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Hockey STAR Methodology

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Laboratory Tests

A pendulum impactor is used to perform all impact tests (Figure 1) [1]. It was chosen for its increased repeatability and reproducibility compared to other impacting methods [2]. The pendulum arm is 190.5 cm long, has a total mass of 36.3 kg with a 16.3 kg impacting mass at the end, and has a moment of inertia of 72 kg·m^2. A flat, rigid nylon impactor face with a 12.7 cm diameter is used to maximize repeatability and reproducibility of tests. A rigid impacting face was chosen to simulate the rigid surfaces in hockey and to eliminate any differences between helmets in comparative testing due to impactor compliance [1]. The pendulum impacts a helmeted, medium NOCSAE head, which is modified to fit a 50th percentile male Hybrid III neck. The head and neck are mounted to a 5-degree-of-freedom Biokinetics slide table with a 16 kg sliding mass. This setup allows for linear and rotational motion to be generated during an impact and is representative of the head, neck and torso of a 50th percentile male. Test conditions include four locations (Table 1) and three velocities (3.1, 4.9, and 6.4 m/s). Helmet position on the headform is set according to fitting guidelines provided by the manufacturer. If the headform size falls between two candidate helmet sizes, the larger size is chosen to avoid pre-compression of inner padding. Two trials are performed at each impact configuration using two helmet samples, resulting in a total of 48 tests per helmet model.

Figure 1: Pendulum impactor used for Varsity Hockey STAR tests.

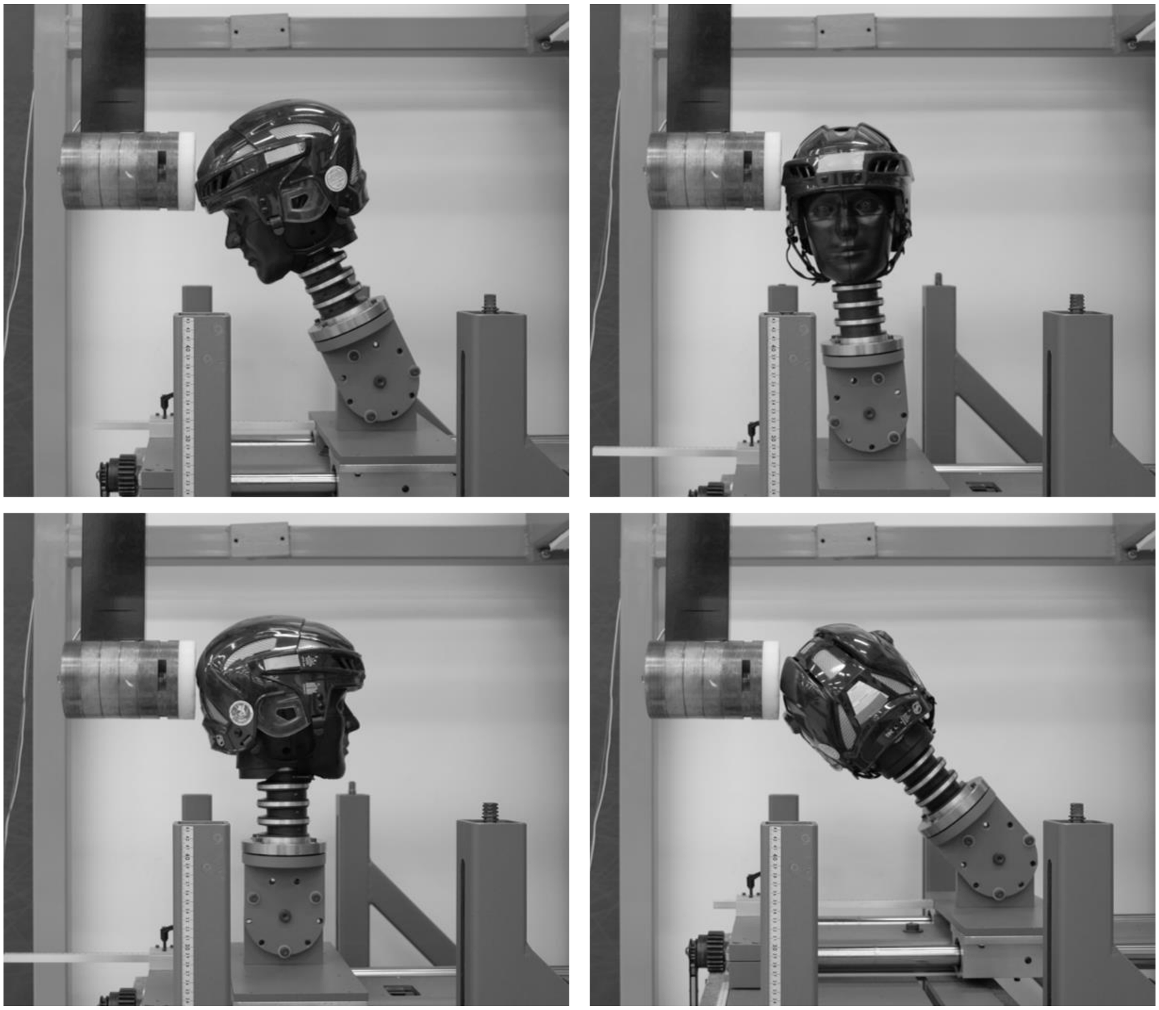

Figure 2: Impact locations clockwise from top left: front, side, back, top.

Table 1: NOCSAE headform translations and rotations on the linear slide table for each test condition.

Location	Y (cm)	Z (cm)	Ry (deg)	Rz (deg)
Front	0	+1.9	-25°	0°
Side	+3.1	+7.3	-5°	-80°
Back	0	+5.9	0°	180°
Top	+2.7	-2.7	-40°	90°

Notes: All measurements are made using the SAE J211 coordinate system in relation to a “zero” condition in which the headform is in a position of 0° Y and Z-axis rotation and the median (midsagittal) and basic (transverse) plane intersection of the headform is aligned with the center of the impactor. The x-position is set such that the helmet contacts the impactor face when the pendulum arm is in a neutral vertical position for each location.

The NOCSAE headform is instrumented with three linear accelerometers and a triaxial angular rate sensor (ARS) at its center of gravity to measure linear and rotational impact kinematics. Data are sampled at 20,000 Hz and filtered using a 4-pole Butterworth low pass filter with a cutoff frequency of 1650 Hz (CFC 1000) for accelerometer data (SAE J211) and 256 Hz (CFC 155) for ARS data.

STAR Ratings

The STAR equation was originally developed to estimate the incidence of concussion that a college football player may experience while wearing a given helmet over the course of one season [1]. Common on-field impacts are simulated using laboratory testing, with the resulting concussion risk for each impact estimated and then weighted based on the relative frequency that a player might experience that impact scenario during a season of play (termed "exposure"). The STAR value is found by multiplying the predicted on-field exposure (E) at each impact location (L) and velocity (V) by the risk of concussion (R) for that impact. Concussion risk is modeled using the peak resultant linear acceleration (a) and rotational acceleration (α) from laboratory impacts (Equation 1).

$$STAR = \sum_{L=1}^{4}\sum_{V=1}^{3} E(L,V) * R(a,\alpha) \qquad \text{(Eq. 1)}$$

Exposure values for each impact configuration were determined from on-ice data collected from collegiate hockey players over three seasons (Table 2).

Table 2: Exposure weightings used for each location and impact velocity to obtain a total STAR value for Varsity Hockey STAR. The average hockey player experiences 227 head impacts per season.

Location	3.1 m/s	4.9 m/s	6.4 m/s
Front	22.150	0.759	0.044
Side	3.441	0.317	0.042
Back	11.027	1.244	0.051
Top	15.474	0.519	0.045

Concussion risk was modeled using a multivariate logistic regression analysis of biomechanical data obtained from instrumented football players who sustained diagnosed concussions [3]. The associated risk function combines peak linear head acceleration (PLA) and peak rotational head acceleration (PRA), which are both known to be associated with brain injury, into a single metric (Equation 2) [4].

$$R(a,\alpha) = \frac{1}{1 + e^{-(-10.2 + 0.0433*a + 0.000873*\alpha - 0.00000092*a\alpha)}} \qquad \text{(Eq. 2)}$$

The range of final STAR values across helmets are then distributed into a discrete number of stars (1 to 5) for consumer interpretation (Table 3). Lower STAR values are associated with a greater number of stars and are representative of better performing helmets.

Table 3: Thresholds to match STAR values to number of stars in a 5-star rating scale.

STAR Value	Number of Stars
< 0.50	5
< 0.75	4
< 1.00	3
< 1.25	2
≥ 1.25	1

References

[1] B. Rowson, S. Rowson, and S. M. Duma, "Hockey STAR: a methodology for assessing the biomechanical performance of hockey helmets," Annals of biomedical engineering, vol. 43, issue, 10, pp. 2429-2443, 2015.

[2] E. J. Pellman, D. C. Viano, C. Withnall, N. Shewchenko, C. A. Bir, and P. D. Halstead, "Concussion in professional football: helmet testing to assess impact performance--part 11," Neurosurgery, vol. 58, pp. 78-96; discussion 78-96, Jan 2006.

[3] S. Rowson and S. M. Duma, “Brain injury prediction: assessing the combined probability of concussion using linear and rotational head acceleration,” Annals of biomedical engineering, vol. 41, issue 5, pp. 873-882, 2013.

[4] A. K. Ommaya, "Biomechanics of Head Injuries: Experimental Aspects," in Biomechanics of Trauma, A. N. a. J. W. Melvin, Ed., ed Eat Norwalk, CT: Appleton-Century-Crofts, 1985.