Cross-comparison of Different Oblique Impact Test Methods for Helmet Performance Evaluation

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I. INTRODUCTION

Despite the fact that many new oblique impact test methods are emerging, with the aim of improving helmet design and reducing traumatic brain injury (TBI), comparative analysis of different test methods, particularly for helmet performance evaluation, is lacking. There is a multitude of variables and decisions to be made when designing a test method, including impact conditions, human head test surrogates and boundary conditions [1]. A recent survey highlighted the disparities in the new oblique test methods even for the same category of helmets [2]. It is not well understood if the presence of a variable, or a combination of variables, between different test methods affects the outcomes of helmet performance evaluation. This study compares three existing oblique impact test methods through experimental testing and computational modelling on helmets of the same model. The final aim is to exploit virtual crash testing in order to assess helmet ranking of different test methods by introducing design variations in a previously validated finite element (FE) helmet model.

II. METHODS

Experimental Testing

AGV Pista GP helmets certified to UN/ECE22.05 were tested via three laboratory methods using 50th percentile Hybrid-III (HIII) head or head-neck assembly. Figure 1 shows the test configuration of each method (at t=0), and principal components of the experimental rigs can be found in [3-5]. All impacts were designated at the frontal area of the helmet and at the same resultant impact speed of 7.5 m/s. In Method A, helmet was dropped vertically onto a 45-degree stationary anvil. In Method B, a striker plate was propelled horizontally at 5.3 m/s while the helmet was falling vertically at 5.3 m/s. In Method C, a head-neck assembly was suspended on a pendulum while an impact was delivered to the helmet by free-falling a 13 kg, 45-degree metal anvil. Three helmets were tested per method, one test in Method B was not recorded.

Computational Modeling

A previously validated FE motorcycle helmet model [6-7] was coupled with a FE HIII head-neck model [8] from Biocore, LLC to replicate the experimental testing (Fig. 1). In the previous paper [7], the baseline FE helmet model was modified into four possible variations by changing density of the expanded polystyrene (EPS) liner, thickness of helmet outer shell and coefficient of friction (COF) between head and helmet. The present study adopt the five helmet variations, with the exception that COF is 0.8 for helmet variation 2, and 0.5 for both helmet variation 4 and 5 (Table I). Thereafter, five helmet variations were virtually tested and ranked by each of three oblique impact test methods. The HIII head translational and rotational accelerations from both experimental testing and computational modelling were applied to the skull of the KTH FE head model [9-10] as a prescribed boundary motion in order to assess the maximum 1st principal Green-Lagrange (G-L) strain (referred to as maximum principal strain or MPS) of the whole brain. MPS was considered to be a predictor of TBI and hence was chosen as the metric for helmet performance ranking in this study.

III. INITIAL FINDINGS

The computational modelling showed reasonably good agreement with experimental results (Figs 1 and 2), especially for the MPS. Despite the differing severity (level of MPS indicated by the grayscale), the three test methods had consistent ranking in terms of the best- and worst-performing helmet (Table II). The computed MPS was similar for helmets 1, 4 and 5, which might be the reason for different ranking between test methods A-C.

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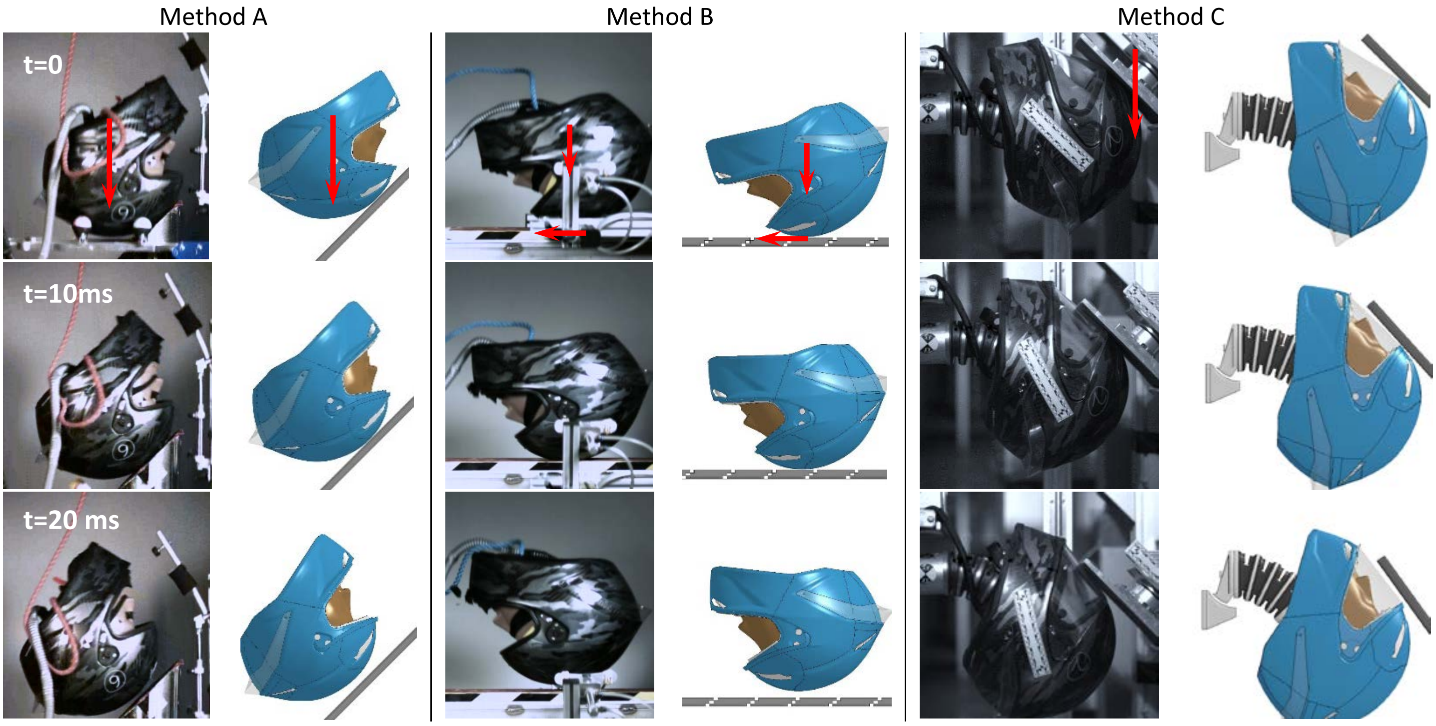

Fig. 1. Experimental testing and computational modelling of three oblique impact test methods shown at three time frames; t=0 indicates the time just prior to the impact.

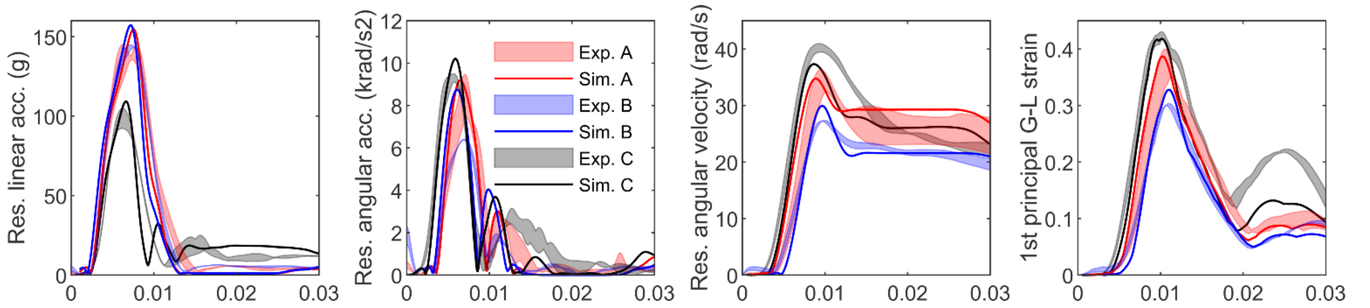

Fig. 2. Comparison of experimental corridors (in shade area) and computational modelling (in solid line), Helmet 1.

TABLE I

FIVE HELMET VARIATIONS [7]

Variations	EPS+Outer Shell	COF
Helmet 1 (H1)	Baseline	0.50
Helmet 2 (H2)	Baseline	0.80
Helmet 3 (H3)	Baseline	0.15
Helmet 4 (H4)	Soft	0.50
Helmet 5 (H5)	Stiff	0.50

TABLE II

RANKING OF FIVE HELMETS BY EACH OF THE THREE TEST METHODS

RANK	I	II	III	IV	V
METHOD A	H3: 0.219	H4: 0.361	H1: 0.386	H5: 0.387	H2: 0.441
METHOD B	H3: 0.201	H5: 0.317	H1: 0.328	H4: 0.335	H2: 0.381
METHOD C	H3: 0.317	H4: 0.406	H5: 0.417	H1: 0.418	H2: 0.431

MPS colour scale: 0.45, 0.4, 0.35, 0.3, 0.25, 0.2, 0.15, 0.1

IV. DISCUSSION

Virtual crash testing has shown to be a promising methodology to investigate the variables in the new oblique impact test methods and to understand how the helmet performance evaluation is affected. Future work will include other impact directions and helmet variations in order to understand the differences and potential recommendations for future helmet test methods.

V. REFERENCES

[1] Halldin, P., *et al.*, *Helmet Performance and Design*, 2013. [2] Whyte, T., *et al.*, *J Biomech Eng*, 2019. [3] Aare, M., *et al.*, *Traf Inj Prev*, 2003. [4] Bourdet, N., *et al.*, IRCOBI, 2016. [5] Roseveare, A., *et al.*, IRCOBI, 2016. [6] Meng, S., *IJ Crash*, 2018. [7] Meng, S., *et al.*, IRCOBI, 2018. [8] Giudice, J. S., *Ann Biomed Eng*, 2018. [9] Kleiven, S., *Stapp Car Crash J*, 2007. [10] Zhou, Z., *et al.*, *Stapp Car Crash J*, 2018.