The Relationship between Bicycle Helmet Performance and the Choice of Injury Metrics, Injury Risk Functions and Headforms

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I. INTRODUCTION

Helmets are the main protection system for head injuries in bicycle accidents. They are evaluated according to different standards and rating programs. Oblique impacts, which have been shown to be a common bicycle accident situation [1], have up to now not been evaluated in the bicycle helmet standards but rather as part of different rating programs.

In these rating programs, different injury metrics and injury risk functions have been used with different headforms. For the standards, the discussion concerns which injury metric should be used in oblique impacts and how the threshold should be chosen. The standards strive for a good correlation with real-world accidents while being robust, repeatable and cost-efficient. The use of an agreed level of risk from a risk curve would be a good way to motivate the threshold value. There are many different injury risk functions presented, e.g. for mild traumatic brain injuries (mTBI), but there can be some discrepancies [2-3]. The risk level could also be influenced by the choice of test methods and headform [4]. The objective of this study was to investigate the influence of the choice of injury metric, injury risk function and headform when evaluating the performance of bicycle helmets relative to each other.

II. METHODS

Oblique impact tests were performed with two helmet models (Helmet 1 and Helmet 2) and two different headforms (EN960 headform (size 575) and Hybrid-III (HIII) headform (50th percentile)). The head and helmet were dropped on to a 45 degree angled surface covered with abrasive paper. The impact velocity was 6.2 m/s and four impact points were evaluated (Fig. 1). The headforms were instrumented with either a 9-array linear accelerometer system or 3 linear accelerometer system together with 3 angular rate sensors.

The injury metrics that were evaluated were peak linear acceleration (PLA), peak angular acceleration (PAA), peak angular velocity (PAV), Brain Injury Criterion (BrIC) [5], strain values based on the KTH model [6], DAMAGE [7], and risk value based on a combination of PLA and PAV [8]. The risk functions that were used in the study were based on data from [5][7-10]. The risk functions BrIC and DAMAGE, based on the NFL, were developed with the same methodology as presented in [10].

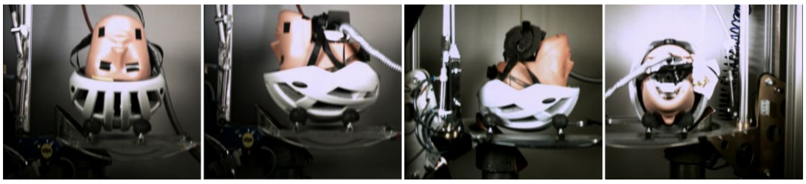

Fig. 1. The test setup illustrated with Helmet 1 and the HIII headform (Xrot, +Yrot, -Yrot, Zrot).

III. INITIAL FINDINGS

Higher values for the injury metrics (Table I) and injury risk (Fig. 2) were found for the HIII headform. The injury metrics for the EN960 headform were between 22% and 95% of the respective value for the HIII headform. The same values for the injury risk varied between 0% and 87%.

The performance between the two helmets varied between the different injury risk functions and headforms. For the Zrot impact location and HIII headform, the reduction of risk for Helmet 1 compared to Helmet 2 was between 25% and 59%, dependent on the injury risk function. For the EN960 headform, the values varied between 51% and 77%. However, it should be noticed that for HIII headform the risk went from 64% to 27% for the VT STAR risk function compared to 5% to 2% for the EN960 headform.

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TABLE I
MINIMUM AND MAXIMUM VALUE OF THE INJURY METRICS

		PLA [g]	PAA [krad/s^2]	PAV [rad/s]	BrIC	DAMAGE	KTH Strain
HIII	Min.	85.9	3.3	18.2	0.329	0.174	0.155
	Max.	120.9	10.1	37.1	0.717	0.369	0.430
EN960	Min.	93.5	1.4	5.0	0.119	0.051	0.063
	Max.	119.4	3.3	19.7	0.455	0.231	0.243

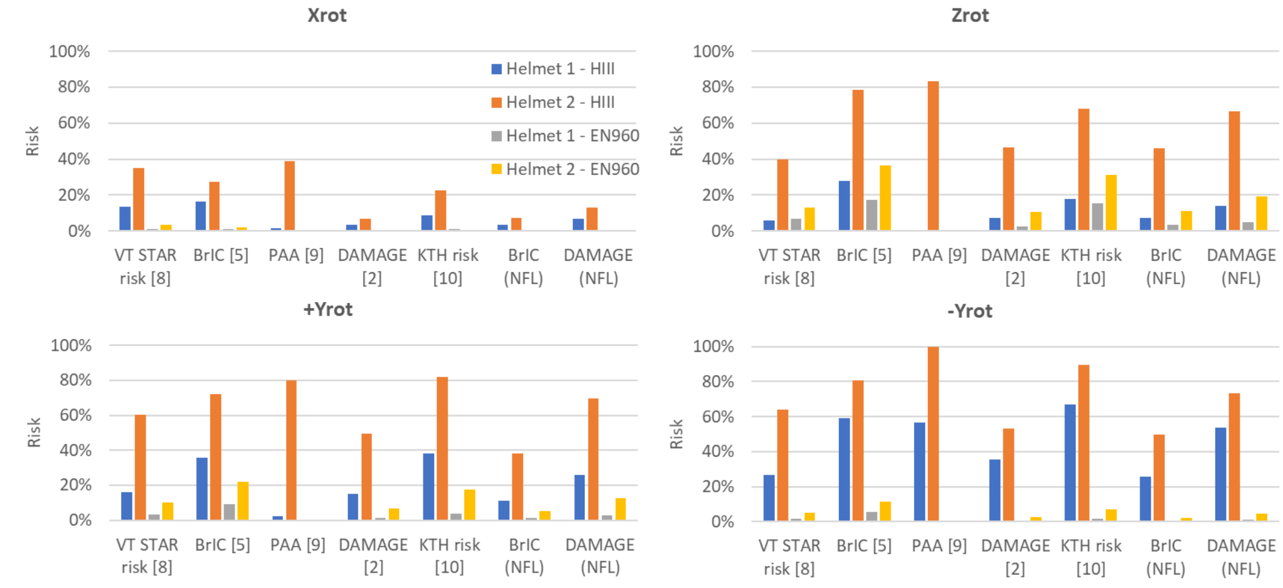

Fig. 2. Risk value for the different impact situations, injury risk functions and headforms.

IV. DISCUSSION

The results from these initial findings show a large variation among the chosen injury metrics, injury risk functions, headforms and impact situations. Not only were the risk values different for the two headforms but also their sensitivity to the different impact situations. For example, HIII has the highest risk for -Yrot and Helmet 2, while the EN960 headform had the highest risk for Zrot and Helmet 2. But there was also difference between the same headform, e.g. Xrot for Helmet 2, and the HIII headform was ranked between 1 (lowest risk) to 5 out of 8 impacts depending on the choice of injury risk function.

The big difference in peak values between the HIII and the EN960 headform is mainly due to the coefficient of friction, as shown by [11], but could also be influenced by the difference in centre of gravity, mass, and moment of inertia. Neither of these two headforms has been developed for oblique helmet impacts. There is a headform under development for oblique helmet impacts (WG11 headform), which will also be evaluated. The results in this and previous study [4] show the importance of threshold value in relation to the choice of headform.

Standards and rating programs have different objectives: standards should remove poorly designed helmets from the market; rating programs should help the end-user to choose a good helmet. This is essential given that accident data show that both mild and severe traumatic brain injuries occur in helmeted impacts [1]. The coefficient of friction between human head and helmet is somewhere between EN960 and HIII [12]. It seems that we have a missing link between injury risk functions and the test results. The authors therefore suggest that, until there is a more robust link between performance in the laboratory and real-world accidents, the pass/fail threshold for standards should be based on testing of helmets on the market with the specific standard specification. The threshold could be at the 10% to 20% most poorly performing helmets. For the future, it would also be preferable to have risk functions that involve bicycle accidents. This could perhaps strengthen the link between real-world accidents and the test standards.

V. REFERENCES

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