests the head and neck are initially tilted forward and may be susceptible to a few degrees of sagging due to gravity. These open source models are available at www.biocorellc.com.

## V. ACKNOWLEDGEMENTS

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