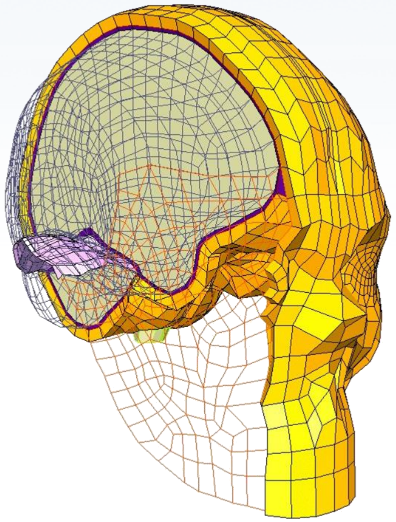
Cycle Helmet Safety Testing & Rating Harmonisation



www.CERTIMOOV.COM. Helmet Rating Platform

And Consequences

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Equipe Matériaux multi-échelles et Biomécanique (MMB)

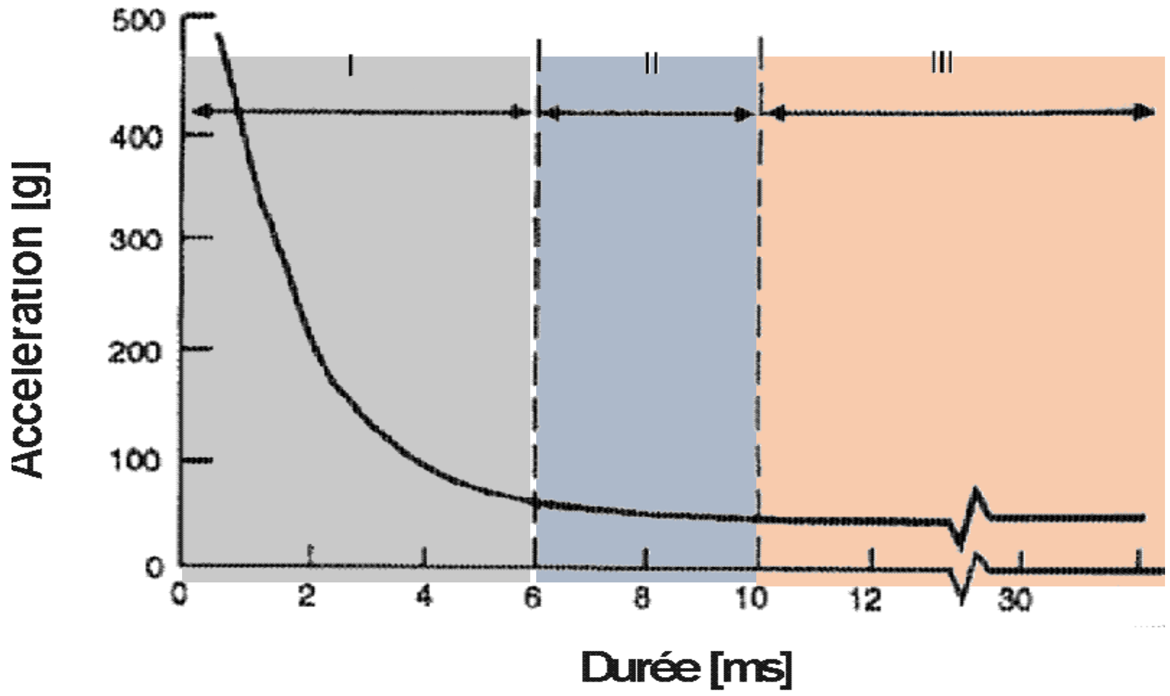
// Presentation overview //

- Current head injury criteria and limitations
- Human head modelling & simulation of Head trauma
- Model based Brain injury criteria
- Numerical head injury prediction tool for end users
- Coupled experimental vs numerical helmet test method
- Helmet Rating Method
- Consequences of CERTIMOOV

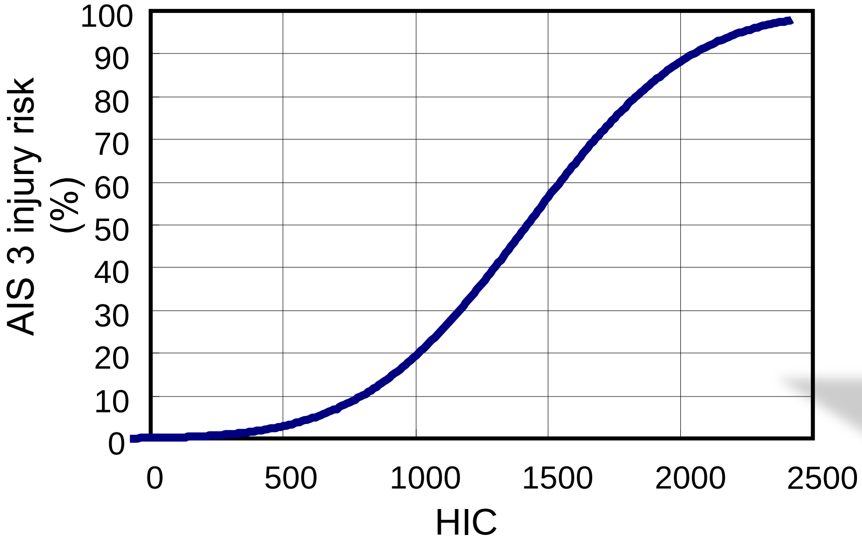
Head tolerance curve proposed by Wayne State University given linear head accelerations versus time : WSUTC (1966).
Head injuries occur in the part upper the curve.

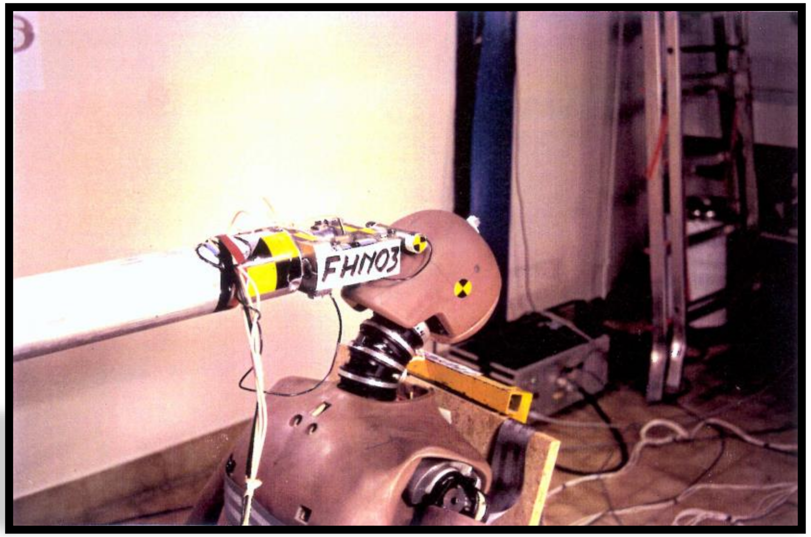
Part I : tests on cadavers, skull failure considered as head injury.

Part II : intracranial pressure recorded on anatomical subjects and animals, head injury : commotion.



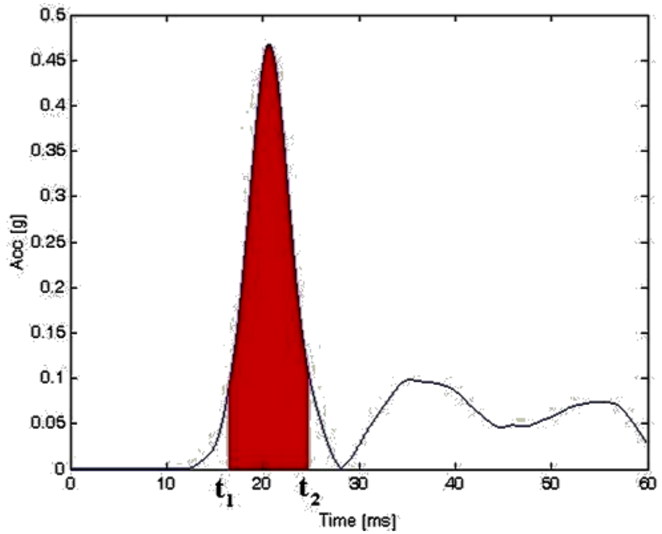
Part III : tests on human volunteers, no head impact, head kinematics recorded during sled tests.





Head mass = 4.58 kg; HIC = 1000

$$HIC = \max_{(t_1,t_2)} \left\{ (t_2 - t_1) \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt \right]^{2.5} \right\}$$



BrIC:

Takhounts et al. 2011

$$BrIC = \frac{\omega_{max}}{\omega_{cr}} + \frac{\alpha_{max}}{\alpha_{cr}}$$

RIC:

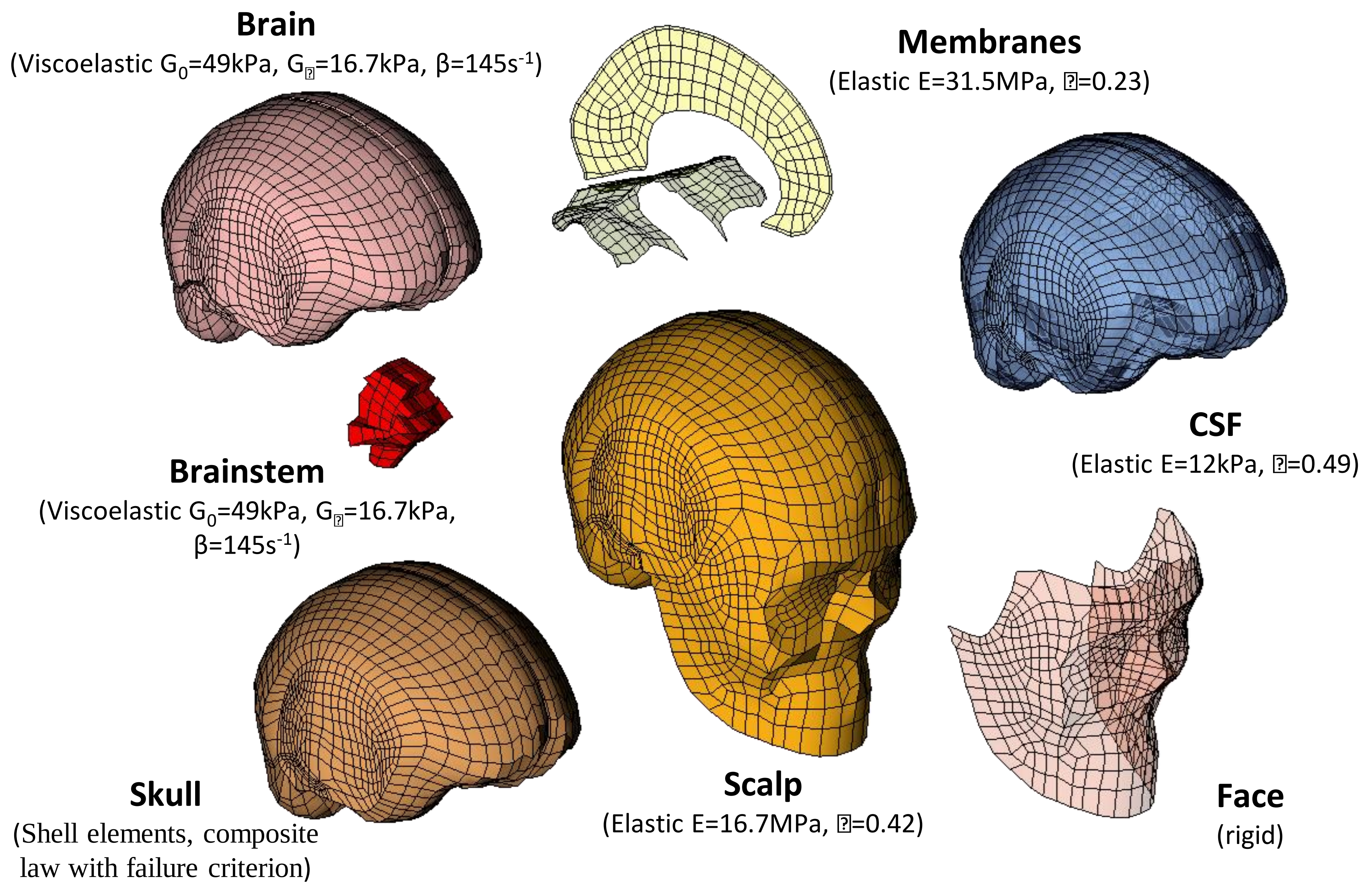
Kimpara et al. (2011)

$$RIC = \left[(t_2 - t_1) \left\{ \frac{1}{(t_2 - t_1)} \int_{t_1}^{t_2} \alpha(t)dt \right\}^{2.5} \right]_{max}$$

U-BRiC

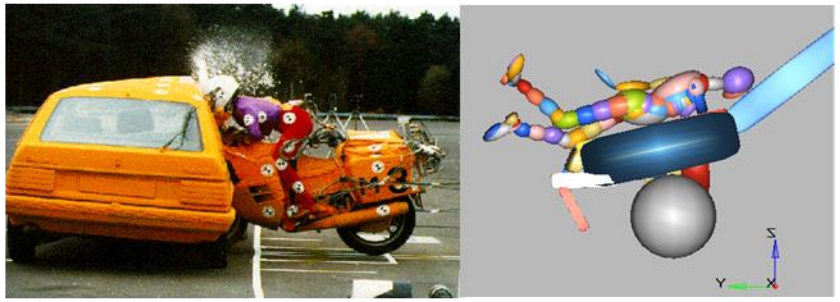
Gabler et al. 2018

$$UBrIC = \left\{ \sum_i \left[\omega_i^* + (\alpha_i^* - \omega_i^*) e^{-\frac{\alpha_i^*}{\omega_i^*}} \right]^r \right\}^{\frac{1}{r}},$$

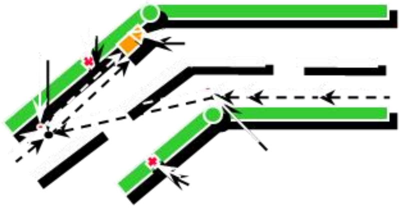

Brain
(Viscoelastic G_0=49kPa, G_∞=16.7kPa, β=145s^{-1})
Membranes
(Elastic E=31.5MPa, ν=0.23)
CSF
(Elastic E=12kPa, ν=0.49)
Brainstem
(Viscoelastic G_0=49kPa, G_∞=16.7kPa, β=145s^{-1})
Skull
(Shell elements, composite law with failure criterion)
Scalp
(Elastic E=16.7MPa, ν=0.42)
Face
(rigid)

HEAD TRAUMA SIMULATION

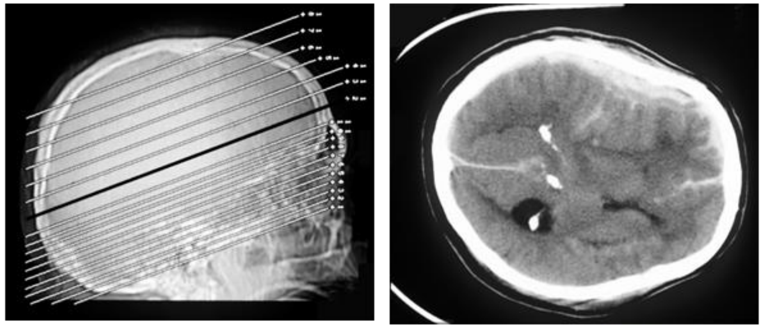
Experimental or analytical replication



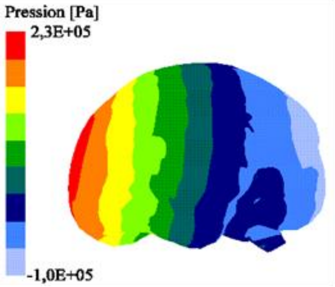
Real accidents



Detailed medical report

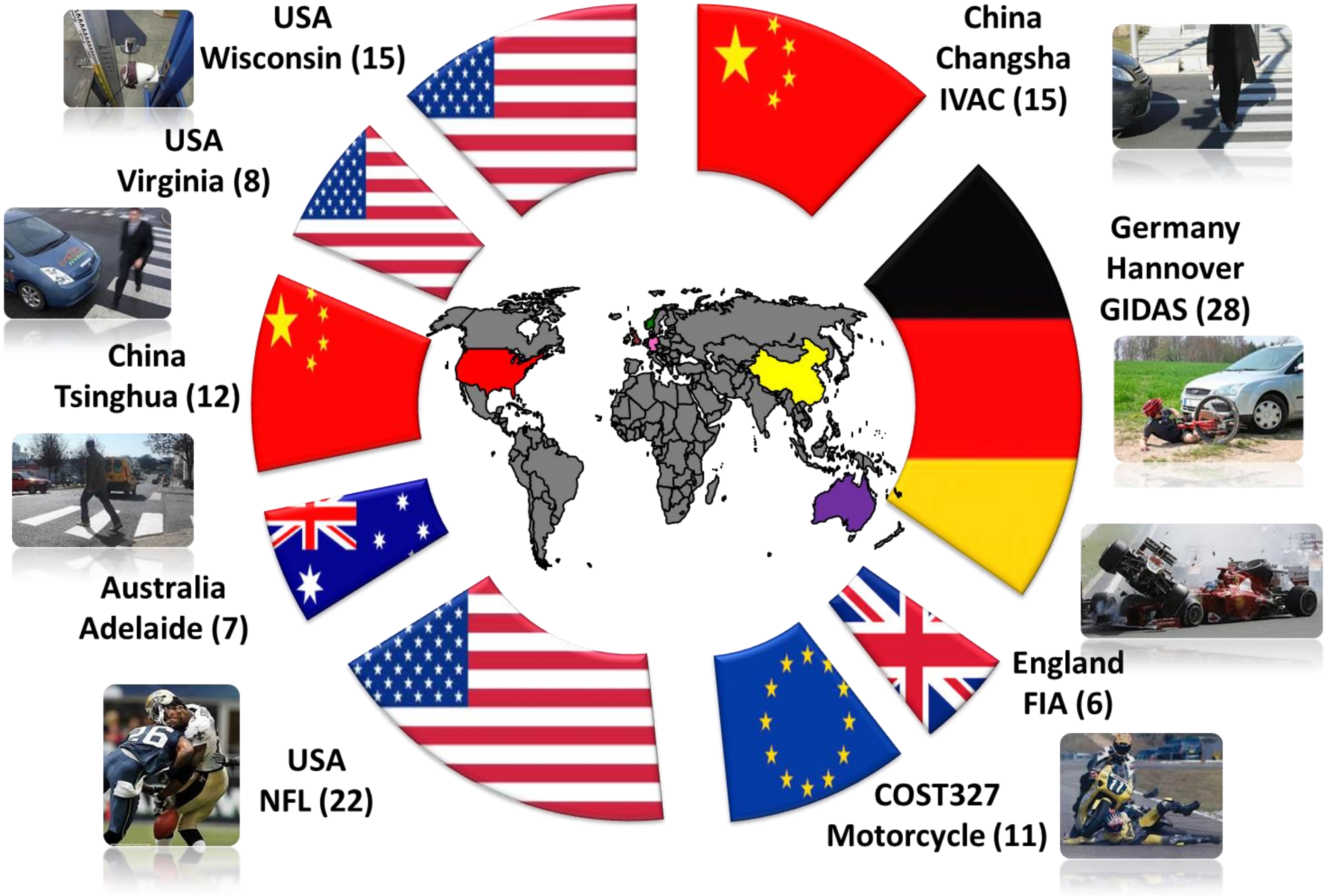


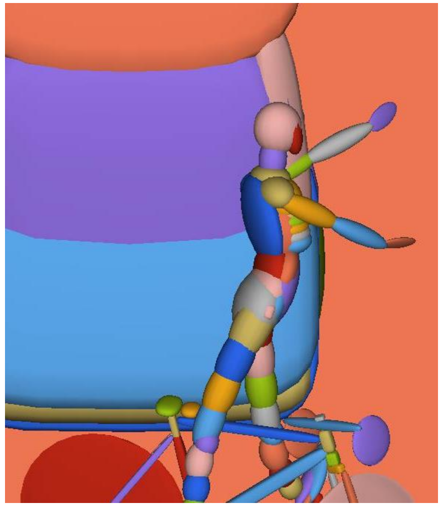
Numerical reconstruction

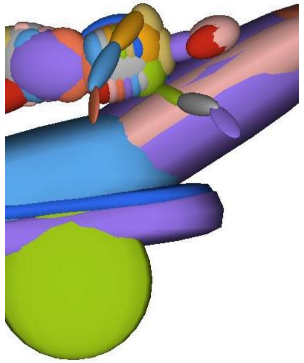


Injury mechanisms and tolerance limits

// Database (125 cases) //







$V_{resultant}$ = 10.9 m/s

V_{normal} = 10.0 m/s

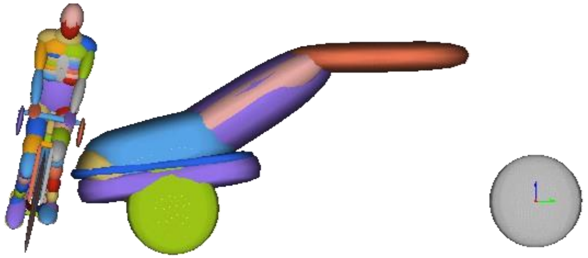
$V_{tangential}$ = 4.4 m/s

Loadcase 1 : Time = 0.000000
Frame 1

Two impacts
- on windshield with the left shoulder,
- on pillar with head area occipito-parieto-temporal.

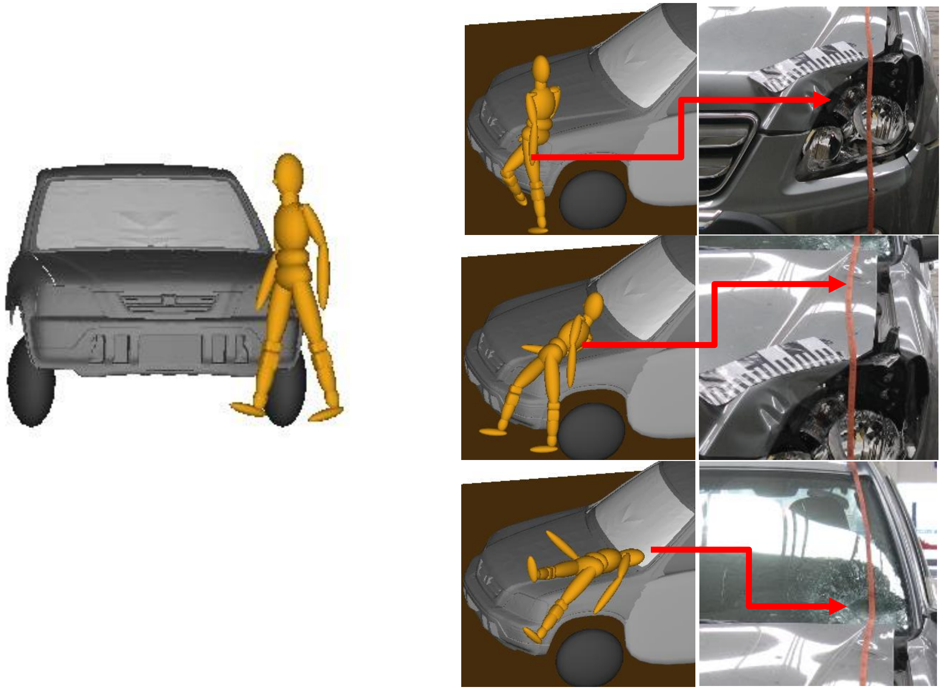
Projection distance of 16.3 m

WAD of 2.10 m

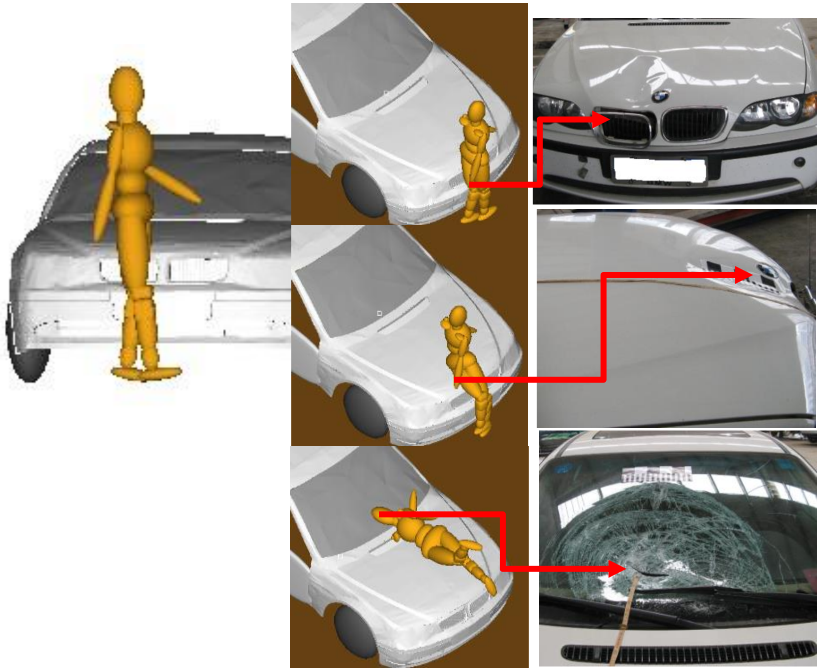


➢ *Reconstruction results*

	Example 1		Example 2	
	Accident	Simulation	Accident	Simulation
Throw distance (m)	12.4	11.3	18	17.5
WAD (mm)	2000	2030	1980	1940
Velocity (km/h)	60	54	60	62.9



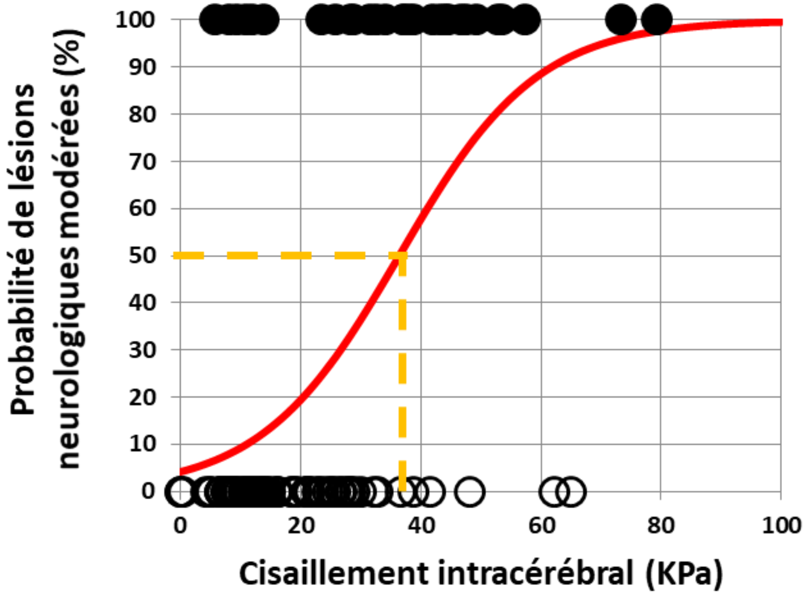
Example 1

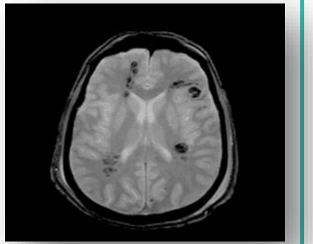


Example 2

BRAIN INJURY CRITERIA

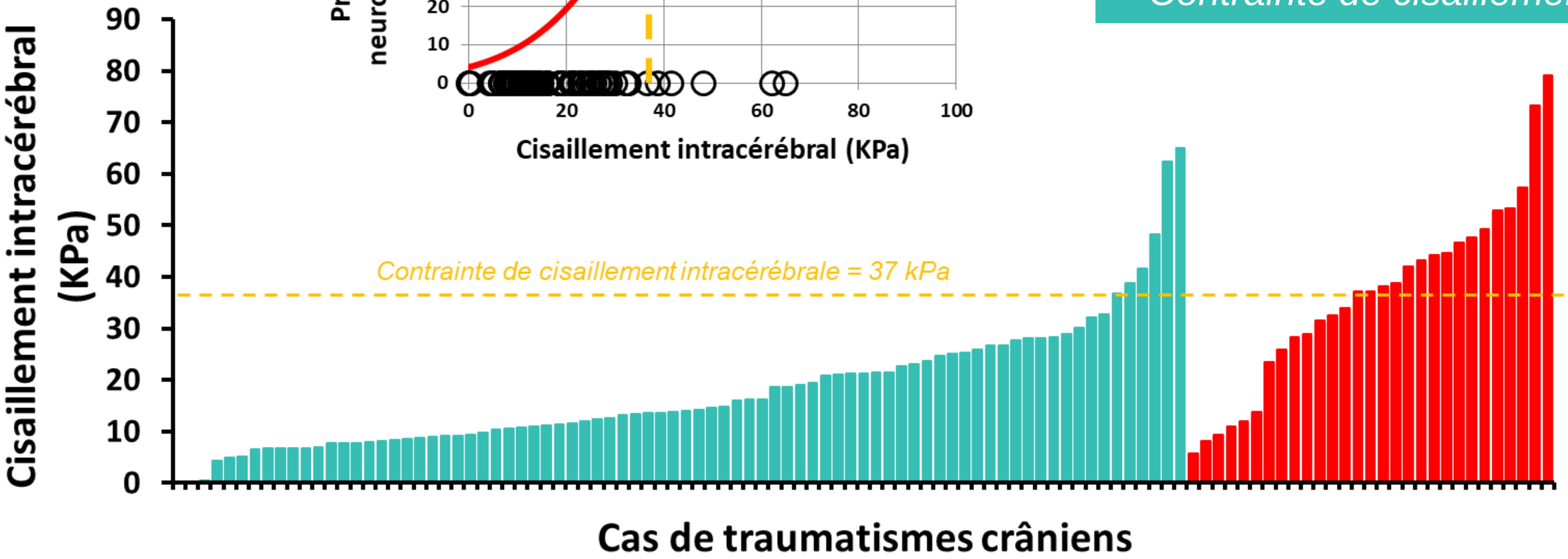
Critère de lésion cérébrale (lésions neurologiques modérées réversibles)





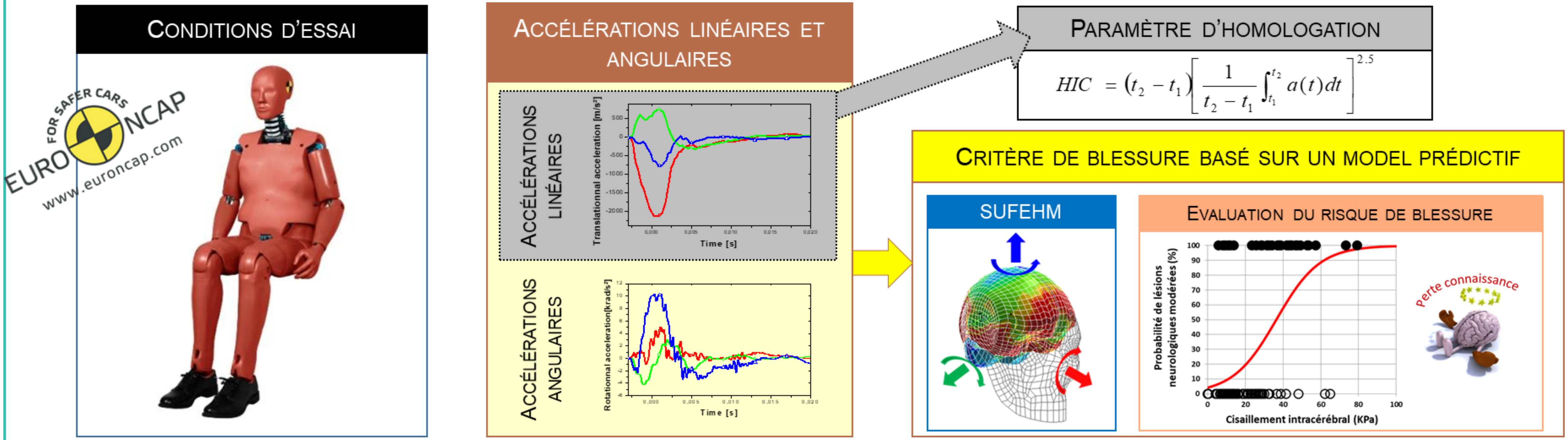
Risque de 50% de lésions neurologiques modérées (AIS 2+) :

Contrainte de cisaillement = 37 kPa



COUPLED EXPERIMENTAL VERSUS NUMERICAL TEST METHOD

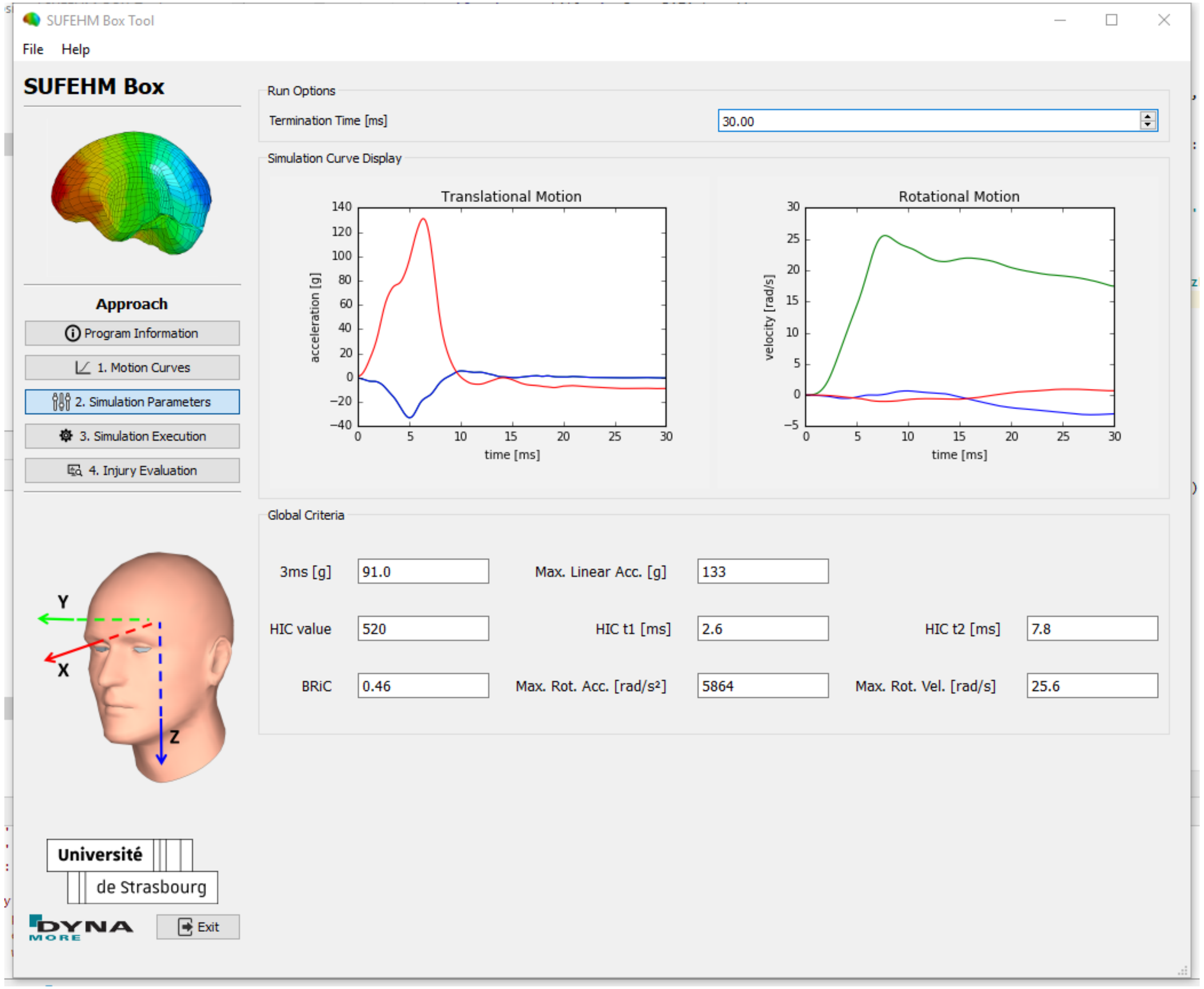
- MODEL BASED BRAIN INJURY IN DUMMY TESTING

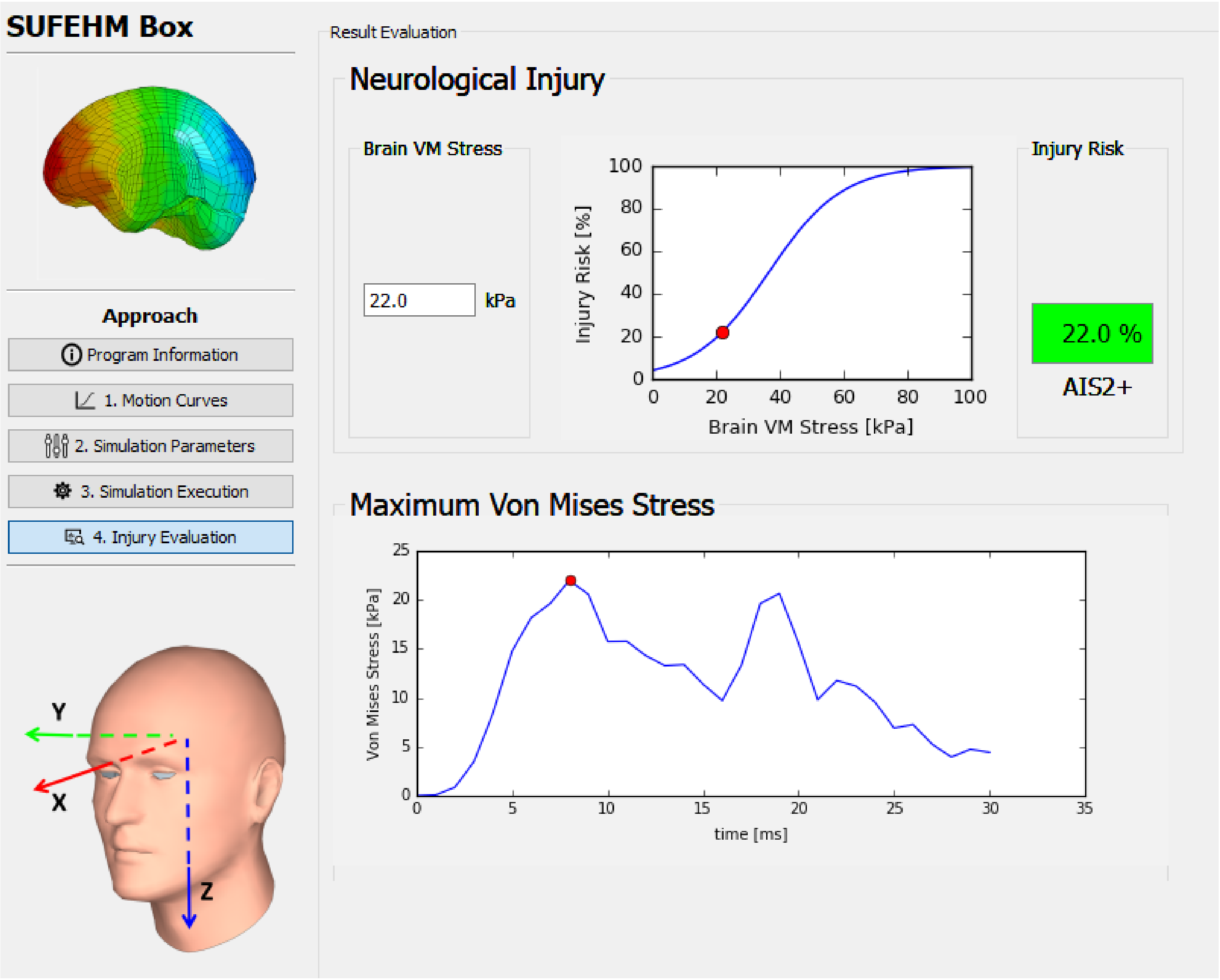


Added value of tissue level injury criteria

- 6D acceleration field
- Direction dependents of head response
- Time evolution of acceleration
- Complexe head loading : Lin + Rot
- High correlation to AIS2+ brain injury

// SUFEHM Pre-Processing //




SUFEHM Box
Approach
Program Information
1. Motion Curves
2. Simulation Parameters
3. Simulation Execution
4. Injury Evaluation
Y
X
Z
Result Evaluation
Neurological Injury
Brain VM Stress
22.0
kPa
Injury Risk [%]
Brain VM Stress [kPa]
Injury Risk
22.0 %
AIS2+
Maximum Von Mises Stress
Von Mises Stress [kPa]
time [ms]

NEW HELMET TEST METHOD

Remy WILLINGER

The Partnership

Marc Rigolot
Directeur Général de la Fondation MAIF

Rémy Willinger
Directeur de recherche en biomécanique

Patrick Jacquot
Président

Support or research | **Research activity** | **Communication and internet**

PRIX INNOVATION
2019 SÉCURITÉ ROUTIÈRE
TOUS RESPONSABLES

3

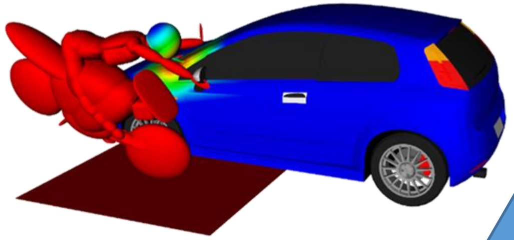
// Test Method//

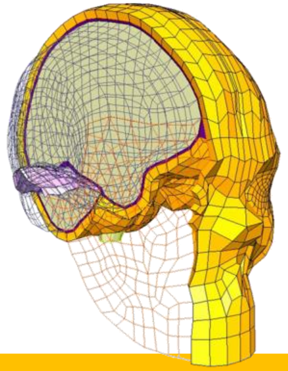
- Impact conditions
- headform
- Injury Criteria
- Final rating

// Thre Key aspects to be considered //

A more realistic 6D instrumented headform

New Test Method





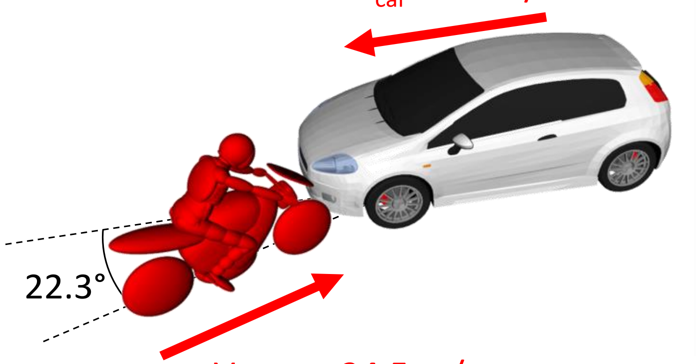
More realistic impact conditions

More Biofidelic Injury criteria

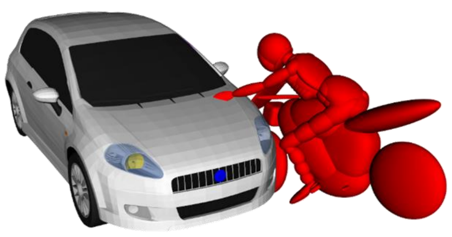
Example : Description of accident case

The initial conditions of the impact and extraction of the victim kinematics

Initial configuration



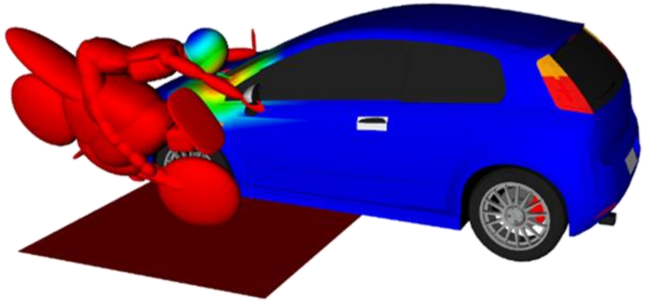
Impact kinematics

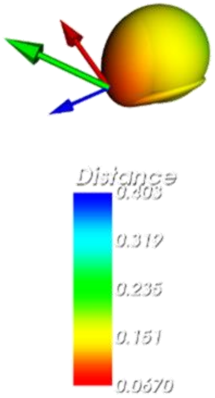


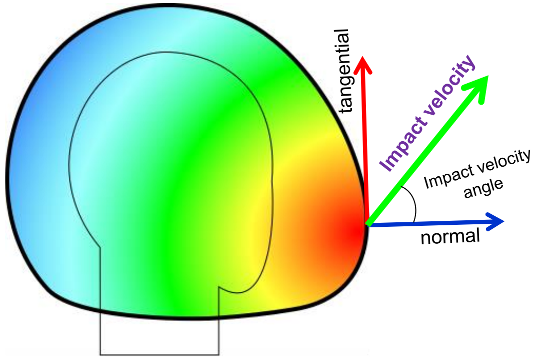
Time = 45 ms

Time = 80 ms

head impact conditions and extraction of the velocity vector







$V_{resultant}$ = 18 m/s
V_{normal} = 10.1 m/s
$V_{tangential}$ = 14.9 m/s
Impact $angle_{/normal}$ = 55.9°

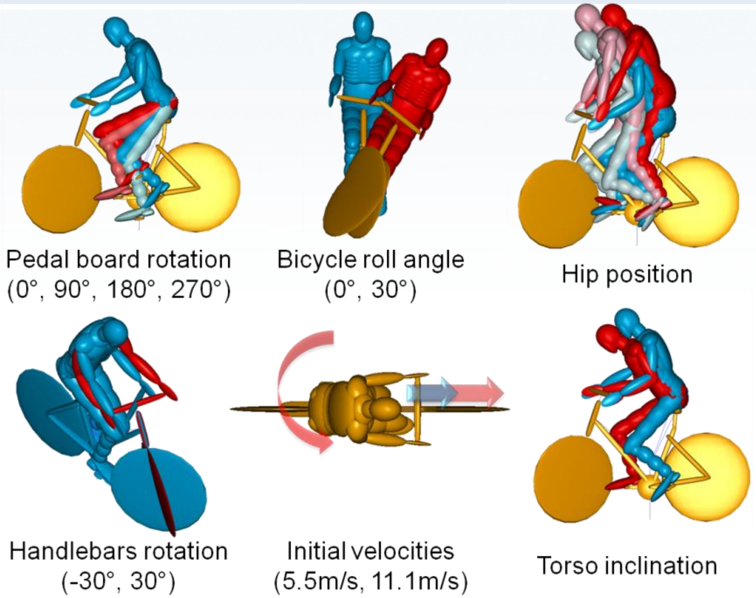
HEAD IMPACT CONDITIONS FOR BICYCLIST

➢in case of bicyclist falling

Study done by *Bourdet et al. (2012)*

- 8 selected factors have been studied
- 2 configurations of falling

A total of 1024 accident simulations was done

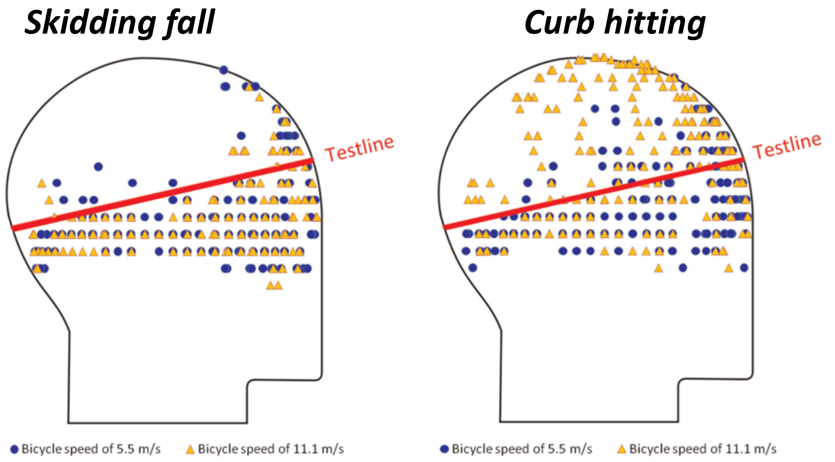


*Head Impact conditions for a bicycle speed of **5,5m/s** :*

	$V_{resultant}$ [m/s]	V_{normal} [m/s]	$V_{tangential}$ [m/s]	Impact angle [°]
Skidding fall	6.9±1.2	5.7±1.3	**3.7±0.9**	32.9±8.7
Curb hitting	6.4±0.9	5.2±1.0	**3.7±0.8**	35.4±7.7

*Head Impact conditions for a bicycle speed of **11,1m/s** :*

	$V_{resultant}$ [m/s]	V_{normal} [m/s]	$V_{tangential}$ [m/s]	Impact angle [°]
Skidding fall	11.3±1.1	6.2±1.0	**9.4±1.0**	56.6±5.1
Curb hitting	9.1±2.1	4.8±1.3	**7.7±1.9**	58.1±6.5

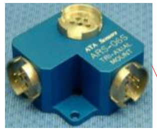


certi moov

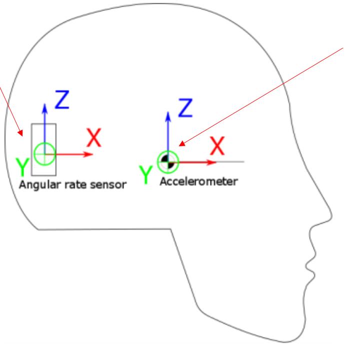
In collaboration with AD Engineering, test method has been made operational

Certificated drop test device helmet testing
absorption test

Anvil with a 45° inclined



ARS-06 and 06S Triaxial MHD Angular Rate Sensor Arrays from ATA sensors



PCB PIEZOTRONICSinc. accelerometers 356B21 ⍰500 g with a sensitivity of 10.00 mV/g, 10.02 mV/g and 10.05 mV/g respectively for x, y and z axes.

ad ENGINEERING srl
DEVICES AND EQUIPMENTS FOR TESTING - INDUSTRIAL PRODUCTION PLANT & PROTOTYPES

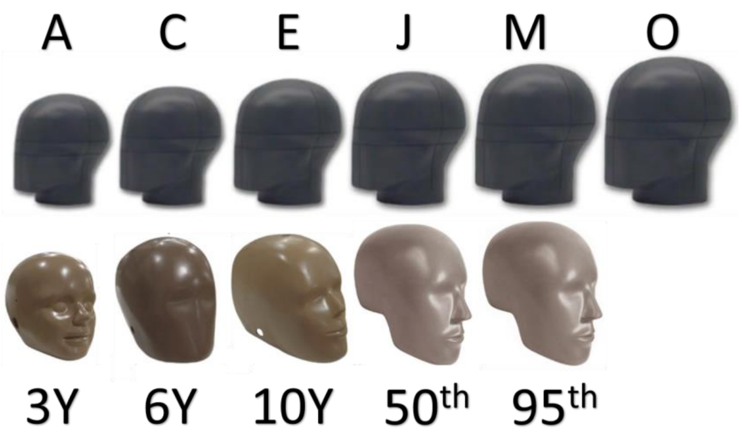
Instrumentation used for the 6D measurement of the headform

ISO headform complying EN 960 requirements

Hybrid III head

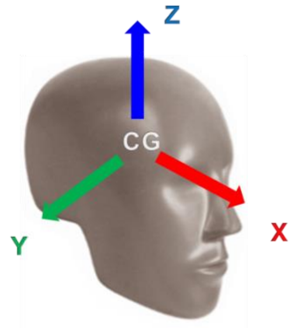
Benefits

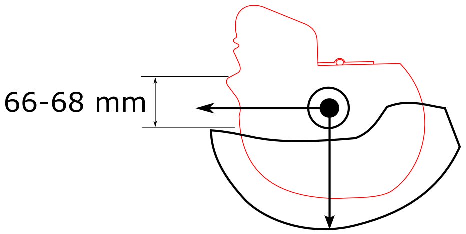
- * **Mass** in accordance with a the average adult head
- * More realistic **Moment of Inertial**
- * Deformable **skin** : soft contact between headform/helmet



EN 960 headform size	Head circumference [mm]	Dummy model	Head circumference [mm]
A	500	Hybrid III 3 Year Old	508
C	520	Hybrid III 6 Year Old	520.7
E	540	Hybrid III 10 Year or 5th Female	538.5
J	570	Hybrid III 95th Large Male	584
M	600	Hybrid III 50th Male	597
O	620		

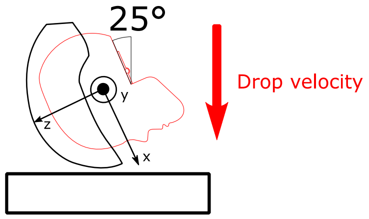
- Headform : Hybrid III 50th
- Impact block :
  - Steel diameter 130
  - Thickness 50
- Condition : ambient
- Number of repetitions : 3 tests



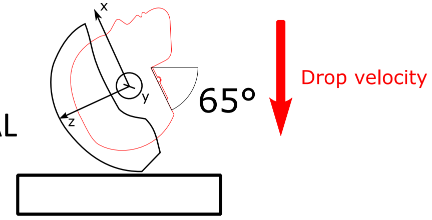


Horizontal Impacts
Drop velocity = 5.5 m/s

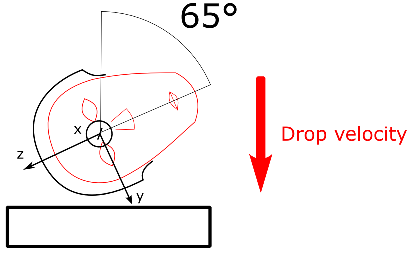
FRONTAL



OCCIPITAL



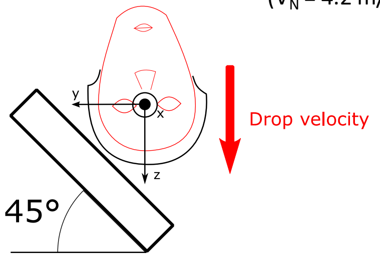
LATERAL



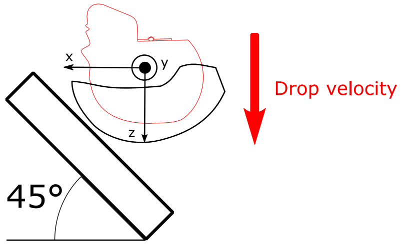
Oblique Impacts
Drop velocity = 6.0 m/s

(V_N = 4.2 m/s)

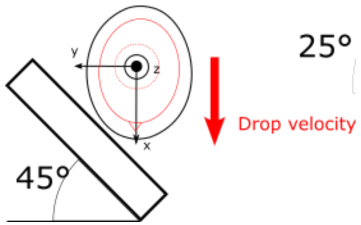
XRot



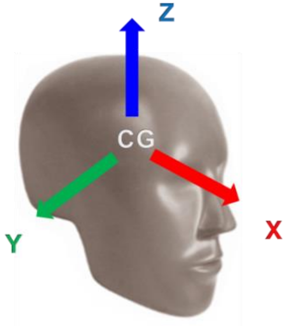
YRot



ZRot

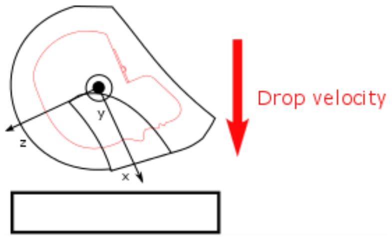


- Headform : Hybrid III 50th
- Impact block :
  - Steel diameter 130
  - Thickness 50
- Condition : ambient
- Number of repetitions : 3 tests

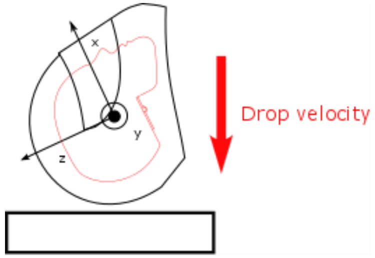


Horizontal Impacts
Drop velocity = 7.5 m/s

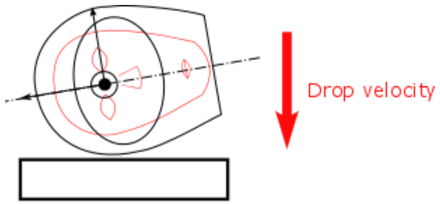
FRONTAL



OCCIPITAL

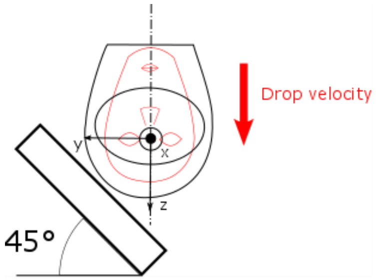


LATERAL

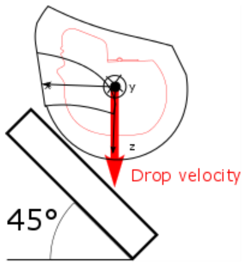


Oblique Impacts
Drop velocity = 6.0 m/s

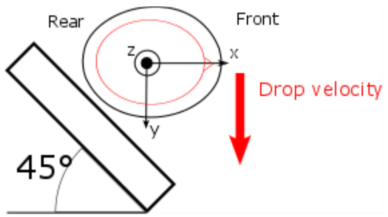
XRot



YRot



ZRot



3 HELMETS FOR HORIZONTAL IMPACTS

Helmet ID	First Impact	Second Impact	Third Impact
H1	FRONTAL	OCCIPITAL	LATERAL
H2	LATERAL	FRONTAL	OCCIPITAL
H3	OCCIPITAL	LATERAL	FRONTAL

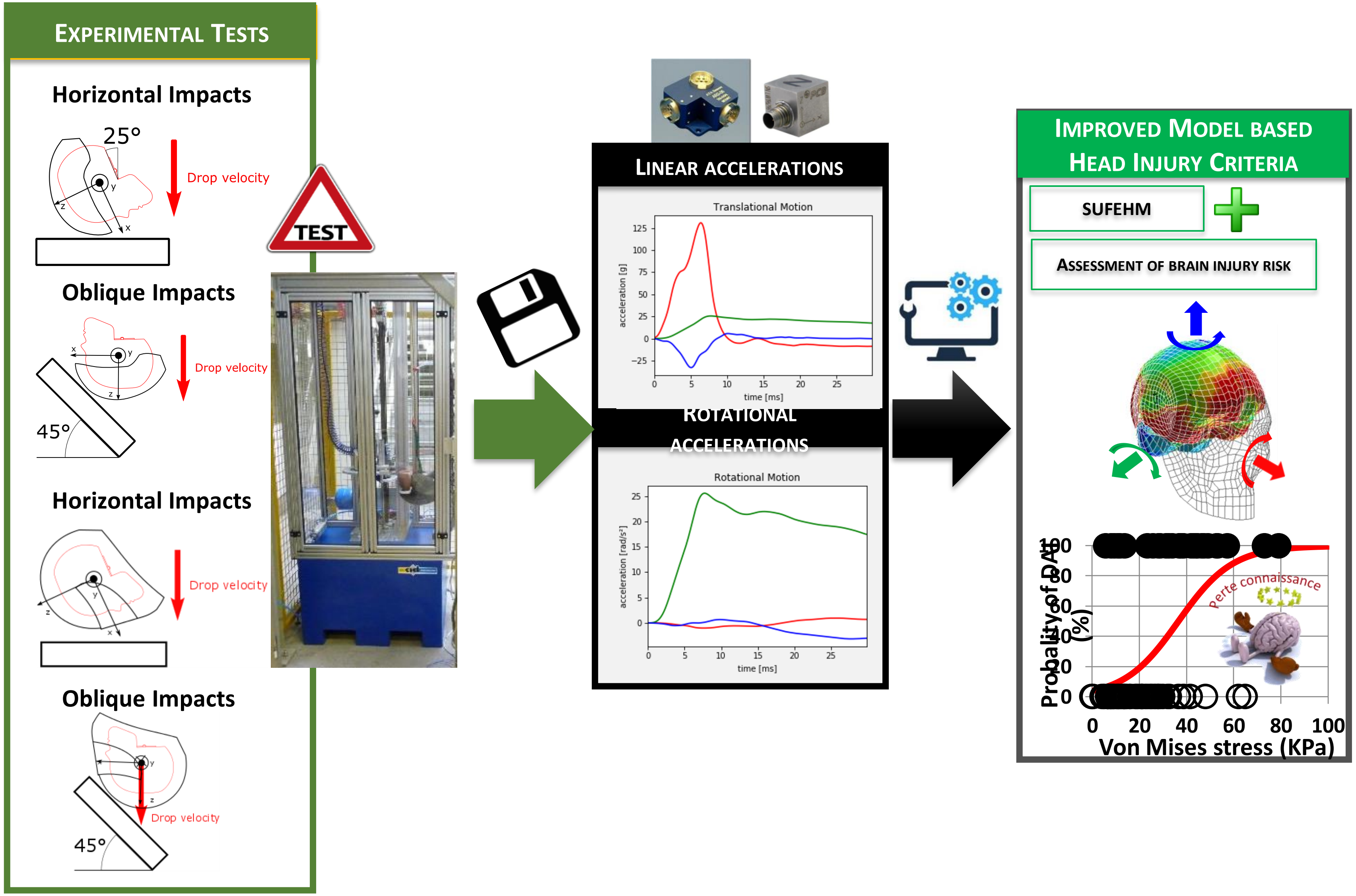
3 HELMETS FOR OBLIQUE IMPACTS

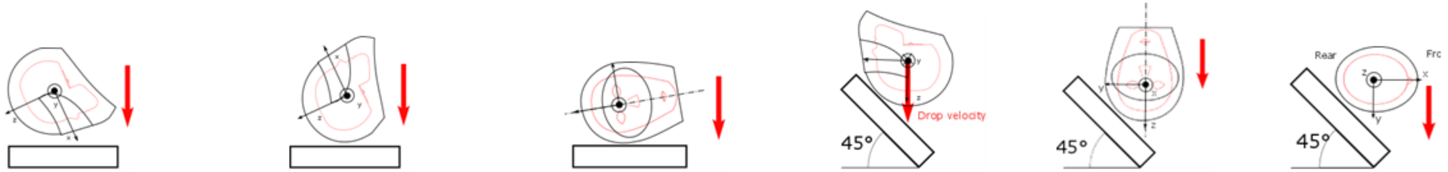
Helmet ID	First Impact	Second Impact	Third Impact
H4	Y-Rot	X-Rot	Z-Rot
H5	Z-Rot	Y-Rot	X-Rot
H6	X-Rot	Z-Rot	Y-Rot

A TOTAL OF :

- **6 HELMETS**
- **18 IMPACTS**

The 18 impact tests are simulated using SUFEHM

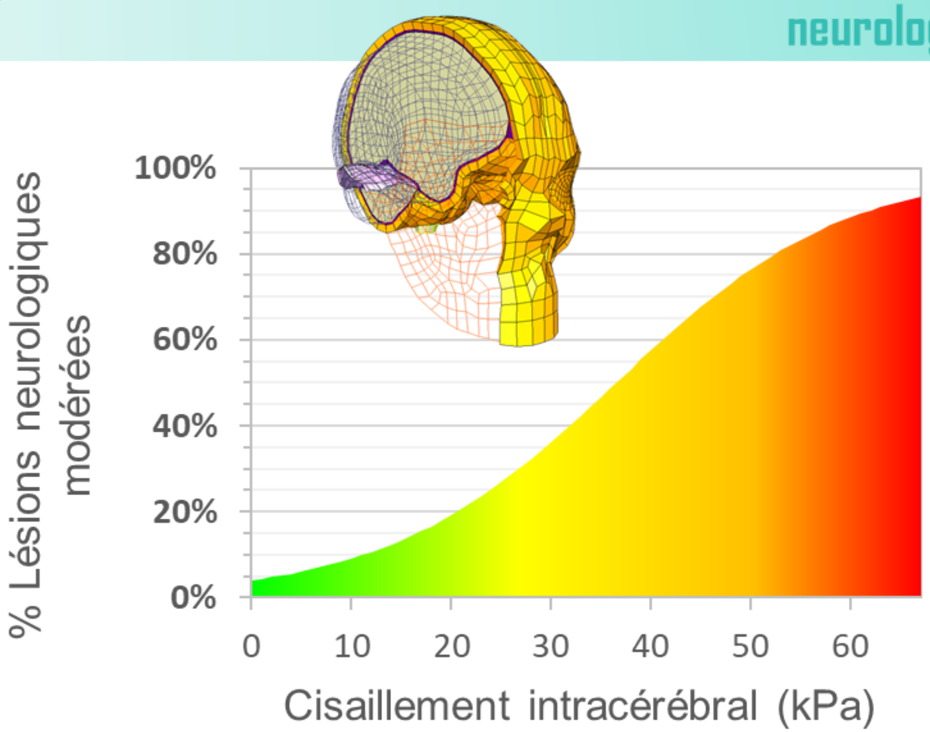


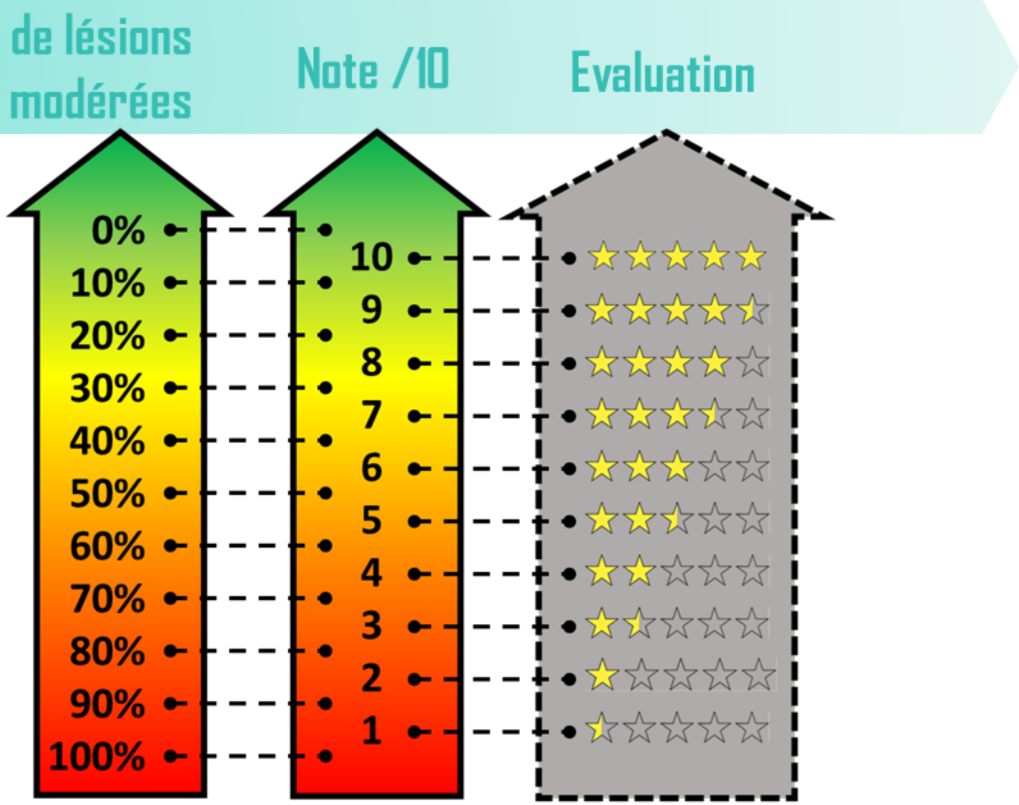


$$MMVMS = \frac{(MVMS_{FRONTAL} + MVMS_{OCCIPITAL} + MVMS_{LATERAL} + MVMS_{YRot} + MVMS_{XRot} + MVMS_{ZRot})}{6}$$

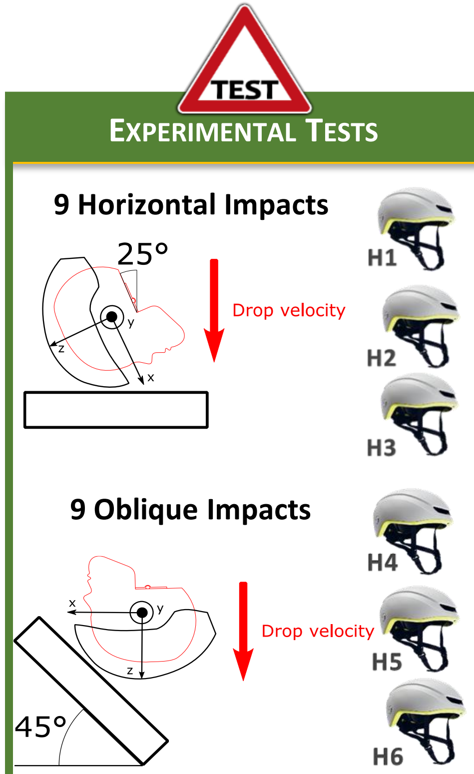
Avec *MMVMS* (*Mean Max. Von Mises Stress*), $MVMS_i$ est le maximum de contrainte de cisaillement pour la configuration *i* (*FRONTAL, OCCIPITAL, LATERAL, YRot, XRot, ZRot*).

évaluation



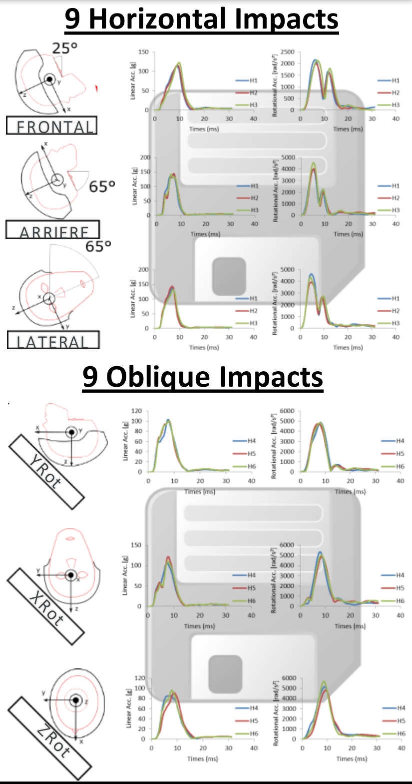


Experimental Tests

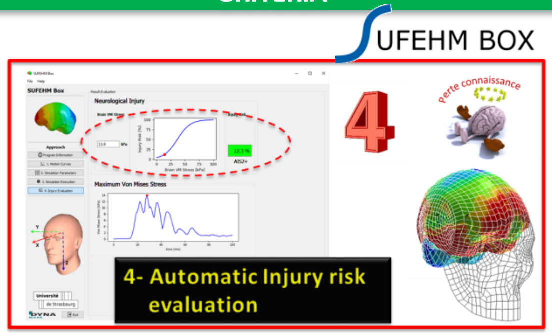


Helmet ID	First Impact	Second Impact	Third Impact
H1	FRONTAL	OCCIPITAL	LATERAL
H2	OCCIPITAL	LATERAL	FRONTAL
H3	LATERAL	FRONTAL	OCCIPITAL
Helmet ID	First Impact	Second Impact	Third Impact
H4	YRot	XRot	ZRot
H5	XRot	ZRot	YRot
H6	ZRot	YRot	XRot

Linear / Rotational accelerations for 18 impacts



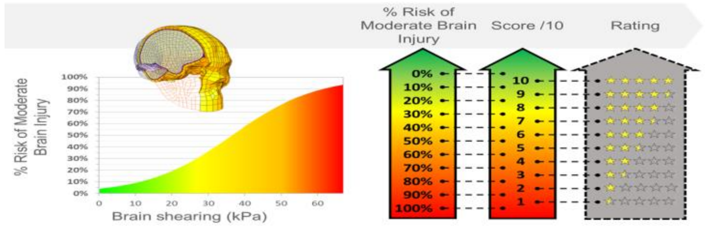
Improved Model based Head Injury Criteria



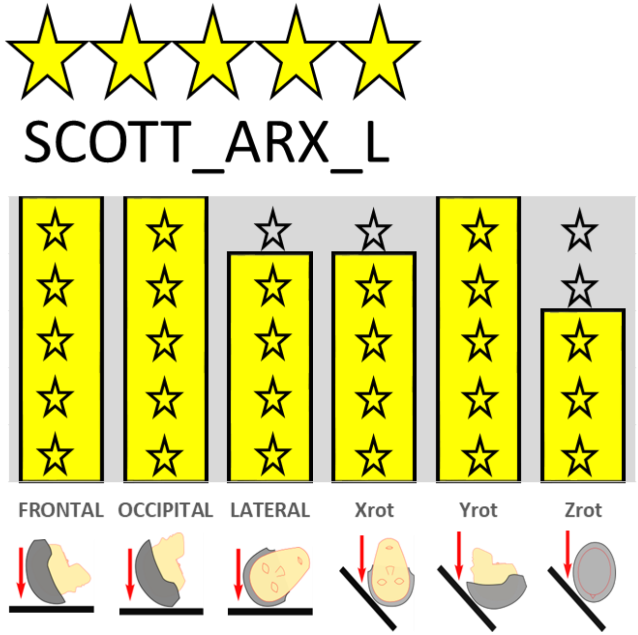
18 Brain Von Mises Stress Values calculated

Helmet Rating

$$MMVMS = \frac{(MVMS_{FRONTAL} + MVMS_{OCCIPITAL} + MVMS_{LATERAL} + MVMS_{YRot} + MVMS_{XRot} + MVMS_{ZRot})}{6}$$



certi moov

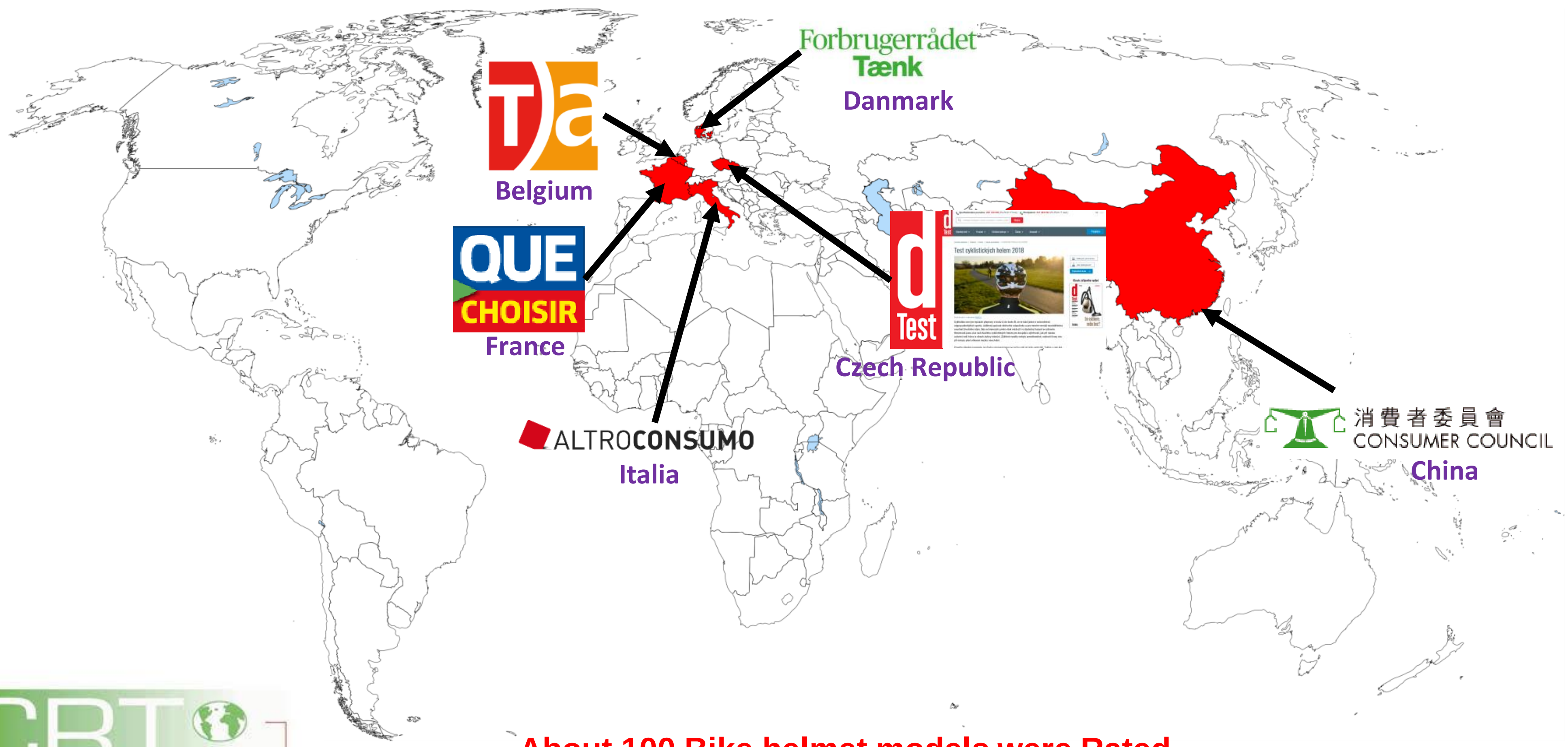

SCOTT_ARX_L
FRONTAL
OCCIPITAL
LATERAL
Xrot
Yrot
Zrot


ALPINA_Mythos-3.0-LE_L
BELL_STRATUS-MIPS_L
BONTRAGER_STARVOS-MIPS_L
GIRO_SYNTHE-MIPS_L
HARALD-NYBORG_BUSETTO_L
LAZER_REVOLUTION-MIPS_L
MET_ESPRESSO_ML
SCRAPPER_SCR-S038_LXL
SCRAPPER_SCR-URBAN-2_LXL
BTWIN_100_L
LIMAR_555_L
UVEX_city-i-vo_L

- Linear impact
  - Free Hybrid III headform,
  - Recording of Linear acceleration and Rotation velocity
  - 5.5 m/s
  - Model Based injury criteria

- Oblique impacts
  - Free Hybrid III headform, Lin and Rot acceleration
  - 6.0 m/s @ 45°
  - Model Based injury criteria

CURENT CYCLE HELMET RATING EFFORTS



ICRT
INTERNATIONAL CONSUMER RESEARCH & TESTING

About 100 Bike helmet models were Rated

HELMET RATING

ALPINA_Mythos-3.0-LE

HARALD-NYBORG_BUSETTO

LAZER_REVOLUTION-MIPS

LIMAR_555

MET_ESPRESSO

SCRAPPER_SCR-URBAN-2

BONTRAGER_STARVOS-MIPS

SCOTT_ARX

SCRAPPER_SCR-S038

GIRO_SYNTHE-MIPS

CRATONI_ALLSET

BTWIN_100

UVEX_city-i-vo

ZERORH_ZY

LIVALL_BH60

KASK_MOJITO-16

NUTCASE_Gen3-Cherry-Blossom

SPECIALIZED_PROPERO-3

BELL_STRATUS-MIPS

AUTHOR_Creek-HST

IKEA_SLADDA

BTWIN_BH500

BBB_BHE35-CONDOR

ABUS_HYBAN

MUSTANG_S-282M

ABUS_Urban-I-2.0

CANNONDALE_RADIUS

CSI_FCJ-201

MANGO_X-Ride

BELL_ANNEX-MIPS

OVERADE_PLIXI

OVERADE_PLIXI-FIT

// EVALUATION OF BYCICLE HELMETS_CHILDREN //

GIRO_SCAMP-MIPS

BTWIN_KH-300

BOBIBIKE_Baby-helmet-ONE

SCOTT_SPUNTO

KED_PUKY-PH1

ABUS_ACY-C-M-Youn-I-MIPS

Polisport_GUPPY

crazySAFETY_CS6-pink-shark

LIMAR_249

BELL_SIDETRACK-B0552

Bbb_BHE-37-Boogy

CASCO_MINI-GENERATION

ECE 22.05

SHARK_SKAWL-2-BLANK-Mat

SCORPION_EXO-510-AIR-SOLID

SCORPION_EXO-920

HJC_IS-MAX-II

6DHELMET_ATS-1

SHOEI_GT-AIR

AGV_K3SV

NOLAN_N44-EVO

HJC_IS-17

HJC_CS-15

SHARK_EVO-ONE

ARAI_CHASER-X

LS2_VALIANT

SHOEI_NEOTEC

SHARK_SPARTAN-CARBON

BELL_QUALIFIER-DLX-MIPS

SHUBERTH_R2

SHARK_SKWAL

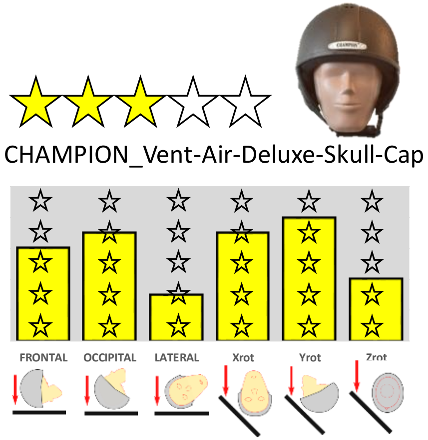
LS2_BREAKER

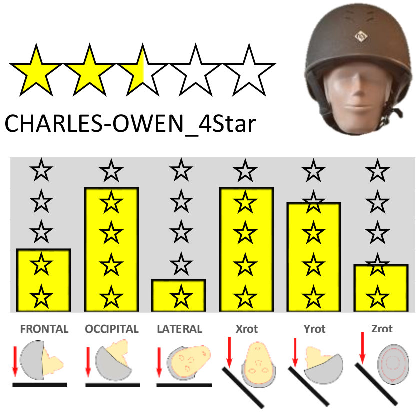
ASTON_MINIJET-RETRO

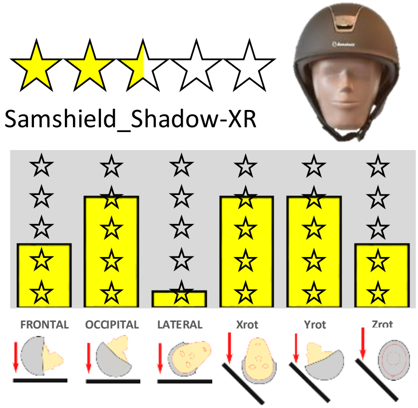
LEATT_GPX-6.5

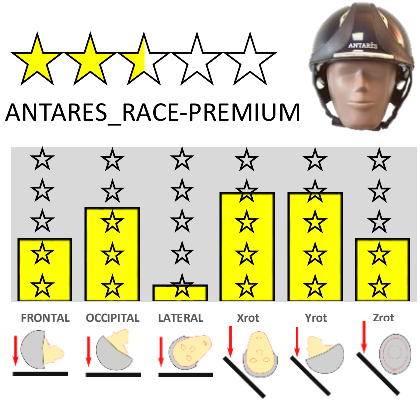
NOLAN_N87

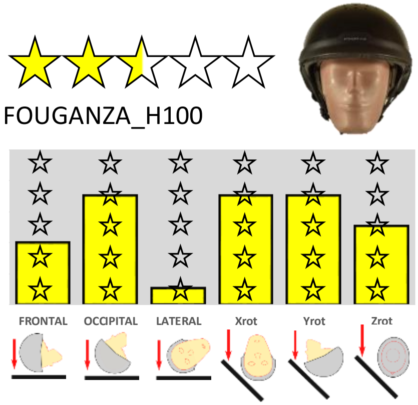
Equestrian Helmet Rating

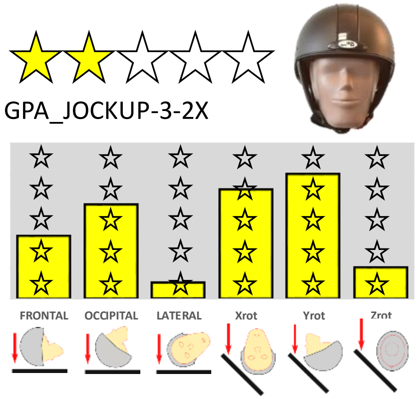












- Strong contribution in CEN TC 158– WG 11
- Strong contribution to ECE R22-06 (motorcycle helmets)
- Rating of over 100 cycle helmets (and about 50 moto helmets)
- Extended interaction with helmet manufacturers for specific impact conditions
- Contribution to helmet protection capability

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PRESENTATIONS AT STANDARD BODIES

- Strasbourg University Head Injury Criteria , *San Diego, October 2003 (ISO-doc N° 594)*
- HIC injury prediction capability versus Strasbourg criteria, *Nashville, October 2004 (Idoc N° 611)*
- HIC injury prediction capability vs Strasbourg criteria and SIMON, *Paris, June 2005 (doc N° 620)*
- State of the art head FE models and guidelines for validation, *Seoul, May 2007 (doc N° 680 & 681)*
- Improved Model Based Head Injury Criteria, *Madrid, January 2008 , EEVC WG 12 meeting*
- Improved Model Based Head Injury Criteria, ISO, WG6 ,*Paris, May 2009*
- Code and Model dependence of model based head injury criteria, *Stuttgart, June 2009 (EEVC-WG 12)*
- Towards new head protection standards, *Saint Louis, MO, USA, May 2010 (ASTM meeting)*
- *Model based Head Injury Criteria : Code, Model and Age Dependence, Paris June 2011, ISO WG6*
- New bicycle helmets test procedure, Milan October 2012, CEN TC158 WG11
- Brain injury criteria based on axon strain, Strasbourg, March 2015, CEN TC158 WG11
- Phase 06 of ECE-R22 Regulation, Geneva since 2018.

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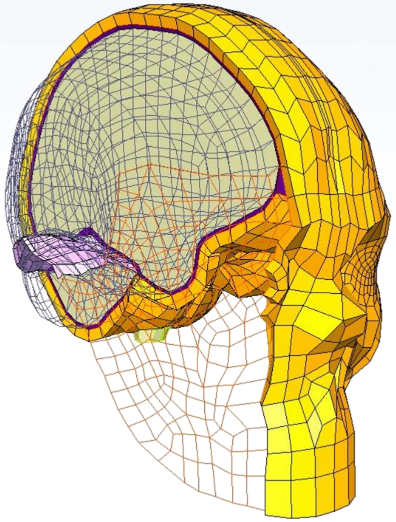
PUBLICATIONS

cnrs

- Bourdet N, Deck C., Willinger R. : Evaluation comparative de casques de cyclistes/ TF1-JT du 20 mars 2017
- Deck, N. Bourdet, P. Halldin, G. DeBruyne, R. Willinger, "Protection Capability of Bicycle Helmets Under Oblique Impact Assessed with Two Separate Brain FE Models," in IRCOBI Conference Proceedings, 13-15 September 2017, Antwerp, Belgium
- Bourdet N., Deck C, Willinger R **:** Coupled experimental versus numerical helmet evaluation under multidirectional impact **:** International Cycling Safety Conference, Davis, CA September 2017.
- Willinger R., Bourdet N., Deck C : Advanced linear and oblique helmet impact test method for consumer tests: Workshop on Bicycle Helmet Consumer tests. Davis – CA, September 2017
- Bourdet N., Deck C., Willinger : Motorcycle accident reconstruction and head impact conditions. COST-1407-Workshop on advanced helmet test methods, Brussels Dec 2017
- Deck C., Bourdet N., Willinger : Advanced head injury criteria for advanced helmet testing. COST-1407-Workshop on advanced helmet test methods, Brussels Dec 2017
- Bourdet N., Deck C., Willinger : Helmet consumer tests at Strasbourg University.COST-1407-Workshop on advanced helmet test methods, Brussels Dec 2017
- Halldin P., Deck C., Willinger : Proposal of a new bicycle helmet test method. Proceed. Int. Cycling Safety Conference, Hannover November 18th 2015.
- Boudet N, Deck C., Meyer F, Willinger R. : A new comparative testing method for equestrian helmets. Int. J. of Crashworthiness, pp1-10, 2020 doi: 10.1080/13588265.2020.1859758
- C. Deck, N. Bourdet, F. Meyer, et R. Willinger, « Protection performance of bicycle helmets », Journal of Safety Research, vol. 71, p. 67-77, déc. 2019, doi: 10.1016/j.jsr.2019.09.003

Cycle Helmet Safety Testing & Rating Harmonisation



www.CERTIMOOV.COM. Helmet Rating Platform

And Consequences

Remy Willinger, Caroline Deck, Nicolas Bourdet

March 18, 2021

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