Influence of two different neck models on the head kinematics in helmet testing during an impact from a striking object: an experimental and simulation-based study

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I. INTRODUCTION

Industrial safety helmets are certified for linear energy absorption, measured by the force transmitted from an impacting striker through the helmet to a rigid headform. As shown in several studies [1-2], the brain may be injured not only by the linear impact forces but also by rotational motion transferred to the brain. This knowledge has lately led to the incorporation of oblique tests, measuring the head rotational motion, in helmet standards such as the motorcycle standard ECE 22.06, where falls with a significant horizontal component are expected.

It is less established how high the risk of injury due to rotational motion is in typical industrial scenarios, with a striking object from above. To evaluate the risk of injury due to rotational motion, the test set-up must allow for the headform to move in both translation and rotation. Thus, the headform must be attached to a flexible neck. Current surrogate neck models are mainly developed for car crash analyses and are therefore not validated for vertical loads to the head, such as a striking object [3-6]. The lack of alternative neck surrogates makes it difficult to evaluate helmets for this load case. With the aim of better understanding how the current neck surrogates perform in impacts with a striking object from above, and to estimate the magnitude of the brain injury criteria in this scenario, two common dummy necks were evaluated experimentally. Also, Finite Element (FE) models of the same two surrogates were used together with a human body model (HBM) neck to evaluate their performance compared to a more biofidelic alternative.

II. METHODS

This study included experimental tests using the head and neck from two different anatomical test devices. Four different helmet models were studied: two hard hat models (H1, H2) and two climbing-style helmets with energy-absorbing foam (H3, H4). All helmets were certified according to EN397.

Experimental Testing with HIII and THOR Dummy Head and Neck

The test set-up was designed to represent a possible accident scenario from construction where an object impacts the helmeted head. The neck and head from each of the respective dummies, HIII and THOR, were rigidly fastened to a pedestal leaning forward 13 degrees to get a slightly forward leaning position, see Fig. 1. The helmet was positioned on the headform according to standard positioning whereafter a 5 kg steel cylinder was impacting the helmet 6 cm in front of the head-neck joint of the HIII dummy. The striking cylinder glided on a drop-slide, angled at 13 degrees, and was dropped from 1.5 m and 2.0 m, respectively, along the drop-slide. Each new test set-up was performed on a new helmet. The translational accelerations were recorded by a 9-accelerometer array, located in the center of each head during the impact, whereafter the rotational accelerations and velocities [7] and the brain injury criteria (BrIC) were computed [2].

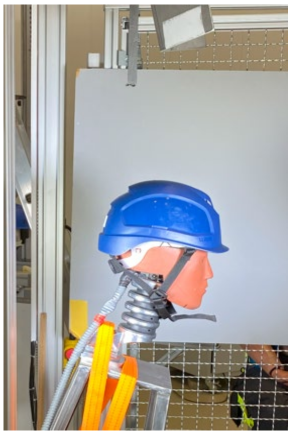

Fig. 1. Test set-up, with HIII head and neck and the drop-slide.

Computational Modeling of the Surrogates in Comparison with a More Biofidelic Neck

To evaluate how the surrogate results compare with a HBM, the experiments were replicated with numerical models. FE models of the HIII dummy 50th percentile male [3] and the Thor 50th percentile v 2.7 [4] were used. As HBM the KTH neck [8] was used attached to the HIII head. A numerical model of the H2 helmet was impacted by a cylinder with the same weight, impact location and velocities as in the experiments.

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III. INITIAL FINDINGS

Figure 2 shows the peak values for each combination of helmet, dummy and drop height. Peak translational acceleration (PTA) was higher for the HIII dummy. Peak angular acceleration (PAA) was slightly higher for the Thor, except for H1. For H3 and H4 the PAA decreased with height, which may be due to increased sliding. BrIC was higher for the Thor dummy, except for H1 at 1.5 m. However, the different helmet models gave a larger spread in the data than the choice of neck. The rating of the helmets based on the BrIC value was the same for the two necks (from low to high: H1,H3,H2,H4), except for the HIII neck at 1.5 m where H1 and H3 changed places. Overall, the BrIC values were high enough to suggest risk of brain injury [2], but especially for the Thor dummy and helmets H2 and H4.

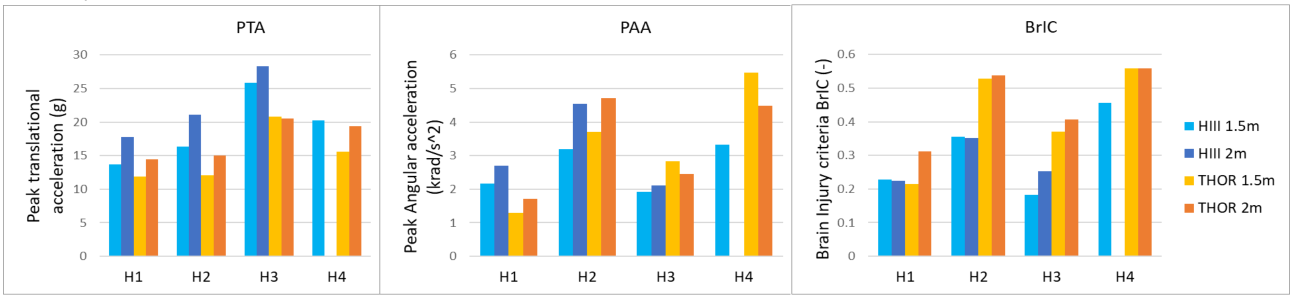

Fig. 2. PTA, PAA and BrIC for four different helmet models tested with Thor and HIII for two different drop heights. The results are from the first helmet impact of each combination. H4-HIII 2 m did not have any valid data to present.

Fig. 3 *left* shows the resultant angular velocity as function of time from experiments with helmet H2. Only the first impact per helmet is shown. The two different surrogate necks both showed a spring-back behaviour, but the HIII neck showed the stiffest response with a smaller peak and shorter duration before turning into extension. Much of the rotation in Thor seemingly occurred in the head-neck joint. Fig. 3 *right* shows the angular velocity from the simulations, where the Thor neck resulted in the closest resemblance to the human neck model.

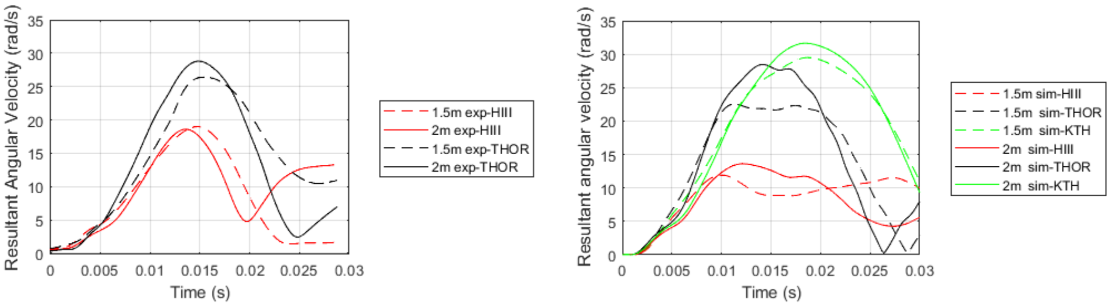

Fig. 3. Head resultant angular velocity for the experimental results with H2 on Thor and HIII to the left, and for the simulation results with a numerical model of H2 on Thor, HIII and the KTH neck model to the right.

IV. DISCUSSION

The results showed that for the studied load case the choice of neck surrogate affected the results in short duration impacts. The test set-up was tilted slightly so that the loading on the neck was not completely vertical. With a more axial load the surrogate necks would probably have shown even more spring-back behaviour with smaller BrIC. The simulations did not completely capture the behaviour of the experimental results due to lack of validation of the models for this load case. However, the results showed similar trends and it could be assumed that with a more biofidelic surrogate, the BrIC would be slightly larger and the duration longer, as seen by the KTH neck model. A new surrogate neck for head impacts would be beneficial for the increased understanding of the protecting properties of a helmet.

V. REFERENCES

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