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Youth Football Helmet 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. The pendulum arm is 190.5 cm long, has a total mass of 36.3 kg that includes a 16.3 kg impacting mass at the end, and has a moment of inertia of 72 kg·m^2. A nylon impactor face 20.3 cm in diameter with a 12.7 cm radius of curvature is used to mimic the curved surface of a football helmet. The pendulum impacts a helmeted, small NOCSAE head, which is modified to fit a 5th percentile female Hybrid III neck. The head and neck are mounted to a 5-degree-of-freedom Biokinetics slide table with an 8 kg sliding mass. This setup allows for linear and rotational head motion to be generated during an impact and is representative of the head, neck, and torso of a 50th percentile 10 to 12 year old boy. Test conditions include four locations (Table 1) and three impact velocities (2.3, 3.4, and 4.9 m/s). The three impact velocities correspond to the 80th, 95th, and 99th percentiles of on-field head impacts measured in youth football players equipped with sensors. All helmets are tested with the lightest standard facemask that has been verified with the manufacturers. Helmet position on the headform is set using the NOCSAE nose gauge for a small headform before each test. Each test configuration is repeated twice with two helmet model samples, totaling 48 tests per helmet model.

Figure 1: Pendulum impactor used for Youth Football STAR tests.

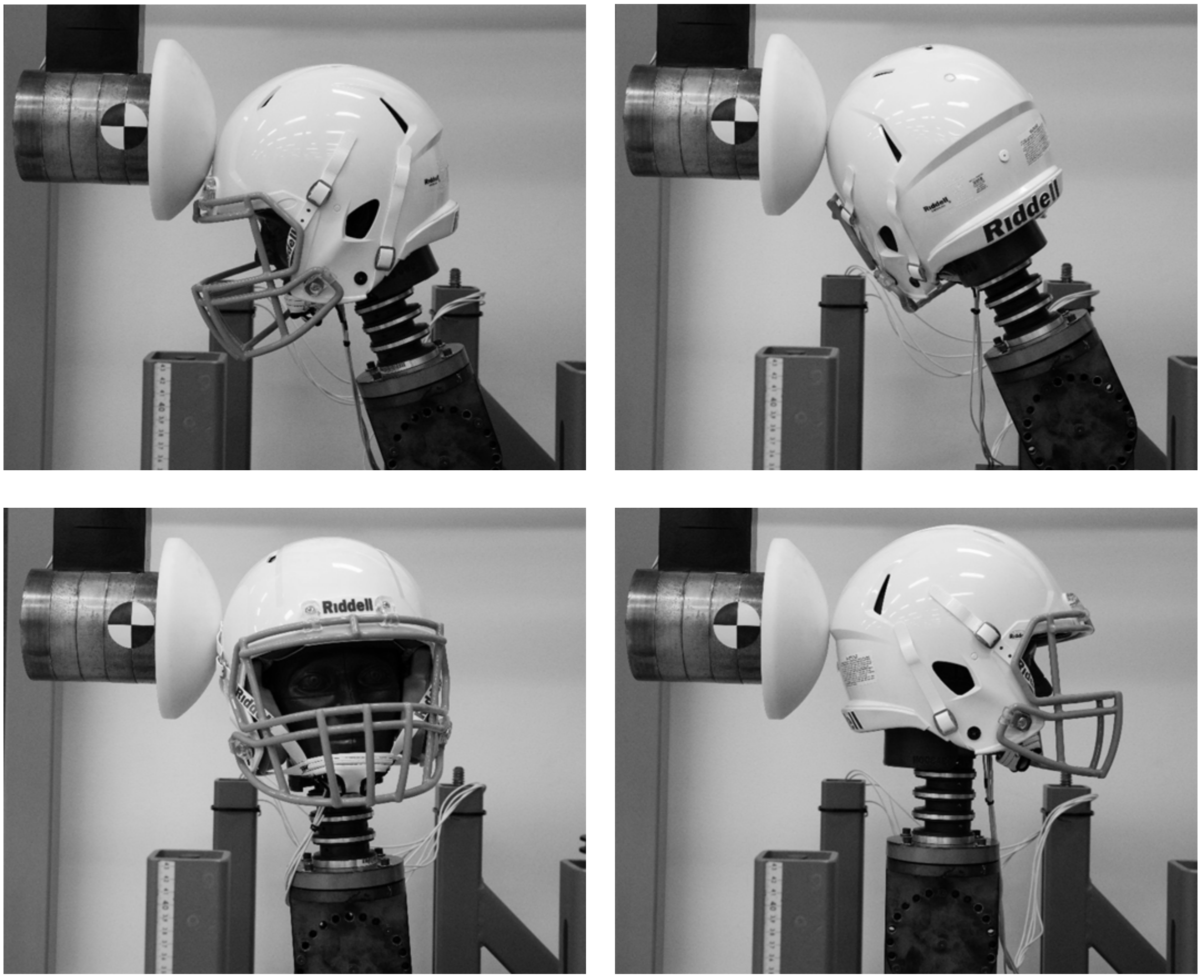

Figure 2: Impact locations clockwise from top left: front, front boss, back, and side.

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	+5.2	-20°	0°
Front Boss	0	+2.2	-25°	+67.5°
Side	-4	+5.7	-5°	-100°
Back	0	+3.7	0°	-180°

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 barely touches 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 (Equation 1) 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, then resulting concussion risk for each impact is estimated and 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 generalized 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 as a function of $YGAMBIT$, which is a metric that combines peak resultant linear acceleration (PLA) and peak resultant rotational acceleration (PRA) into a single metric in the context of concussive accelerations for youth football players (Equation 2).

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

$$YGAMBIT = \sqrt{\left(\frac{PLA}{62.4}\right)^2 + \left(\frac{PRA}{2609}\right)^2} \qquad \text{(Eq. 2)}$$

Exposure values for each impact configuration were determined from on-field data collected directly from youth football players and weighting optimization impact testing to ensure that no impact location is overly skewed (Table 2).

Table 2: Exposure values used for each location and impact velocity to obtain a total STAR value for Youth Football STAR. The average youth football player experiences 214 head impacts per season.

Location	2.3 m/s	3.4 m/s	4.9 m/s
Front	112.6	21.1	7.1
Front Boss	22.3	4.2	1.4
Side	13.8	2.6	0.9
Back	22.4	4.2	1.4

Concussion risk was modeled using a log-normal cumulative distribution function that was fit to biomechanical data of instrumented youth football players who sustained diagnosed concussions. The log-normal distribution for this concussive dataset has a mean of 0.967 and a standard deviation of 0.331. The following functions in common software can be used to compute risk; MATLAB: *logncdf*; Microsoft Excel: *lognorm.dist*; and R: *plnorm*.

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: STAR value thresholds to assign star ratings.

STAR Value	Number of Stars
0 – 5	5
5 – 10	4
10 – 15	3
15 – 20	2
20 – 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, pp. 1-15, 2015.