The Difference in Ranking of Bike Helmets when Using Different Finite Element Head Models

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I. INTRODUCTION

European standard organisation (CEN/TC158) is developing a new test method for helmets, which also includes oblique impacts. The test method has already been used in helmet ratings [1-2]. In the evaluations, finite element (FE) models were used to evaluate the helmet performance. There are several different models developed around the world. Previous studies [3-6] have evaluated the difference between different FE head models and shown a large spread in response when it comes to peak strain value and strain pattern. To the authors' knowledge no previous study has evaluated how helmet ranking is influenced by using different FE head models. The objective of this study was to evaluate the influence of helmet ranking and the linear correlation between different head models and global injury criteria for bicycle helmet tests.

II. METHODS

The FE head models were evaluated against helmet drop test against a 45 degrees angled surface with a vertical impact velocity of 6.0 m/s. The experimental tests are described in detail in a previous study [1]. Seventeen different helmets (Helmet A-Q) were tested in three different loading conditions (Xrot, Yrot and Zrot; letter indicating the main rotation around the axis of the local coordinate system of the head). The measured linear and angular accelerations from the centre of gravity of the Hybrid III head form were applied to the centre of gravity of the head models.

The pulses were applied to four different FE head models: KTH Royal Institute of Technology [7], the isotropic version of the Worcester Head Injury Model (WHIM) [8], Total Human Model for Safety (THUMS) v.4.02 [9] and PIPER 18 years old model [10]. The results for the anisotropic Strasbourg University FE Head Model (SUFEHM) presented in a previous study [2] were also included in the comparison. For the KTH model the peak value of the first principal Green-Lagrange (G-L) strain of the brain tissue was used as output from the model. From the WHIM, THUMS and PIPER models the 95th percentile value of the first principal G-L strain of the brain tissue was used as output. For the SUFEHM peak axonal strain was used as output. As a global injury criterion, Brain Injury Criterion (BrIC) [11] was also included in the comparison.

The correlations between the models were evaluated for the correlation of ranking between the different models with Kendall's tau coefficient and linear correlation was evaluated with Pearson's correlation coefficient. The statistical analysis was performed in Matlab (2017b, The MathWorks, Inc., Natick, Massachusetts, US).

III. INITIAL FINDINGS

The average values of the outputs were lowest for Xrot condition and highest for Zrot condition (Table I). The ranking of the helmets were influenced by the choice of head model to different extent (Table II). Kendall's tau (Kendall Rank Correlation) coefficient varied between 0.494-0.985 for Xrot, 0.588-0.941 for Yrot and -0.162-0.794 for Zrot (Table III). The Pearson correlation coefficient (r) varied between -0.488-0.998 for the three loading conditions with lowest correlation for the Zrot.

TABLE I.
MEAN VALUES ±STANDARD DEVIATION FOR THE DIFFERENT FE HEAD MODELS AND BrIC

	WHIM	THUMS	PIPER	KTH	SUFEHM	BrIC
Xrot	0.246+0.029	0.258+0.047	0.245+0.041	0.228+0.040	0.126+0.019	0.456+0.065
Yrot	0.264+0.035	0.367+0.070	0.286+0.048	0.348+0.058	0.160+0.036	0.612+0.091
Zrot	0.389+0.012	0.621+0.042	0.404+0.018	0.508+0.022	0.239+0.068	0.985+0.050

TABLE II.

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RANKING OF THE HELMETS (A-Q) FOR YROT, BEST RANKED TO THE LEFT AND WORST TO THE RIGHT

WHIM	M	Q	D	H	L	O	J	N	C	E	I	F	A	B	K	P	G
THUMS	M	Q	D	H	L	O	E	N	I	J	F	C	A	K	B	P	G
PIPER	M	Q	D	H	L	O	N	J	E	I	C	F	A	B	K	P	G
KTH	Q	M	D	H	L	J	O	E	N	C	I	A	B	F	K	P	G
SUFEHM	D	L	C	O	H	M	E	Q	N	J	F	A	B	K	I	P	G
BrIC	M	Q	D	H	L	O	N	I	E	J	F	C	A	K	B	P	G

TABLE III.
KENDALL'S TAU AND PEARSON'S CORRELATION BETWEEN THE DIFFERENT FE HEAD MODELS AND BRIC

	Kendall's tau coefficient			Pearson's correlation coefficient		
	Xrot	Yrot	Zrot	Xrot	Yrot	Zrot
WHIM – THUMS	0.897	0.882	0.647	0.992	0.988	0.885
WHIM – PIPER	0.912	0.956	0.765	0.987	0.998	0.947
WHIM – KTH	0.721	0.912	0.074	0.939	0.991	0.391
WHIM – SUFEHM	0.494	0.647	-0.162	0.716	0.694	-0.488
THUMS – PIPER	0.985	0.926	0.794	0.99	0.995	0.972
THUMS – KTH	0.735	0.853	0.103	0.943	0.98	0.335
THUMS – SUFEHM	0.539	0.618	-0.015	0.725	0.676	-0.273
PIPER – KTH	0.721	0.897	0.132	0.903	0.989	0.38
PIPER – SUFEHM	0.524	0.632	-0.074	0.687	0.688	-0.369
KTH – SUFEHM	0.598	0.588	0.029	0.771	0.728	-0.235
WHIM - BrIC	0.926	0.882	0.863	0.978	0.967	0.976
THUMS - BrIC	0.882	0.971	0.701	0.981	0.99	0.925
PIPER – BrIC	0.897	0.926	0.775	0.965	0.978	0.955
KTH – BrIC	0.676	0.824	0.066	0.921	0.951	0.292
SUFEHM – BrIC	0.45	0.588	-0.229	0.679	0.589	-0.488

IV. DISCUSSION

Differences exist in helmet ranking between the different head models, especially for Zrot, which was also the impact condition with lowest spread in BrIC and strain except for the SUFEHM model (Table I). The lower spread could partly explain the lower Kendall's tau for Zrot.

All models have been compared to experiments. For example, the same validation experiments were used for the KTH and THUMS model with similar total CORA score [5]. Still, differences were seen in the mean values and helmet ranking but for the moment it is not possible to distinguish what is correct.

BrIC showed high linear correlation with most models (r>0.9) but lower for the SUFEHM model in all three loading directions and for KTH model in Zrot. Future work will include further analysis of the results and also include other global injury criteria.

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