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Snow Sport Helmet STAR Protocol

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Laboratory Tests

An oblique impact drop tower is used to conduct impact testing (Figure 1). An adjustable steel anvil produces normal and tangential incident velocities associated with oblique impacts. The anvil angle is adjusted to 35° to generate impacts with a high normal component and a low tangential component of velocity. The anvil angle is also adjusted to 55° to generate impacts with a high tangential component and a low normal component. The steel surface of the anvil simulates the frictionless conditions for snow and ice. For each test, a helmeted medium NOCSAE headform is positioned in a support ring connected to the drop tower and secured in place with a lever arm that is released just prior to impact. The support ring passes around the outside of the anvil upon impact. No anthropomorphic test device (ATD) neck or effective torso mass is used in this testing, as previous work has suggested that oblique impacts may subject the neck to considerable axial loading, a scenario known to present limited biofidelity for current ATD necks [1-3].

Six impact configurations are evaluated for STAR testing, including three helmet locations (Figure 2, Table 1), two anvil angles (35° and 55°), and one resultant velocity (6.7 m/s). Impacts are dispersed around the helmet and generally located at the front, side, and rear boss locations. To position the helmeted headform, various rods distributed around the support ring are adjusted to move the head into its desired position. The position is specified using a dual-axis inclinometer mounted on a custom holder that fits inside the NOSCAE instrumentation channel, which measures X and Y angles relative to gravity. The inclinometer base faces the neck region of the headform and lays parallel to the base of the headform (2.5° offset from the Frankfort plane). The support ring is also inscribed with 5 degree increments so that Z rotation can be specified as well.

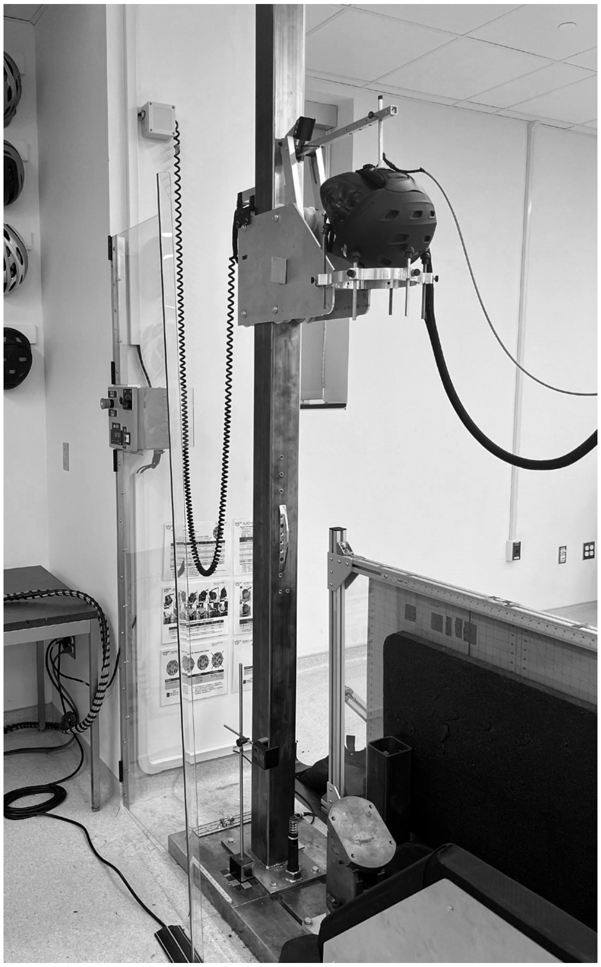

Figure 1. Oblique impact drop tower used for snow sport helmet STAR testing.

Four samples of each helmet model are subjected to one impact per location (Figure 2), with impact centers set to maintain a minimum distance of 120 mm apart to avoid overlap of damage profiles. Velocities were selected based on real-world head impact data and current testing standards [4-5]. Each of the six configurations is tested twice, producing a total of 12 impacts per helmet model. Helmets are tested without extraneous attachments and are fitted in accordance with manufacturer recommendations.

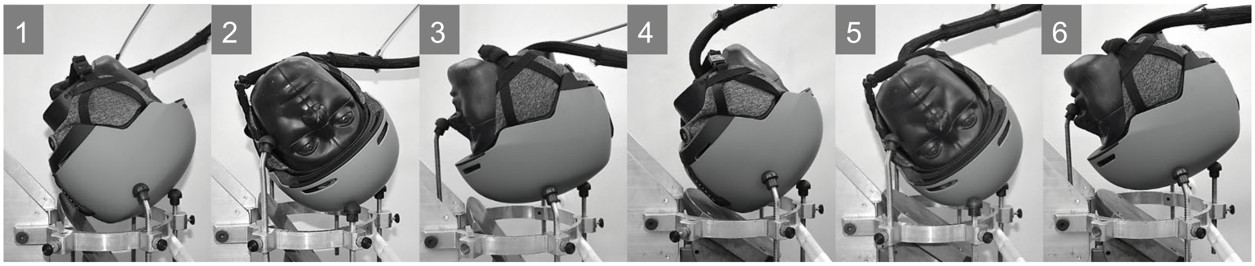

Figure 2. Six impact configurations. Configurations 1, 2, and 3 are tested on a higher anvil angle (55°) and represent impacts with a higher tangential component. Configurations 4, 5, and 6 are tested on a lower anvil angle (35°) and represent impacts with a higher normal component.

Table 1: NOCSAE headform rotations in the support ring for each impact location. X and Y rotations are determined using a dual-axis inclinometer. The positive and negative signs correspond to SAE J211 coordinate system of the NOCSAE headform.

Configuration	Anvil Angle (deg)	X (deg)	Y (deg)
1	55	-35	35
2	55	30	-10
3	55	0	-15
4	35	-35	45
5	35	40	-10
6	35	0	-30

Table 2: Prescribed impact velocities for STAR testing, including the normal, tangential, and resultant components. Velocities were chosen based on real-world head impact data and current testing standards.

Anvil Angle (deg)	Normal Velocity (m/s)	Tangential Velocity (m/s)	Resultant Velocity (m/s)
35	5.5	3.8	6.7
55	3.8	5.5	6.7

The NOCSAE headform contains three linear accelerometers and a triaxial angular rate sensor (ARS) at the center of gravity to obtain linear and rotational kinematics. Data are sampled at 20 kHz 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 289 Hz (CFC 175) for ARS data [6]. Peak resultant linear acceleration and peak resultant change in rotational velocity are then determined per test and used to estimate risk of concussion. Risks are averaged together per impact configuration to compute Summation of Tests for the Analysis of Risk (STAR) values.

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 [7-8]. The snow sport STAR equation sums the exposure-weighted risks for each impact to generate a single representative concussion incidence value per helmet model. The predicted exposure (E) is determined for each impact location (L) and velocity (V), while concussion risk (R) is computed as a function of the average peak resultant linear acceleration (a) and average peak resultant change in rotational velocity (ω) in each impact configuration (Equation 1). Exposure weightings are assigned based on an optimization scheme to ensure that helmets are not under-designed in any one location.

$$STAR = \sum_{L=1}^{6} \sum_{V=1}^{1} E(L,V) * R(a,\omega) \qquad \text{(Eq. 1)}$$

Table 3: Exposure values assigned to each impact configuration.

Configuration	Exposure
1	0.904
2	2.119
3	1.025
4	0.253
5	0.248
6	0.295

Risk of concussion is estimated based on an adaptation of a previously-published multivariate risk function [8]. This function was developed using logistic regression analysis of head impact data from instrumented football players along with associated concussion diagnoses, and incorporates both linear and rotational peak acceleration values. The combination of both linear and rotational kinematics is known to be associated with brain injury [9]. The risk function used for snow sport STAR differs from the previous function by using peak linear acceleration and rotational velocity instead of rotational acceleration. Rotational velocity includes less inherent measurement variability and accounts for the duration component of acceleration. Additionally, peak rotational velocity has been shown to be well-correlated to strain development in the brain leading to concussive injury [10-12]. To modify the previous risk function, a published estimated linear relationship between rotational velocity and acceleration was used to replace the rotational acceleration term, resulting in Equation 2 [13].

$$R(a,\omega) = \frac{1}{1 + e^{-(-10.2\, +\, 0.0433 * a\, +\, 0.19686 * \omega\, -\, 0.0002075 * a\omega)}} \qquad \text{(Eq. 2)}$$

The range of final STAR values across helmets are then distributed into a discrete number of stars (1 to 5) for ease of consumer interpretation (Table 4). The STAR value for each helmet model is related to a reduction in the risk of concussion. A 5-star rating threshold was set to a 50% reduction relative to the average helmet, and then each subsequent rating threshold was set in increments of 50% more risk from the 5-star threshold.

Table 4: Thresholds to match STAR values to number of stars in a 5-star rating scale.

STAR Value	Number of Stars
< 0.5	5
< 0.75	4
< 1	3
< 1.25	2
≥ 1.25	1

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