KRS Protocol

Helmets have been proven to reduce the risk of head injury in activities with a high risk of head impacts. However, the main focus of most helmet standards is protecting the head against skull fracture through a pass or fail criterion. Moreover, some standards only measure the head's linear acceleration during impact. Yet, it is known that most impacts result in both linear and rotational acceleration to the head.

A pass-or-fail criterion does not inform the consumers how well a helmet performs. In recent years, the Virginia Tech Summation of Tests for the Analysis of Risk (STAR) rating system was introduced, which was a great step forward. The rating system was introduced to provide more insight into helmet performance. The STAR rating system quantifies the risk of concussion based on the linear and rotational performance of a helmet.

A new kinematic-based helmet grading method, the Kinematic Rating System (KRS), was developed based purely on its impact attenuating capability. Prediction of risk of injury is based on factors that are uniquely dependent on the user. KRS also takes into account all the crucial factors of a helmet response such as acceleration and the duration of an impact scenario. In summary, the main benefits of KRS are:

- Purely based on helmet's kinematic response (not predicting injury)
- Takes into account both the magnitude and duration of an acceleration pulse when rating a helmet
- Takes into account a helmet's ability to reduce the tangential and normal component of the impact force

Each helmet is to be tested at five locations on and around the helmet outer surface, as shown in Figure 3a-c. The distance between each impact location must be a minimum of 120 mm.

Figure 3: Impact locations

The helmeted headform orientations with respect to each impact location are given in Table 1 and illustrated in Figure 4a-e.

Table 1: Headform orientations

Location #	Z	Y	X
1	-30*	-18	0
2	-90*	18	0
3	125*	37.5	0
4	45	0	90*
5	-45*	0	-32

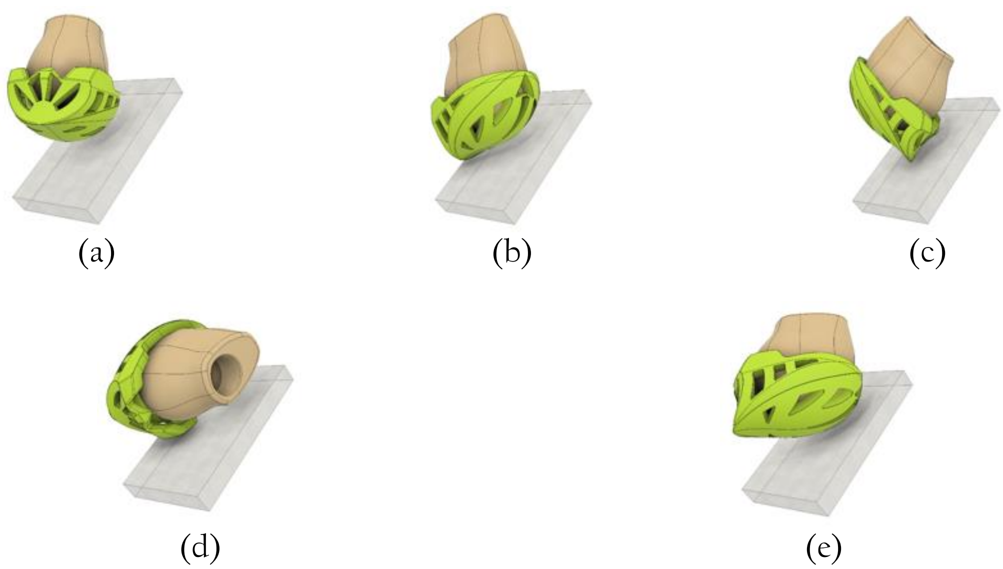

Figure 4a-e: Illustration of the helmeted headform orientation when tested at impact locations #1-5

Helmets are tested without the visors, facemasks, or other attachments and are fitted according to the manufacturer specifications.

At every impact location, a minimum of three trials or tests are performed. The data acquired trials must be within 10% of each other. Therefore, a minimum of three helmets are required per helmet model. In total, fifteen tests were performed per helmet model in a sequential order starting from location 1, moving on to 5 and repeating three times. For some helmet designs, having the 120 mm distance between one location to another may not be possible. In this case, more helmets will be required as the five locations should not be tested on one helmet. The 50th percentile Hybrid III headform has a 59.7 cm head circumference. It is found that the dummy headform fits well with most medium to large-size helmets.

Data Processing and Analysis

At every impact location (n = 1 to 5), the average peak linear and rotational acceleration values are measured ($a(n)$ and $\alpha(n)$) in g and krad/s^2, respectively. The average linear and rotational velocity gain are also computed in g.s and krad/s, respectively. The velocity gain is also called the Area Under the Curve ($AUCL(n)$ and $AUCR(n)$).

Then, the $Linear\ Grade(n)$ and $Rotational\ Grade(n)$ are calculated using Equation 1 and 2, respectively.

$$\boldsymbol{Linear\ Grade} = \sum \boldsymbol{E(n)} \times \frac{\boldsymbol{a_{,baseline}(n)}}{\boldsymbol{a_{measured}(n)}} \times \frac{\boldsymbol{AUCL_{baseline}(n)}}{\boldsymbol{AUCL_{measured}(n)}} \quad (1)$$

$$\boldsymbol{Rotational\ Grade} = \sum \boldsymbol{E(n)} \times \frac{\boldsymbol{\alpha_{,baseline}(n)}}{\boldsymbol{\alpha_{measured}(n)}} \times \frac{\boldsymbol{AUCR_{baseline}(n)}}{\boldsymbol{AUCR_{measured}(n)}} \quad (2)$$

The Exposure values ($E(n)$) denote the probability of receiving an impact at the specific area where the impact location is situated and are summarized in Table 2. The baseline values were determined by performing impact attenuation tests on the Hybrid III dummy headform without any helmets (bare dummy). The baseline values are obtained by performing the impact test procedure on the Hybrid III dummy head without any helmets.

Table 2: Impact exposure (E(n)) values.

Location [n]	***Exposure [E(n)]***
1	0.16
2	0.16
3	0.12
4	0.16
5	0.39

Finally, the final grade is calculated using Equation 3.

$$\boldsymbol{Final\ Grade = Linear\ Grade \times Rotational\ Grade} \tag{3}$$

Letter Grade

The final grade is transformed into a letter grade, which provides a more comprehensive and easy-to-understand helmet performance result. To obtain the letter grade, the final grade of each helmet tested is normalized with Equation 4.

$$\boldsymbol{Normalized\ Final\ Grade = \frac{Final\ Grade}{Maximum\ Grade}} \tag{4}$$

The maximum grade in Equation 4 is the final grade of the best performing helmet of the same type. The maximum grade is 'floating' as its value can change as more helmets are tested. The normalized final grade value ranges between 0.00 and 1.00 and is categorized into five different letter categories, as shown in Table 4.

Table 4: KRS letter grade category.

Normalized Final Grade (nFG)	***Letter Grade***
$0.80 < nFG \leq 1.00$	A+
$0.60 < nFG \leq 0.80$	A
$0.40 < nFG \leq 0.60$	B
$0.20 < nFG \leq 0.40$	C
$0.00 < nFG \leq 0.20$	D