Development of Headforms for Oblique Helmet Testing

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on the behalf of CEN Technical Committee 158 Working Group 11

I. INTRODUCTION

The energy absorption of helmets is evaluated in many of the certification standards by dropping a helmeted headform on a horizontal surface, which until recently has been limited to a flat, kerbstone or hemisphere surface. Now oblique (rotational) impacts are being introduced to the certification standards. Headforms used today in helmet testing (e.g. EN960, NOCSA, Hybrid III) have not been developed for oblique impacts. Several studies have shown that features of the headform, such as moment of inertia (MOI) and coefficient of friction (COF), can strongly influence the kinematics of the headform [1-3]. Within the European standard organisation for head protection (CEN TC 158), a working group (WG11) has developed an oblique test method, and crucially they have identified the need to develop a new headform for oblique test methods. The objective of this paper is to report on the development of this new headform and its initial evaluation.

II. METHODS

The main features that were considered when developing the headforms were: head shape, mass, MOI, centre of gravity (CG), and the COF between the headform and helmet. A range of headform sizes was developed from a head circumference of 470 mm to 630 mm with an increment of 20 mm.

Head Shape

The headform size was based on the Caesar 3-D anthropometric database limited to the Dutch, Italian and American population. In total, 3D scans of 4,000 individuals were included in the analysis. Due to limited scans from the smaller individuals with a circumference below 520 mm, data from TU Delft database [4] of 303 scanned Dutch children were used to develop the shape for the smallest headforms (470 and 490). The size 510 was designated a blend between the two databases. The headform shapes were derived from 3D scans via statistical shape modeling [5]. Open-source CAD files are available for each headform size.

Inertial Properties

The mass, MOI and CG were based on the review by [6-8] with some exclusions. First, for the mass and MOI, only data where no major parts of the neck were included were used. For the MOI, studies that measured the MOI around all anatomical axes (x,y,z) were included. Studies that included embalmed heads were excluded. Linear scaling was performed for the adult headform sizes (530 to 630). The smallest headform sizes (470 and 490) were based on the data presented by [9]. Headform size 510 was based on a mix of adult and child data.

Coefficient of friction

For the COF between the headform and the helmet comfortliner, post-mortem human subject (PMHS) data from [10] were used. Therefore, the specification for the headform COF was set to 0.30 ± 0.03.

Initial evaluation of Size 570

The headform was evaluated through oblique testing of one bicycle helmet model in six different laboratories. Four impact points were evaluated (Fig. 1). Two impact points were evaluated on each helmet and each impact point was evaluated three times (in total, six helmets per laboratory). The head is instrumented with one 6DOF

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sensor, measuring accelerations in 3 directions and angular rate around 3 axis. The linear acceleration was filtered with a CFC 1000 filter and angular velocity with a CFC 180 filter. The analysis was performed for peak linear acceleration (PLA), peak rotational acceleration (PRA), peak rotational velocity (PRV), head injury criterion (HIC), and Brain Injury Criterion (BrIC). The standard ISO5725 Accuracy (trueness and precision) of measurement methods and results was used to analyse the results.

III. INITIAL FINDINGS

The developed headform sizes are presented in Fig. 2 and their specifications are shown in Table I. The mean value and standard deviation from the impact tests are presented in Table II. The coefficient of variation was below 5% for 69% of the different impacts, injury metrics and labs, and 95% was below 10%.

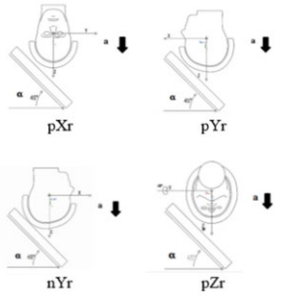

Fig. 1. Impact points.

Fig. 2. The physical headforms in size 470, 490, 530, 570, 610, and 630.

TABLE I
SPECIFICATIONS FOR THE HEADFORMS

Circum-ference [mm]*	Distance 'a'*	Mass [kg]	Centre of gravity X [mm]	Centre of gravity Y [mm]	Centre of gravity Z [mm]	Moment of inertia Ixx [kg cm^2]	Moment of inertia Iyy [kg cm^2]	Moment of inertia Izz [kg cm^2]
470	22.5	2.29	2.7	0.0	29.3	68.2	82.5	52.1
490	23.5	2.64	4.0	0.0	28.8	89.4	106.6	67.3
510	24.5	3.01	5.2	0.0	28.3	113.6	134.1	85.0
530	25.5	3.39	6.5	0.0	27.9	139.1	163.1	104.3
550	26.5	3.79	7.8	0.0	27.4	167.4	195.0	126.2
570	27.5	4.23	9.0	0.0	26.9	199.5	231.0	151.4
590	28.5	4.67	10.3	0.0	26.4	233.9	266.8	175.9
610	29.5	5.11	11.6	0.0	26.0	268.3	302.6	201.5
630	30.5	5.55	12.8	0.0	25.5	302.7	338.4	228.1

**in the plane on the headform angled 10° from the reference plane at the rear of the head at the intersection of the reference plane and the midsagittal plane. The reference plane is horizontal plane distance 'a' above the Frankfort plane.*

TABLE II
KINEMATICS FOR THE IMPACT TESTS

	Mean Value				Repeatability standard deviation				Reproducibility standard deviation			
	pXr	pYr	nYr	pZr	pXr	pYr	nYr	pZr	pXr	pYr	nYr	pZr
PLA [g]**	152.6	118.8	89.6	142.5	2.8	4.3	5.8	4.8	7.0	5.1	3.4	4.5
PAA [rad/s^2]	5168	6486	6306	6904	391	296	448	450	592	794	738	758
PAV [rad/s]	20.1	27.6	31.6	27.8	1.0	0.9	0.4	1.3	1.2	1.5	1.5	2.7
BrIC	0.347	0.494	0.561	0.634	0.015	0.014	0.008	0.017	0.013	0.023	0.027	0.047
HIC**	895	529	262	761	43	13	16	30	71	54	28	24

***Only four laboratories were included due to problems with the accelerometers, but the angular rate sensor worked.*

IV. DISCUSSION

WG11 has developed specifications for nine different headform sizes, suitable for oblique impact test methods. Within and between lab tests the headform size 570 showed consistency in the results. These findings provide strong support for the adoption of the headforms in oblique test methods.

Other headform sizes have been tested with similarly positive outcomes, but the results have not been included in this short communication. This work is limited to testing a single helmet model. In the future, other helmet models with different design and for other helmet types will be evaluated. A comparison with other headforms used for oblique helmet testing may be interesting for the community. This study supports the adoption of the new headforms for improving the fidelity of oblique impact test methods.

V. REFERENCES

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