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STAR Methodology for Rugby Headgear

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Laboratory Tests

A pendulum impactor is used to simulate the rugby head impacts (Figure 1) [1]. The pendulum is chosen for its high repeatability and reproducibility compared to other impacting methods. The pendulum arm is 190.5 cm long and has a total mass of 37 kg (including a 15.5 kg impacting mass at the end). Its moment of inertia is 72 kg·m^2, 78% of which is the impacting mass. The impactor face is a CELL-FLEX® vinyl nitrile 740 foam and is 12.7 cm in diameter and 1.27 cm thick. The pendulum impacts a medium NOCSAE headform modified with a custom adaptor plate to fit to a Hybrid III 50th percentile neck [2, 3]. The NOCSAE headform is used because of its more realistic fit between the headform and headgear [2].

The NOCSAE head is instrumented with three linear accelerometers and a triaxial angular rate sensor to measure linear and rotational kinematics. Data are sampled at 20,000 Hz and filtered using an SAE J211 4-pole Butterworth low pass filter. Cutoff frequencies of 1650 Hz (CFC 1000) for accelerometer data and 256 Hz (CFC 155) for angular rate sensor data are used. The head and neck assembly is mounted to a 5-degree-of-freedom Biokinetics slide table with a 16 kg sliding mass.

Figure 1: Pendulum impactor used for Rugby STAR tests.

Test conditions include four impact locations (Table 1) and three impact velocities (3.0, 3.6, and 4.5 m/s). Appropriately sized headgear is fit to the NOCSAE headform. Chinstrap and laces (if applicable) are tightened for best fit according to manufacturer instructions. Adjustments are made before each test as needed. Two headgear samples are tested for each model. Each test condition is repeated twice on each sample, totaling 48 tests per headgear model.

The same test conditions (four locations and three velocities, two trials each) are performed without headgear as a control scenario. Headgear are assigned STAR values based on risk reductions relative to not wearing headgear.

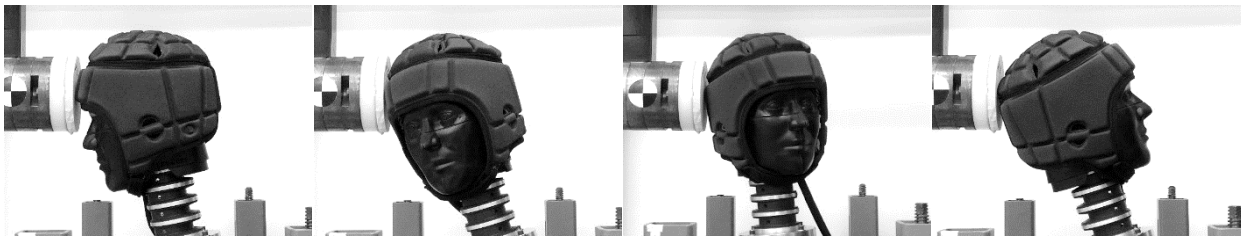

Figure 2: Impact locations from left: front, front boss, rear boss, rear

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	+3.0	-10°	0°
Front Boss	-3.5	+7.0	-15°	-60°
Rear Boss	+2.0	+6.0	-5°	-120°
Rear	0	+5.0	-15°	180°

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

STAR Ratings

The STAR equation was originally developed to estimate the number of concussions that a college football player might experience while wearing a given helmet throughout one season [4]. Common on-field impacts are simulated through laboratory tests. The resulting concussion risk for each impact is estimated using a statistical model and weighted based on how often a player might experience a similar impact during a season of play (termed "exposure"). Rugby STAR uses this framework wherein common rugby head impact scenarios are simulated in the laboratory, and resulting concussion risks are weighted based on the relative frequency of a rugby player experiencing similar impacts.

The rugby 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) [5].

$$STAR = \frac{\sum_{L=1}^{4}\left(\sum_{V=1}^{3} E(L,V) * R(a,\omega)\right)_{HG}}{\sum_{L=1}^{4}\left(\sum_{V=1}^{3} E(L,V) * R(a,\omega)\right)_{BARE}} \quad \text{(Eq. 1)}$$

Exposure weightings total 100 head impacts with a distribution matching on-field head impact data collected using instrumented mouthguards from collegiate rugby players. The 3.0 m/s velocity is representative of the the 90th percentile of the on-field head impact data, the 3.6 m/s velocity is representative of the 95th percentile, and the 4.5 m/s is representative of the 99th percentile. Exposure values are weighted so that each location contributes equally to the STAR value if a headgear performed the same at each location (Table 2). Exposure values for each location are different because of differences in impact responses due to the non-isotropic nature of the Hybrid III neck and the variance of the impact location relative to the center of gravity of the head. Exposure weightings are optimized based on impacts to a bare head with a 12.7 mm thick VN-740 foam impactor.

Table 2: Exposure values used for each location/velocity combination to obtain a total STAR value, giving each location 25% contribution based on the laboratory impact responses with a padded bare head.

Location	3.0 m/s	3.6 m/s	4.5 m/s
Front	20.0	0.7	0.6
Front Boss	26.9	1.5	1.1
Rear Boss	19.1	1.1	0.6
Rear	26.1	1.5	0.8

Concussion risk is estimated based on an adaptation of a previously published multivariate logistic regression analysis of instrumented football player data paired with diagnosed concussions [4]. It incorporates linear and rotational peak acceleration values, which are known to be associated with brain injury [6]. The risk function varies for Rugby STAR in that it uses peak linear acceleration and peak rotational velocity. To modify the previous risk function, a published estimated linear relationship between rotational velocity and acceleration was used to replace the rotational acceleration term (Equation 2) [7].

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

Concussion risk is calculated for each impact condition, weighted according to exposure at the given condition, and summed to yield an overall performance score for each headgear. Scores are normalized to the summed weighted risk for the control conditions. The resulting STAR values range from 0 to 1, with 1 representing identical performance to the bare head condition. Ratings, denoted by a number of stars, are assigned based on risk reductions described by the STAR values (Table 3). For example, a STAR value of 0.5 represents a 50% reduction in concussion incidence for the impacts tested.

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

STAR Value	Number of Stars
< 0.3	5
< 0.4	4
< 0.5	3
< 0.6	2
≥ 0.6	1

References

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