Skilled Motorcyclist Association
SMARTER
Responsible, Trained, & Educated Riders

Riding SMART!

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SPECIAL EDITION
Motorcycle Helmet Standards, Part II

President's News & Views

Since SMARTER's incorporation in 2007, I have written the content for more than 80 newsletters, including this ninth special edition. The complexities involved in helmet standards has made this the most difficult for me to write. While this subject can easily become confusing, I have learned a great deal. My goal has been to provide SMARTER members with more in-depth information than most articles on helmet standards provide and at the same time keep the content understandable.

The focus of this *Special Edition - Motorcycle Helmet Standards, Part II* will be on

- oblique/angle impacts resulting in rotational forces to the brain
- the publication of oblique impact motorcycle helmet standards, and the
- technologies developed to mitigate the resulting head/brain trauma.

I am indebted to Hong Zhang, Snell Foundation, Inc. Director of Education, for her willingness to review my drafts, correct errors, share with me additional information on the background of the references and provide technical details for Snell's positions on various standard related issues. Her knowledge is unmatched and her help extensive.

Dan

Riding Smart Preview

Background

My helmet standard investigation began after considering the claims made in a FortNine video regarding the Snell standard. We recommend readers review our previous *Riding Smart Special Edition - Motorcycle Helmet Standards, Part I* available at: https://smarter-usa.org/wp-content/uploads/2022/01/1-2-Jan.-Feb.-Helmet-Standards-part-I.pdf.

Riding Smart newsletters are normally sent to members only, but occasionally we have posted special editions, as we did with Part I. One person responding to a posting of Part I on a motorcyclist safety orientated Facebook page pointed out the "elephant in the room" is the g-forces passed on the brain from an impact, not penetrating trauma.

The same well-informed person noted that some of the issues we addressed in Part I were highlighted in an article by Dexter Ford published in June 2005 titled *Blowing the Lid Off* which contended Snell helmets were too hard and transmitted too high a g-force to the head. The author, Ford, maintained that DOT-only certified helmets are inherently safer than Snell certified helmets, which are tested at much more severe impact levels. The rationale was that any improvement in high end performance must be due to harder helmets which would likely transmit greater levels of shock, especially in less severe and more commonly encountered incidents.

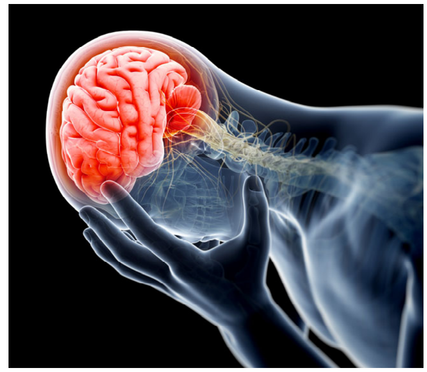
The article *Blowing the Lid Off* and an open letter to the motorcycling public from Snell plus a September 2005 Technical Response from Snell are all available at https://smarter-usa.org/research/helmets-laws/standards-and-testing/. This information is also recommended reading, with the caveat that the g-force standards discussed in these 2005 articles are not the same as current standards.

Snell conducted research on this issue and presented the results at a 2015 conference, https://smarter-usa.org/wp-content/uploads/2017/06/1_2015_Motorcycle_Helmet_Imp.pdf .
The results show that Snell "M2010/DOT helmets transmit equivalent shock to that of DOT-only helmets in minor impacts." In other words, riders with Snell certified helmets are not giving up any head protection in minor impact crashes.

An important source for the content of this newsletter is the 2013 report *Motorcycle Helmets - A State of the Art Review* found here:
https://smarter-usa.org/wp-content/uploads/2017/06/2_2013_Motorcycle_Helmets_.pdf
This is an excellent, extensively referenced article. Remember also that this review was published in 2013 prior to any standard containing criteria for oblique impacts.

A second important source for the content in this newsletter are the slides and notes of a Snell Foundation presentation at the International Council of Motorsport Sciences (ICMS) virtual event held December 8-10, 2021. Initial slides present history and background information regarding the Snell Foundation. Slide 12 and slides 15 - 25 present Snell's research regarding oblique impact testing. The slide notes contain significant information. The document is available here:
https://smarter-usa.org/wp-content/uploads/2022/01/2021-Snell-presentation-at-the-ICMS-with-PDF-Notes.FINAL_.pdf

Skull Penetration



A helmet is widely accepted as the most important piece of motorcyclist personal protective equipment. A helmet acts to mitigate head injury, not only by preventing the skull from being perforated, but also dampens the force of the impact transmitted to the brain. It is well accepted that almost every motorcycle helmet does an excellent job at preventing skull penetration. The challenge for any helmet, as summarized by Hong Zhang, "is to slow down the sudden stop of the brain inside the skull during the crash. This is when the protective liner comes into play to absorb the shock energy so that risks of soft brain tissue damage and internal brain bleeding can be reduced to prevent permanent brain injury and, possibly, death."

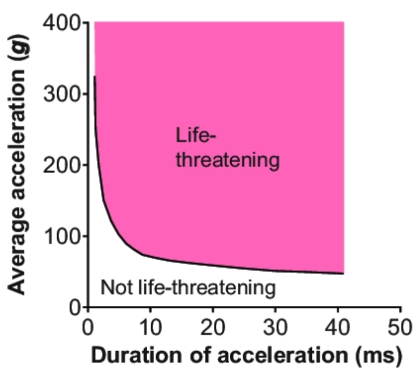
It is also well accepted that full-face helmets offer more protection (with no drawbacks) than ¾ helmets, which in turn offer more protection than ½ helmets. There are disagreements, however, about the thresholds set for transmitted g-force.

G-Forces Transmitted

Helmet standards rely on a threshold model of g-force transmission. That is, there is a level of g-force that a person can safely withstand, and with a force beyond that threshold the risk of injury increases significantly. This is different than thinking about g-force on a continuum, different than thinking the injury risk is proportional to g's where lower g-force is safer and higher is less safe. A threshold model contends that injury risk changes from a low level to a high level when the impact g's pass an established threshold.

For example, if the g-force for low risk of injury (a safe helmet) is established at 275 g's, and we test two helmets and find helmet #1 transfers 272 g's and helmet #2 transfers 233 g's, then both meet the standard (i.e., both limit g-force to a level lower than the standard) and both are deemed safe. Traditionally, helmet standards have established a threshold in the 250 to 400 g range.

Where does the g-force threshold come from?



The g-force threshold established by the helmet standard organizations originated in the research on the biomechanics of brain injury. That's a good thing. These criteria were initially derived in 1960 from the Wayne State Tolerance Curve (WSTC) based on human cadaver head impact tests, which show the relationship between the average acceleration of head movement and its duration (https://www.researchgate.net/figure/Wayne-State-Tolerance-Curve-WSTC-The-WSTC-describes-the-relationship-between-linear_fig2_256705764).

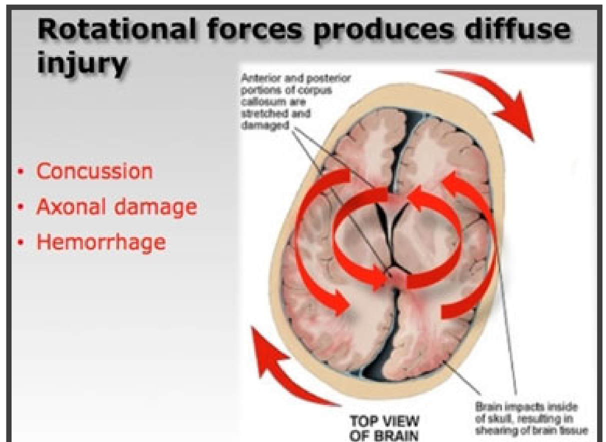
Other early research proposed a severity index (SI) and later research modified the SI as a head injury criterion (HIC), which over time became the most commonly acknowledged and most widely applied head injury criterion. However, as the HIC only considers linear acceleration and action time and does not regard the rotational movement of the head, its deficiencies have been pointed out by ongoing research (https://www.frontiersin.org/articles/10.3389/fbioe.2021.677982/full).

Two Big Complications

Even if we accept the g-force threshold model based on the widely accepted HIC, there are two big complications that make it impossible to choose the safest helmet based solely on this information. First, experts disagree on what value of g should be selected. Second, the different standard setting/testing organizations do not use the same test procedures or test apparatus.

A direct comparison of g-forces doesn't help much in answering the "which helmet is the safest" question, because even if the accepted peak g-force threshold of different standards is the same, the drop height to test this might be different, the testing apparatus might be different, the anvil the helmet is dropped onto might be a different shape, the location of the strike on the helmet might be different or the number of strikes

Oblique impacts and rotational forces



Source: https://drbiomechanics.com/motorcycle-expert-witness/motorcycle-helmet-expert/

We have known for many years that oblique impacts can cause serious brain injuries as the brain potentially rotates violently inside the skull causing tears in the structure of the brain. Until 2019 no helmet standard assessed the rotational acceleration, even though rotational acceleration is believed to occur in every motorcyclist crash. Oblique impact/rotational force standards have been long in coming primarily because there have been no accepted global injury thresholds for rotational acceleration (as opposed to the commonly accepted HIC for translational acceleration). Also, there has been no commonly accepted test configuration capable of reproducing impacts similar to the most commonly observed impacts in real life motorcyclist crashes.

This all changed in mid-2019 when the Fédération Internationale de Motocyclisme (FIM) announced a standard and program for helmet testing used in their events.

Following the FIM announcement, in June 2020 the Economic Commission for Europe (ECE) announced an update to their standard. The update is ECE R 22-06. Similar to the standards set for translational forces, two critical decisions need to be established regarding rotational forces: (1) what will be the standard - the rotational force the brain can withstand without injury and (2) how will this be tested.

<u>As we have noted, even after years of debate there is no world-wide accepted standard and testing method for translational force, so it is likely we are at the beginning of another decades long debate regarding a standard for rotational forces and how to test if a helmet meets the standard.</u>

Note, prior to FIM's standard and testing announcement, helmet manufacturers had developed testing in order to show the results of their newly developed technologies designed to reduce rotational forces. The results of the helmet manufacturers' testing are often used in advertising.

DOT, FIM and Snell Standards

DOT

SMARTER has not located any information (news releases, conference presentations, etc.) regarding recent DOT consideration of standard changes. Minor potential changes were outlined in 2001 by David Thom at the International Motorcycle Safety Conference (https://www.msf-usa.org/downloads/imsc2001/Thom.pdf). To our knowledge, these proposed changes have not been made. DOT labeling was updated in 2014 to make the label more difficult to fake. We are not aware of any consideration by DOT regarding changing the threshold for translational impacts or considerations for establishing a standard and testing methods for oblique impacts.

FIM

We provided an overview of the FIM standard in Part I and will provide a bit more detail here. FIM states that their test protocol "aims to trigger the development of helmets offering an optimal protection for riders." Additionally, FIM states "Innovatively, the FIM test procedure pioneers the assessment of the helmet response to medium severity oblique impacts, aiming at evaluating the level of protection against brain injuries generated by critical rotational accelerations. The oblique test constitutes the most novel and modern aspect of the methods of testing and reflects a very common scenario occurring in real world accidents, although never addressed in international standards so far." Note the use of the phrase "medium severity oblique impacts" above. According to Zhang, none of the helmets submitted for early testing (September 2019) "failed to meet their requirements for rotational acceleration and their (FIM) rotational velocity criterion, BrIC." Zhang goes on to say the FIM standard for oblique impacts seems arbitrary and few, if any helmets "might reasonably have any problems passing the oblique impact requirements set by FIM and adopted by ECE 22.06." The result, to use Zhang's phrase, "would seem to render these tests completely toothless." If the FIM medium severity oblique impact standard does not trigger actual helmet design change, it certainly has triggered discussion within the helmet standard organizations.

Every motorcyclist crash where the riders' head hits something, is an angled impact simply because the likelihood of a perfect direct hit is essentially zero. Tradition has been to test helmets for absorbing direct impacts and the assumption has been the better a helmet is at absorbing direct impacts, the better the wearer is protected from any angle impact. That assumption may not be true. A 2017 study which investigated this correlation directly found "a trend, but not strong correlation, was found between peak linear acceleration and peak angular acceleration, indicating that reducing impact-related peak linear acceleration may not necessarily mitigate peak angular acceleration" (https://smarter-usa.org/wp-content/uploads/2022/03/2017-Biomechanical-Evaluation-of-Motorcycle-Helmets-Protection-against-Head-and-Brain-Injuries.pdf) This is, however, just one study and their conclusion language, "may not necessarily," is far from a certain conclusion.

SNELL

Snell Foundation has been investigating aspects of standards and testing methods for oblique impacts since at least 2015 when they were one of the co-sponsors of an International Angular Head Motion workshop conducted under the auspices of the International Research Council on Biomechanics of Injury.

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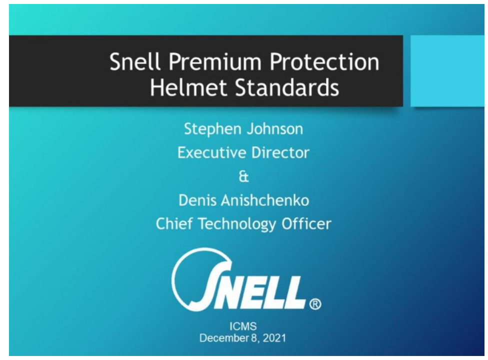
A presentation by Snell representatives at the December 8, 2021 Annual Congress of the International Council of Motorsport Sciences provides an update on Snell work in this regard.



Snell's conclusions are below:

1. *We're confident that we can perform repeatable, reliable oblique impact testing should the requirement ever be included in testing for Snell certification, or if the service is ever added to our prototype testing service for Snell clients interested in pursuing FIM certification.*

2. *We have demonstrated that at least one anti-rotational innovation can change the response of helmets tested in oblique impact. However, we have also demonstrated that different test conditions which might reasonably simulate performance in the field nullify the effect.*

3. *Finally, although the testing has demonstrated that this anti-rotational feature does reduce peak angular velocity and peak angular acceleration for some tests conducted to FIM protocols, whether these findings bear on the protective performance of these features in real world crashes appears uncertain. Fortunately, helmets incorporating these features are already in use. Epidemiological studies of crash outcomes may one day tell us what we need to know.*

Source: Slide 25 - https://smarter-usa.org/wp-content/uploads/2022/01/2021-Snell-presentation-at-the-ICMS-with-PDF-Notes.FINAL_.pdf

It is so complicated! Number 2, line 2 is referring to the fact that technologies to reduce rotational forces generally provide for some kind of slip or sliding (see the diagram on following pages) and Snell testing found out that hair (placing a wig on the test head form) also provides a mechanism for slip which might nullify the effect of the technology built into the helmet.

As Hong Zhang says "At least "nullify" in the sense of "renders moot" the advantage that the technology provides. It's as if a good head of hair is so effective at reducing rotational shock that the tested anti-rotational innovation didn't really matter."

Number 3 means Snell does not have much confidence that the apparent standard used by FIM and ECE has enough scientific base to be useful. According to Snell, we are still a long way from full understanding of brain injury mechanisms due to rotational force (June 2019, Snell newsletter, Heads Up, page 2 Rotational Testing (https://smf.org/docs/headsup/pdf/headsup72.pdf).

Anti-rotational Features

There are a growing number of technologies on the market used by manufacturers that claim the innovation provides protective benefits involving oblique impacts. These designs to limit/reduce rotational forces basically introduce some sort of slip or movement. The first is between impacted surface (road) and the outer shell of the helmet. Helmets are already very smooth on the outside so improvements there are limited.

PHPS: Phillips Head Protection System (PHPS*)* prototype was introduced in 2004. This system added a special lubricated membrane over the outside of the helmet. The membrane reduces the friction of the helmet surface by moving over the hard shell - similar to how your scalp (skin) will move over skull when you push on it at an angle.

A helmet with this design was introduced about 2009, but the current manufacturer's website makes no mention of this technology, and our search did not turn up any companies currently manufacturing a helmet with this technology.

A second area where slip can be introduced is between the shell and the liner. There are a number of proprietary designs that incorporate this idea.

Omni-Directional: The Omni-Directional Suspension Technology from 6D Helmets (https://www.6dhelmets.com/innovation/) is a leading example of this design. According to 6D the "suspended dual -liner assembly will displace and shear omni-directionally when subjected to impact. This capability provides significantly improved performance against both linear and angular accelerations."

RHEON™: The name originates from the branch of physics "Rheology" - a unique discipline exploring the flow of matter and how that matter reacts when force is applied. (https://rheonlabs.com/rheon-technology-how-it-works/). Ruroc is a UK company whose stated mission is "*to create quality helmets to enhance head protection in the most extreme environments*." Ruroc has "*teamed up with RHEON™ to further improve the safety of our motorcycle helmets. The ATLAS 4.0 headliner now has strips of reactive polymer developed by RHEON™ to help reduce rotation and linear impact forces on a rider's head."*

The company states the *"ATLAS 4.0 is one of the first motorcycle helmets on the road to meet ECE 22.06. Not only that, we exceed all testing standards by a minimum of 20%, to give you the ultimate protection."* (https://www.ruroc.com/en_us/atlas-4)

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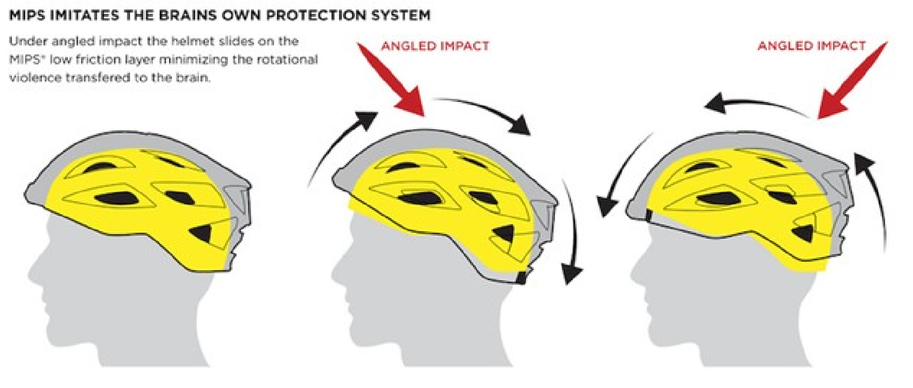
MIPS is likely the most recognized technology (https://mipsprotection.com/science-technology/ or https://mipsprotection.com/moto). The *Multi-directional Impact Protection System (MIPS)* was introduced in 2004. The technology is licensed to manufacturers - currently 143 brands incorporate MIPS technology into their helmets (https://mipsprotection.com/helmets-with-mips/)

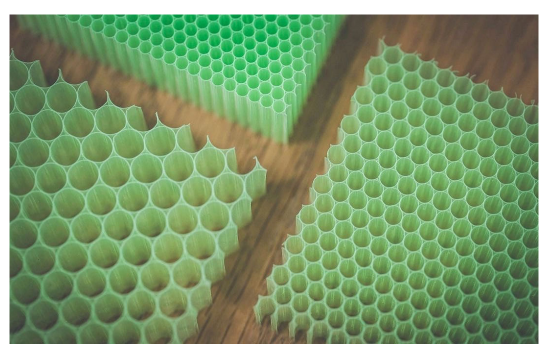


The MIPS is based on a sliding low friction layer between the head and the helmet liner. This layer is designed to rotate inside the helmet with the intent to slow or reduce the amount of energy transferred to or from the head.

Other anti-rotational technologies available in equestrian, bicycle or other protective helmets, but not necessarily motorcycle helmets at the present time, include those below. A good article on various liners is here: https://helmets.org/liners.htm

WaveCel : currently used in some bicycle helmets. WaveCel uses a honeycomb structure that helmet manufacturer Trek claims crushes and shears laterally on impact to lessen linear and rotational energy. In its marketing, Trek claimed that WaveCel was "up to 48 times" more protective against concussions than conventional, foam-only helmets. Here is a link to an explanation of a law suit against Trek which claims Trek misrepresented the technologies value in an effort to justify higher prices (https://www.outsideonline.com/outdoor-gear/bikes-and-biking/trek-wavecel-lawsuit-explained/). Current advertisements claim WaveCel is "designed to be more effective than traditional foam helmets in protecting your head from injuries caused by certain cycling accidents."

SPIN or Shearing Pads INside: https://www.spin.app/helmets



Koroyd: is not a "slip" design but claims "by absorbing the maximum amount of force from all impact types, Koroyd is also able to reduce the rotating motion which your brain could endure as a result of an angled impact. Studies prove, in the event of an angled impact, when direct acceleration is reduced (by absorbing energy), there is a 91% correlation* with a reduction in the rotational motion of your head and brain. In simple terms, if your helmet absorbs more energy, you are better protected from any angle of impact." https://koroyd.com/faqs - note the * in the above quote references the 2001 COST 327 report found on the SMARTER site here: https://smarter-usa.org/wp-content/uploads/2022/03/2001-COST-327-Motorcycle-Safety-Helmets-Final-report.pdf. However, as we noted earlier, a 2017 study which investigated this correlation directly found "a trend, but not strong correlation."

Summary and discussion with some opinion

Our introductory "Helmet standards, Part I, the key points" provides an overview, which may be helpful to review https://smarter-usa.org/wp-content/uploads/2022/01/1-2-Jan.-Feb.-Helmet-Standards-part-I.pdf. Until recently, helmet testing has not included oblique impact standards however there is no doubt the linear impact standard requirements have made motorcycle helmets much more protective over the years.

According to the authors of *Motorcycle Helmets - A State of the Art Review (section 4 Oblique impact)* we have known for at least twenty years that the most frequent severe injuries in motorcyclists are brain injuries caused by rotational forces that are generated as a result of oblique (angular) impacts. Hong Zhang with Snell disagrees on this point writing "Oblique impacts happen often. But whether they lead to the most serious brain injuries is unclear. There is no conclusive data showing the level of brain injuries in connection of impact types or severity. However, since majority crash impacts must have involved certain level of angular acceleration, current helmets must have already provided some level of protection in oblique impacts."

Over the same period our understanding of the mechanisms of brain injury has been rapidly improving thanks to the publication of about 50 research papers per year on head injury mechanism. But according to Zhang, our "current understanding of the connection between rotational forces and brain injuries is still not adequate."

Oblique helmet tests were proposed as early as the 1990's. FIM and ECE have now established standards and testing criteria for oblique impacts. Snell has recently confirmed reliability and repeatability of its testing apparatus for oblique impact tests. The problem for new helmet standards regarding rotational impacts is that no one agrees what the metric should be that defines the test threshold. Sound familiar?

At the beginning of Part II of this investigation, I (Dan) thought the FIM standard driving the ECE and impacting Snell decisions was definitely a step forward. Now I am not so sure we have taken any step forward because the FIM threshold for oblique impacts may be so low as to not require manufactures to make any changes to meet the standard. We are however, definitely talking about it and that is a very good thing.

While it is apparent that standards drive helmet design and innovation, the standards must have "teeth" to push protection forward. Future (asap) standards ought to be evaluated at higher impact velocities onto multi-shaped anvils and must include measures for both linear and angular acceleration. However, as Hong Zhang puts it "To improve existing helmet standards, we must keep in mind the importance of holding onto the total impact capacity already accomplished by today's best helmets, any new requirement must be evidence based, not based on unfounded assumptions or insufficient data."

In my opinion, it is long past time for U.S. DOT to make significant upgrades in the DOT motorcycle helmet standard. Zhang cautions me "Until medical science has a better understanding of what angular motion metrics should be measured and limited by standards, it may not be the best idea to give up too much of the 'traditional' protection level trying to satisfy some arbitrarily selected criteria for oblique impacts." She likens it to throwing the baby out with the bath water.

I don't think we need to throw the baby out, but the baby is now an adult. It is time for the adults at DOT to initiate action to update our helmet standard.