The STAR Rating System for Football Helmets

STAR = Summation of Tests for the Analysis of Risk

The STAR value for each helmet model is derived from 120 impacts on 3 new helmets using the following equation and methodology:

$$STAR = \sum_{L=1}^{4}\left(\sum_{H=1}^{6} E(L,H) \bullet R(a)\right)$$

Using NOCSAE style tests with the following nomenclature:
L = helmet location, four total: front, top, side (combined), and rear
H = drop height, six total: 60", 48", 36", 24", 12", and lowest
E = exposure (function of drop height), number of impacts at that drop height for that location a player may experience in one year
R = Concussion injury risk (function of peak acceleration)
a = peak resultant acceleration

$$STAR = \sum_{Location=1}^{4}\left(\sum_{Height=1}^{6} Exposure(L,H) \bullet Risk(a)\right)$$

The STAR value represents a **Generalized Concussion Incidence**

In other words, the STAR value is the number of concussions that one player may experience through the duration of playing one complete season with a specific helmet. So, the lower the STAR value, the better the helmet at reducing the risk of concussion, and subsequently the higher '# stars' in the rating system.

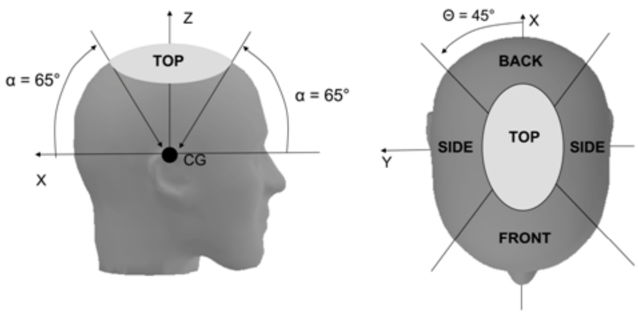
Limitations

1) Any player in any sport can sustain a head injury with even the very best head protection.
2) This analysis is based on data trends and probabilities, and therefore a specific person's risk may vary. This variation is likely dominated by genetic differences, health history, and impact factors such as muscle activation.
3) The exposure is for a starting competitive collegiate football player for a full season of practices and games; however, it can be scaled for any given exposure in high school or NFL.
4) All head impacts result in both linear and rotational accelerations. This methodology utilizes only linear acceleration as currently there is substantial data on linear accelerations relating to concussion risk. Moreover, linear and rotational accelerations are highly correlated, and in general lowering linear will lower rotational. As more data become available for rotational accelerations associated with concussions, this methodology could be modified to include them.

Exposure

$$STAR = \sum_{L=1}^{4}\left(\sum_{H=1}^{6} E(h) \bullet R(a)\right)$$

Exposure by Location:

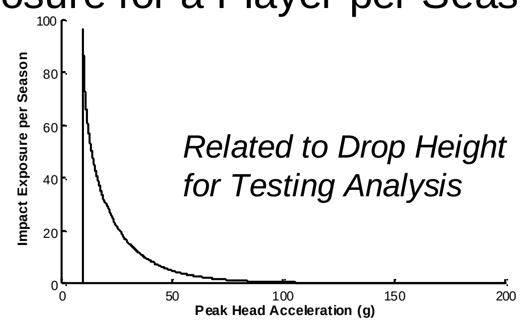


	VT Data	Mihalik et al. 2007
Front	34.7%	35.9%
Rear	31.9%	30.9%
Side	16.3%	14.4%
Top	17.1%	18.8%

Exposure for a Player per Season:

Study	Impacts per Season	Subjects
VT Data (Crisco et al. 2010)	1000	Collegiate
Guskiewicz et al. 2007	950	Collegiate
Schnebel et al. 2007	1115	Collegiate and High School
Broglio et al. 2009	565	High School

Exposure for a Player per Season per Location:



	Percent of Impacts	Number of Impacts
Front	34.7%	347
Rear	31.9%	319
Side	16.3%	163
Top	17.1%	171
Total	100%	1000

References:

Broglio, S. P., Sosnoff, J. J., Shin, S., He, X., Alcaraz, C., and Zimmerman, J., 2009, "Head Impacts During High School Football: A Biomechanical Assessment," J Athl Train, 44(4), pp. 342-9.

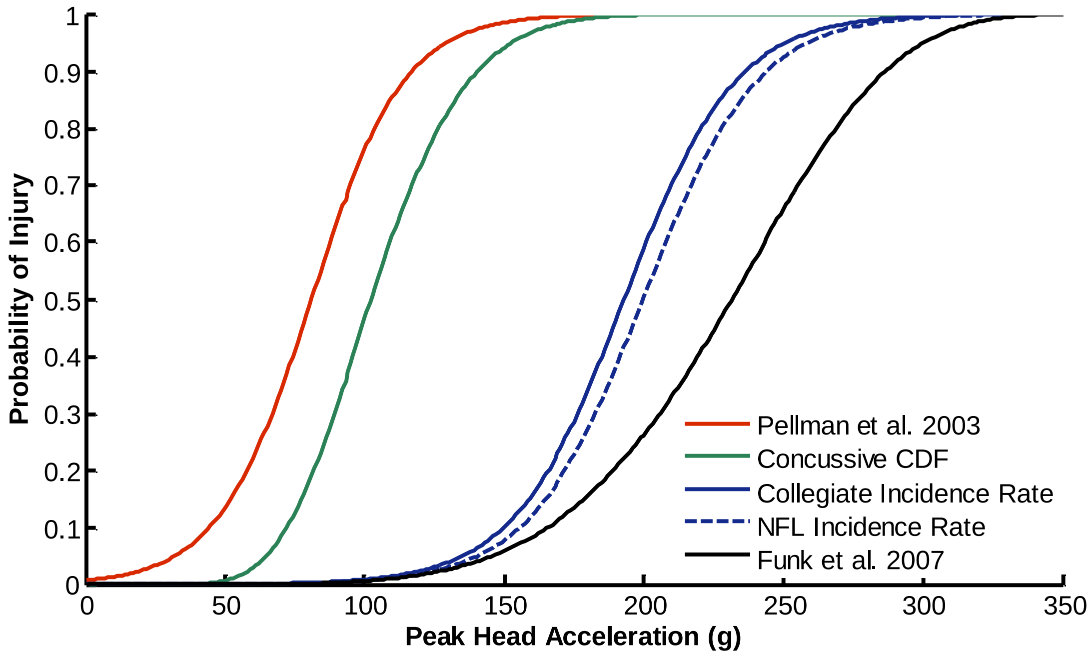
Crisco, J. J., Fiore, R., Beckwith, J. G., Chu, J. J., Brolinson, P. G., Duma, S., Mcallister, T. W., Duhaime, A. C., and Greenwald, R. M., 2010, "Frequency and Location of Head Impact Exposures in Individual Collegiate Football Players," J Athl Train, 45(6), pp. 549-59.

Guskiewicz, K. M., Mihalik, J. P., Shankar, V., Marshall, S. W., Crowell, D. H., Oliaro, S. M., Ciocca, M. F., and Hooker, D. N., 2007, "Measurement of Head Impacts in Collegiate Football Players: Relationship between Head Impact Biomechanics and Acute Clinical Outcome after Concussion," Neurosurgery, 61(6), pp. 1244-53.

Schnebel, B., Gwin, J. T., Anderson, S., and Gatlin, R., 2007, "In Vivo Study of Head Impacts in Football: A Comparison of National Collegiate Athletic Association Division I Versus High School Impacts," Neurosurgery, 60(3), pp. 490-5; discussion 495-6.

Risk	$STAR = \sum_{L=1}^{4}\left(\sum_{H=1}^{6} E(h) \bullet R(a)\right)$

Concussion Risk R(a) = Collegiate Incidence Rate Curve



$$Risk = \frac{1}{1+e^{-(\alpha x+\beta)}}$$

Where
x = peak resultant linear acceleration in g
α = 0.0508
β =-9.8047

References:

Guskiewicz, K. M., Mihalik, J. P., Shankar, V., Marshall, S. W., Crowell, D. H., Oliaro, S. M., Ciocca, M. F., and Hooker, D. N., 2007, "Measurement of Head Impacts in Collegiate Football Players: Relationship between Head Impact Biomechanics and Acute Clinical Outcome after Concussion," Neurosurgery, 61(6), pp. 1244-53.

Broglio, S. P., Schnebel, B., Sosnoff, J. J., Shin, S., Fend, X., He, X., and Zimmerman, J., 2010, "Biomechanical Properties of Concussions in High School Football," Med Sci Sports Exerc, 42(11), pp. 2064-71.

Funk, J. R., Duma, S. M., Manoogian, S. J., and Rowson, S., 2007, "Biomechanical Risk Estimates for Mild Traumatic Brain Injury," Annual Proceedings of the Association for the Advancement of Automotive Medicine, 51, pp. 343-61.

Pellman, E. J., Viano, D. C., Tucker, A. M., Casson, I. R., and Waeckerle, J. F., 2003, "Concussion in Professional Football: Reconstruction of Game Impacts and Injuries," Neurosurgery, 53(4), pp. 799-812; discussion 812-4.

Summary STAR Calculation Worksheet

$$STAR = \sum_{L=1}^{4}\left(\sum_{H=1}^{6} E(L,H) \bullet R(a)\right)$$

Impact Location	Drop Height	Peak G	Risk of Injury	Exposure per Season	Incidence per Season
Front	Impacts < 19 g	-----	0.0000	164	0.00
Front	12 in	Average of 2 Tests	From Risk(a)	138	*Exp * Risk*
Front	24 in	Average of 2 Tests	From Risk(a)	31	*Exp * Risk*
Front	36 in	Average of 2 Tests	From Risk(a)	10	*Exp * Risk*
Front	48 in	Average of 2 Tests	From Risk(a)	3	*Exp * Risk*
Front	60 in	Average of 2 Tests	From Risk(a)	1	*Exp * Risk*
Side	Impacts < 19 g	-----	0.0000	81	0.00
Side	12 in	Average of 2 Tests	From Risk(a)	75	*Exp * Risk*
Side	24 in	Average of 2 Tests	From Risk(a)	4	*Exp * Risk*
Side	36 in	Average of 2 Tests	From Risk(a)	1	*Exp * Risk*
Side	48 in	Average of 2 Tests	From Risk(a)	1	*Exp * Risk*
Side	60 in	Average of 2 Tests	From Risk(a)	1	*Exp * Risk*
Rear	Impacts < 19 g	-----	0.0000	139	0.00
Rear	12 in	Average of 2 Tests	From Risk(a)	165	*Exp * Risk*
Rear	24 in	Average of 2 Tests	From Risk(a)	11	*Exp * Risk*
Rear	36 in	Average of 2 Tests	From Risk(a)	2	*Exp * Risk*
Rear	48 in	Average of 2 Tests	From Risk(a)	1	*Exp * Risk*
Rear	60 in	Average of 2 Tests	From Risk(a)	1	*Exp * Risk*
Top	Impacts < 19 g	-----	0.0000	63	0.00
Top	12 in	Average of 2 Tests	From Risk(a)	85	*Exp * Risk*
Top	24 in	Average of 2 Tests	From Risk(a)	14	*Exp * Risk*
Top	36 in	Average of 2 Tests	From Risk(a)	5	*Exp * Risk*
Top	48 in	Average of 2 Tests	From Risk(a)	2	*Exp * Risk*
Top	60 in	Average of 2 Tests	From Risk(a)	2	*Exp * Risk*
		Total Head Impacts In One Season:		***1000***	*Sum Incidence*
					STAR Value

STAR Calculation Overview: The STAR value for each helmet model is derived from 120 impacts on 3 new helmets using the following equation and methodology:

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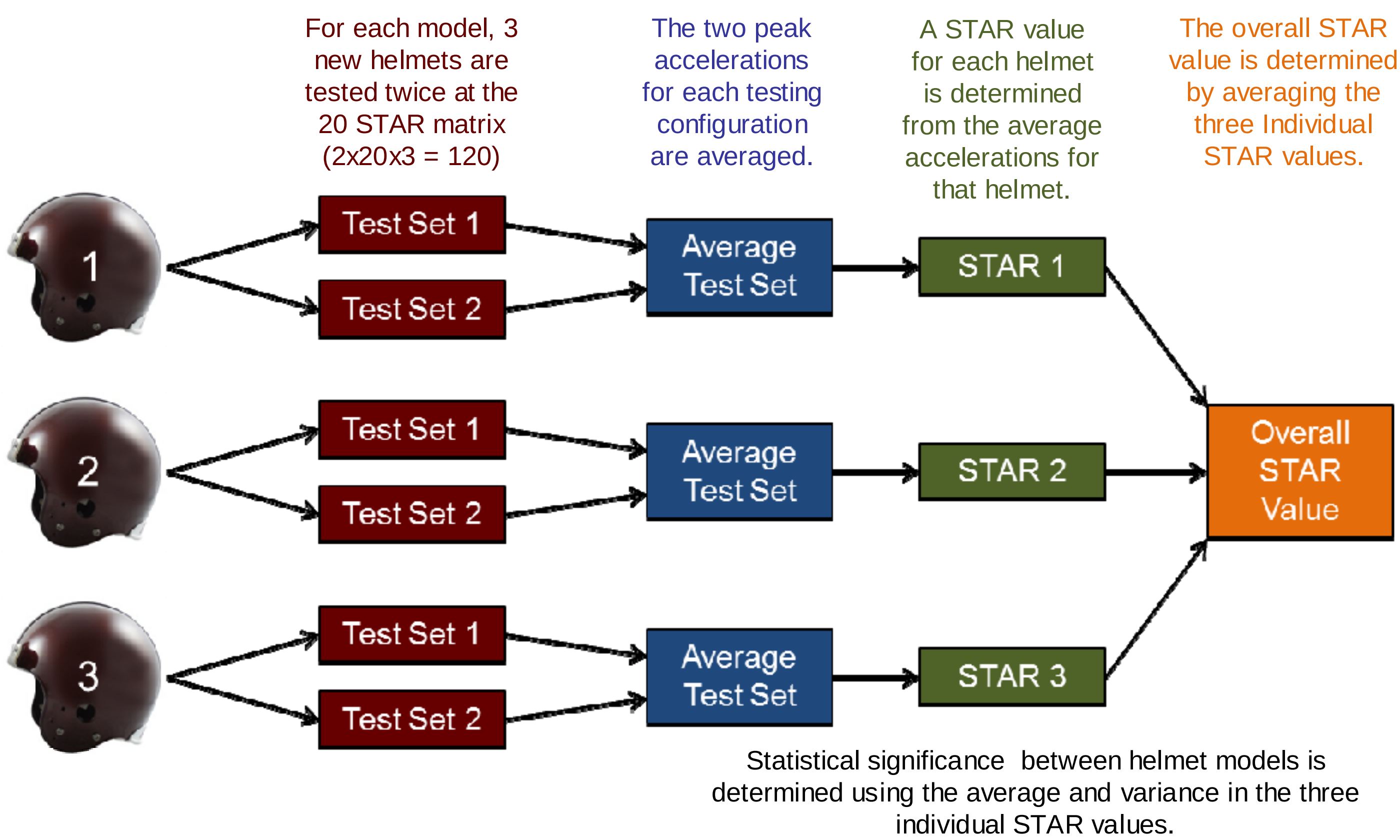

A manuscript for with this methodology has been peer reviewed and accepted (April 30, 2011) for publication by the *Annals of Biomedical Engineering*. It should be available on-line in late May or Early June 2011.

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