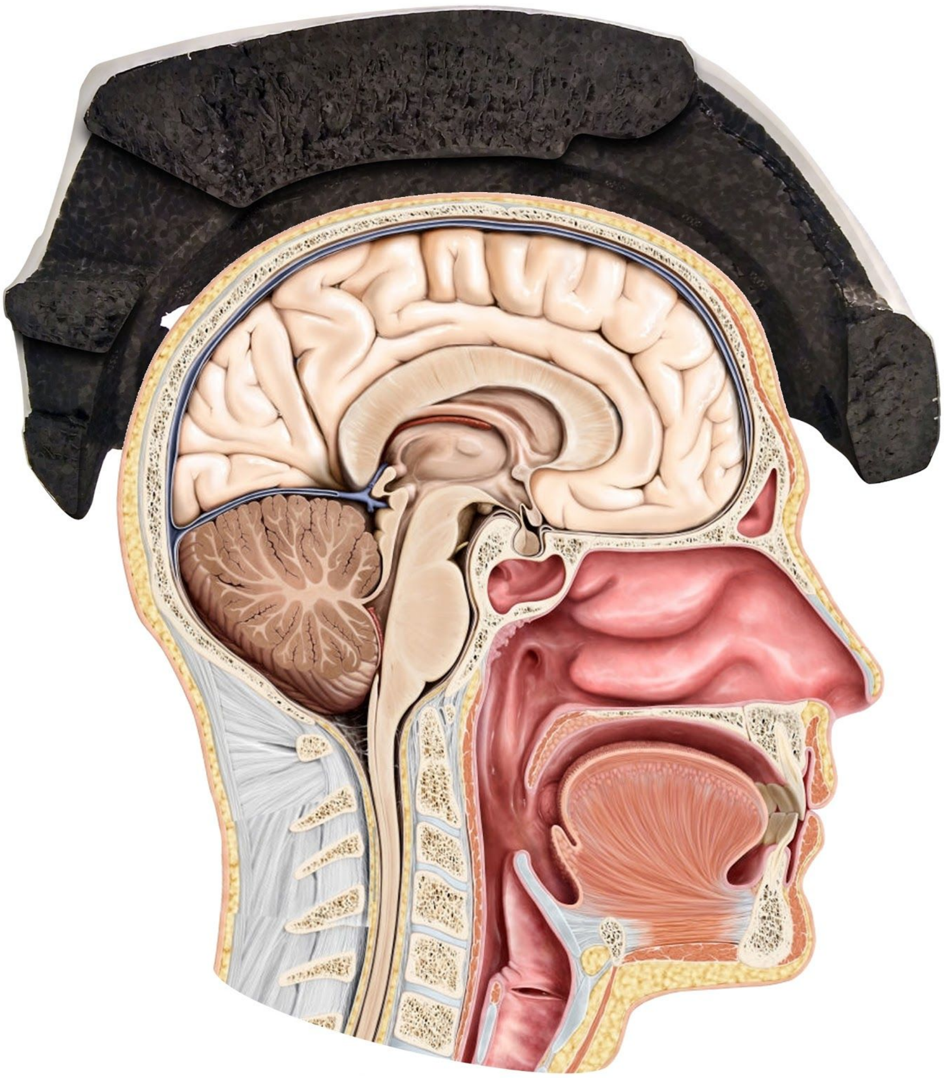
Increasing the Safety of the Modern Bicycle Helmet:
Design of an Additional Impact Protection Mechanism

Appendix



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1. Introduction

This is the appendix of the graduation project *Increasing the Safety of the Modern Bicycle Helmet: Design of an Additional Impact Protection Mechanism*. It contains all the necessary (background) information that did not end up in the final report. The chapters are mirrored to the final report, meaning for example chapter 2 of the appendix is that of chapter 2 of the report.

2. Orientation

The bicycle helmet

Brief history of the modern bicycle helmet

The first modern bicycle helmet predates back to 1975, when the Snell Foundation created a hard plastic shell which was padded with foam[1].

[1] http://www.davison.com/blog/2013/05/14/history-tuesday-the-bicycle-helmet/. Accessed november 30th, 2017.

The first hard shell helmet with an EPS liner as we know it now, was created in the 1980s by Bell Biker[2]. Then in 1990 helmets were introduced that featured an in mould design[3].

The at the time PET hard shell was injected with EPS, creating a single unit. This method is still used today, however the outer hard shell nowadays is mostly made of PC, and sometimes ABS.

Production process

Most medium to high end bicycle helmets nowadays are produced using a process called in-moulding. It is called in-moulding because the PC outer shell is placed inside the a mould, afterwhich the EPS liner is injected, bonding the PC and EPS together. This creates a lighter and stronger helmet, which also allows for more and larger ventilation holes[4].

[2] https://www.helmets.org/history.htm. Accessed november 30th, 2017.
[3] https://www.helmets.org/history.htm. Accessed november 30th, 2017.
[4] https://helmets.org/molded.htm. Accessed november 2nd, 2017.

3. Analysis

Problem definition

Injury

To get a better idea of the consequences of linear accelerations, Hynd et al (2009) have proposed a way of classifying the chance of certain levels of injury.

Probability of fatality as a result of peak linear acceleration:

Peak linear acceleration	AIS head injury severity	Injury interpretation	Approximate probability of fatality
< 50 g	0	No injury	0.0%
50 - 100 g	1	'Minor' injury	0.0%
100 - 150 g	2	'Moderate' injury	0.1 – 0.4%
150 – 200 g	3	'Serious' injury	0.8 – 2.1%
200 - 250 g	4	'Severe' injury	7.9 – 10.6%
250 – 300 g	5	'Critical'	53.1 – 58.4%
> 300 g	6	'Unsurvivable' (Maximum)	> 58.4%

Source: The Potential For Cycle Helmets To Prevent Injury - A Review Of The Evidence [5]

This gives an initial rough idea of the effect of certain acceleration levels, however the probability of fatality numbers leave a lot of uncertainty. A more accurate and complete way of assessing the injury risk was developed by Mellander (1986), called 'head injury criterion' (HIC).

HIC

Head Injury Criterion (HIC) can be calculated using the following formula:

$$\mathrm{HIC} = (t_2 - t_1)\left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2}(a_{cg}dt)\right]^{5/2}$$ [6]

"*A value of 700 is the maximum allowed under the provisions of the U.S. advanced airbag regulation (NHTSA, 2000) and is the minimum score for an "acceptable" IIHS rating for a particular vehicle.*"[7]

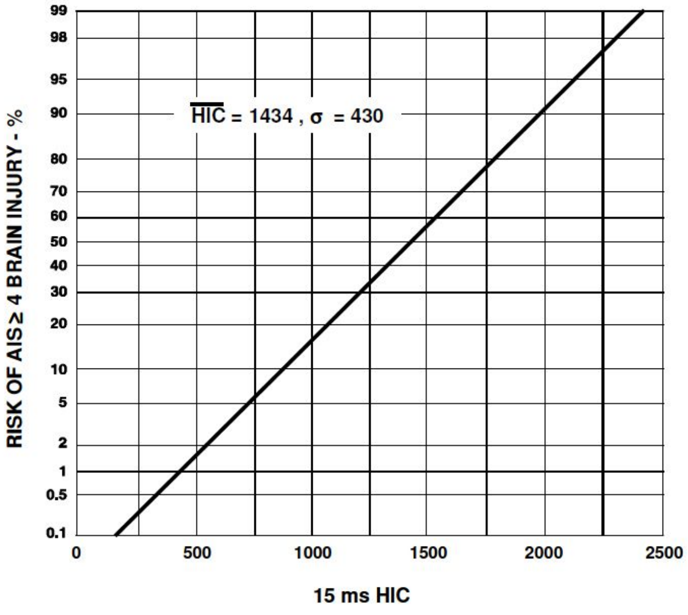
IIHS

AIS ≥ 4 Brain Injury Risk Curve for the Adult Population Based on 15 ms HIC:

5 https://www.headway.org.uk/media/3406/trl-report-the-potential-for-cycle-helmets-to-prevent-injury-2009.pdf. Accessed october 4th, 2017.

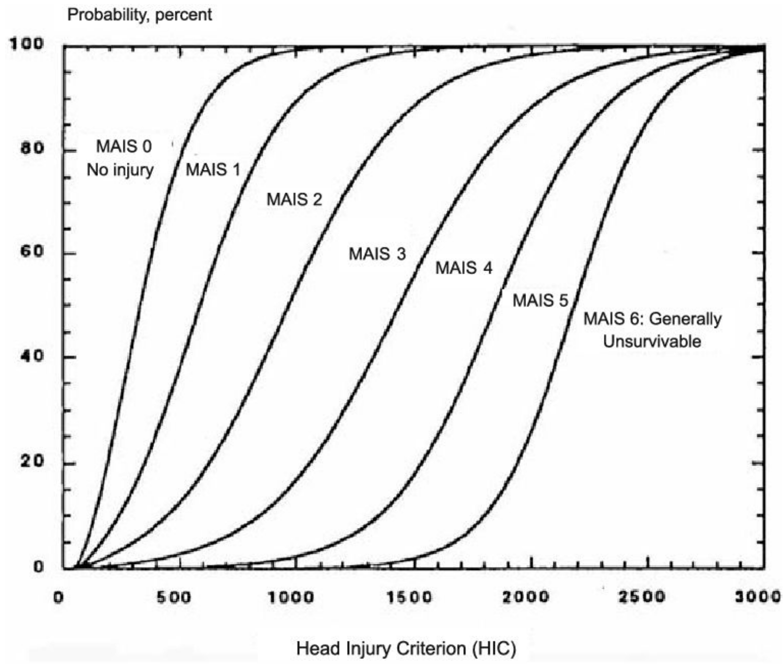
6 http://www.sciencedirect.com/science/article/pii/S0001457507002175?via%3Dihub. Accessed october 10th, 2017.

7 http://www.iihs.org/iihs/ratings/technical-information/technical-protocols. Accessed november 28th, 2017.



Source: Biomechanical and scaling bases for frontal and side impact injury assessment reference values [8]

Probability of head injuries of different severities for given HIC values:



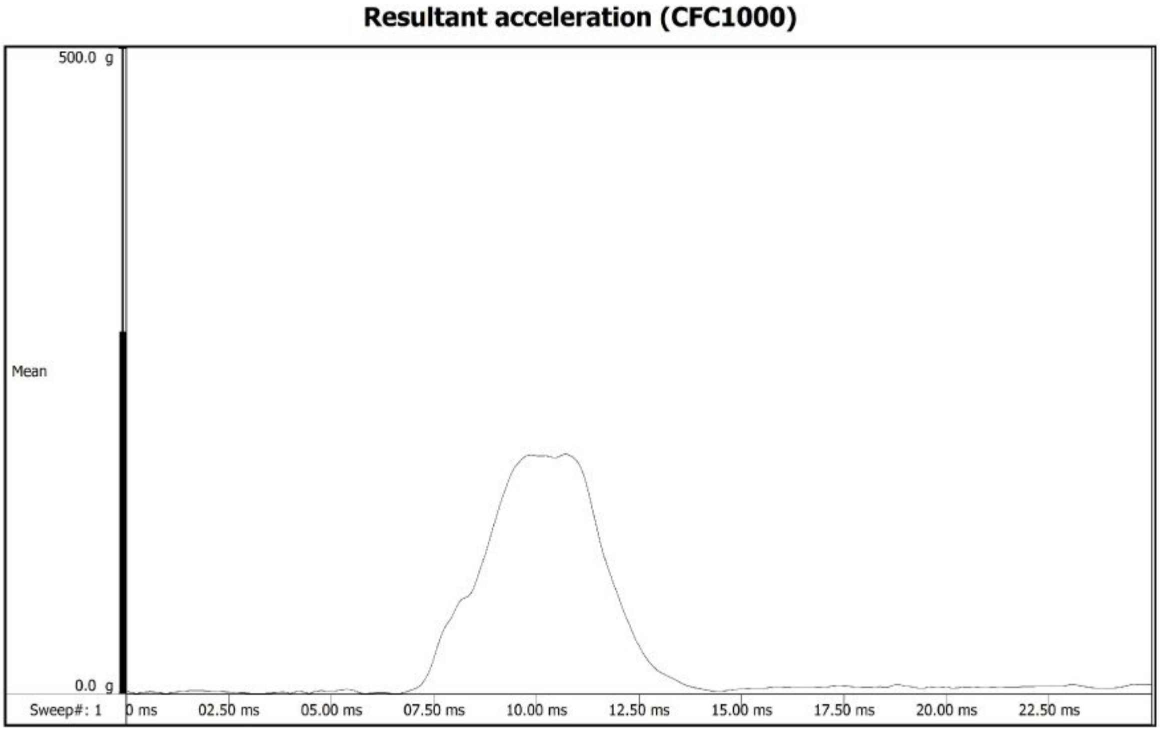
Source: The increasing importance of the biomechanics of impact trauma [9]

8 https://www.researchgate.net/profile/Priya_Prasad6/publication/6701661_Biomechanical_and_scaling_bases_for_frontal_and_side_impact_injury_assessment_reference_values/links/54c7b1000cf238bb7d0b05fe/Biomechanical-and-scaling-bases-for-frontal-and-side-impact-injury-assessment-reference-values.pdf. Accessed november 28th, 2017.

9 http://www.ias.ac.in/article/fulltext/sadh/032/04/0397-0408. Accessed november 28th, 2017.

Real life example

Impact data of a BBB Cycling helmet:



[10]

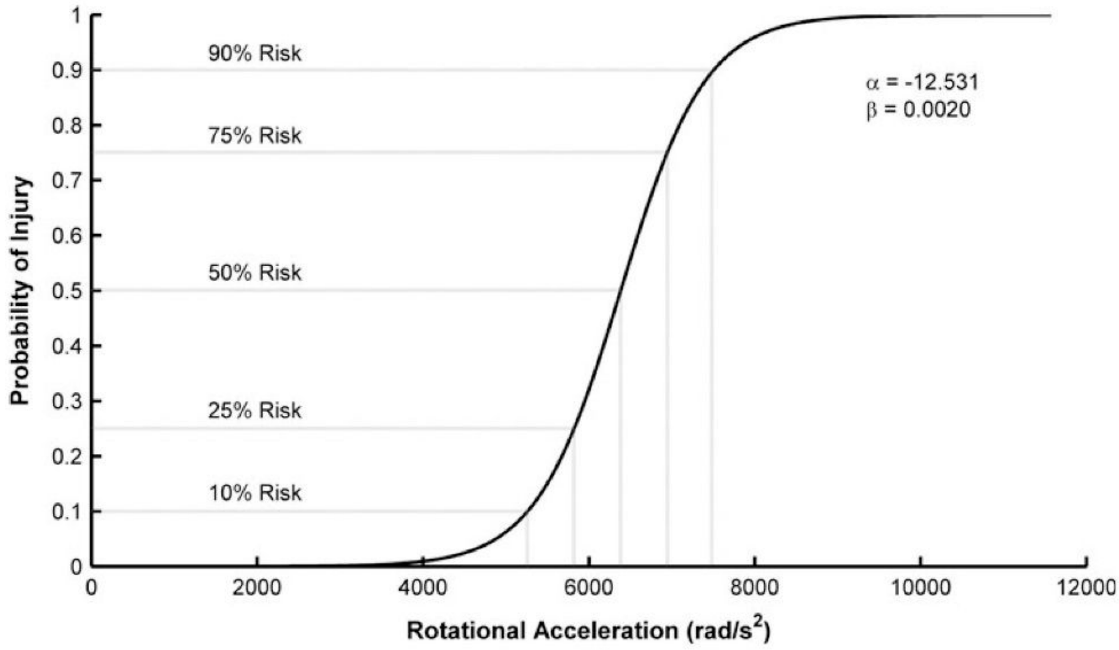
[10] Data retrieved from BBB Cycling, received from their helmet manufacturer. Accessed october 3rd, 2017.

Empirical/practical research

Accelerations

Angular accelerations

Besides linear accelerations, angular accelerations can provide great brain trauma. Injury risk as a function of peak resultant angular acceleration:



Source: Rotational Head Kinematics in Football Impacts: An Injury Risk Function for Concussion [11]

Rotational accelerations and rotational velocities associated with nominal injury risk values:

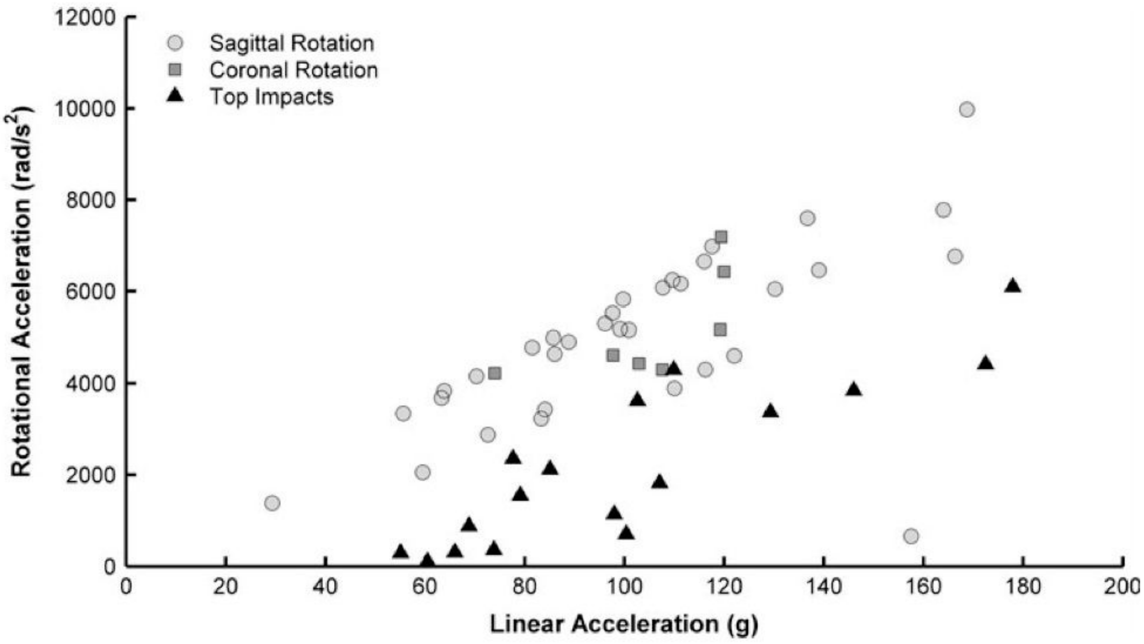
Nominal injury risk	Rotational acceleration (rad/s²)	Rotational velocity (rad/s)
10%	5260	23.3
25%	5821	25.8
50%	6383	28.3
75%	6945	30.8
90%	7483	33.2

Source: Rotational Head Kinematics in Football Impacts: An Injury Risk Function for Concussion [12]

[11] http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1718&context=psychfacpub. Accessed october 4th, 2017.

[12] http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1718&context=psychfacpub. Accessed october 4th, 2017.

Linear and rotational accelerations for concussive impacts grouped by impact:



Source: Rotational Head Kinematics in Football Impacts, An Injury Risk Function for Concussion [13]

"*Rotational kinematics for impacts to the top of the helmet were substantially lower than impacts to the front, back, or sides of the helmet. This supports the notion that both linear and rotational components of acceleration contribute to concussion.*"[14]

Rowson et al.

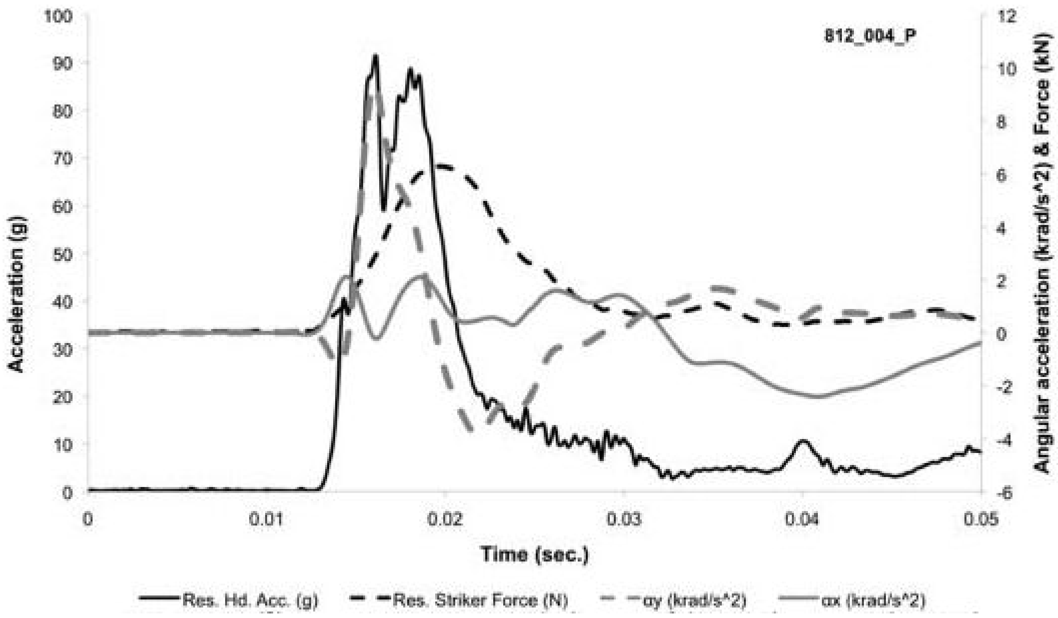
Average concussive linear acceleration and rotational kinematics for impacts:

	Number of concussions	Linear acceleration (g)	Rotational acceleration (rad/s²)	Rotational velocity (rad/s)
Sagittal plane rotation	33	102.7 ± 33.6	4986 ± 1909	22.1 ± 8.5
Coronal plane rotation	7	105.8 ± 16.6	5192 ± 1166	23.0 ± 5.2
Impacts to helmet top	17	100.6 ± 37.1	2192 ± 1790	9.7 ± 7.9

Source: Rotational Head Kinematics in Football Impacts, An Injury Risk Function for Concussion [15]

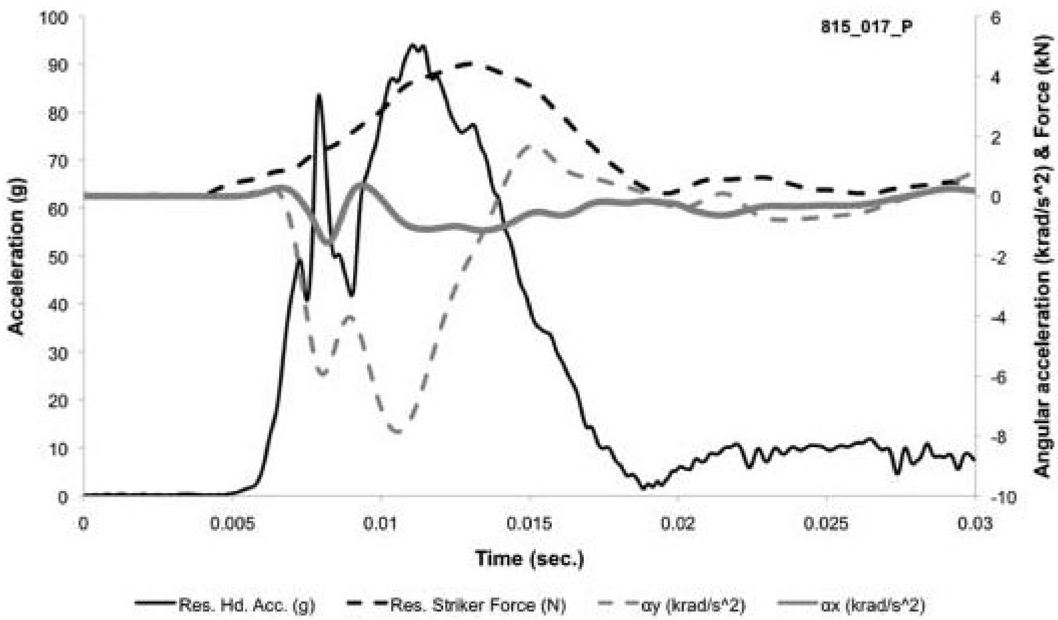
[13] http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1718&context=psychfacpub. Accessed october 4th, 2017.
[14] http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1718&context=psychfacpub. Accessed october 4th, 2017.
[15] http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1718&context=psychfacpub. Accessed october 4th, 2017.

Lateral 1m 15 kph impact with bicycle helmet:



Source: Bicycle Helmets: Head Impact Dynamics in Helmeted and Unhelmeted Oblique Impact Tests [16]

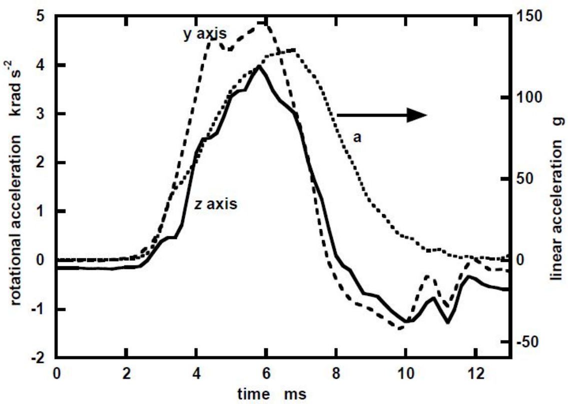
Occipital 1m 15 kph impact with bicycle helmet:

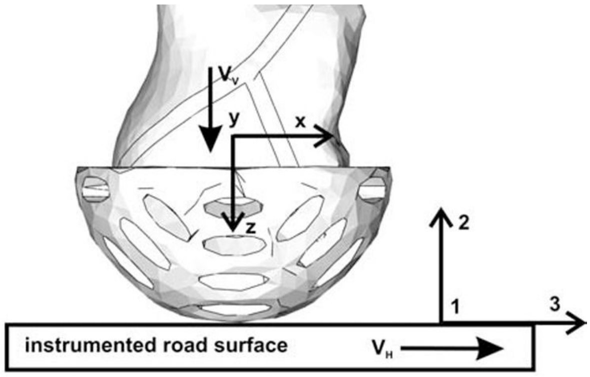


Source: Bicycle Helmets: Head Impact Dynamics in Helmeted and Unhelmeted Oblique Impact Tests [17]

[16] https://www.ncbi.nlm.nih.gov/pubmed/23697898. Accessed october 5th, 2017.
[17] https://www.ncbi.nlm.nih.gov/pubmed/23697898. Accessed october 5th, 2017.

Oblique impact with VN 4.5 m s-1 and VT 3.6 m s-1 on left 70° site of Aventicum helmet resultant linear and rotational:



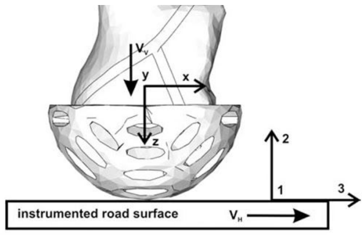


Source: Oblique impact testing of bicycle helmets [18]

Direct impacts with normal velocity 4.5 m s-1 onto a rough aluminium surface:

Helmet	site	Max linear acc. g	Max. F_N kN	Max. F_T kN	Max. z axis rot. acc. krad s^{-2}	Max. y axis rot. acc. krad s^{-2}	Max. liner crush mm	Loading slope N mm^{-1}
Avanti	crown	148	6.5	1.1	3.5	< 1	13	oscill
Avanti	F 60°	125	5.5	1.0	-4.0	-1.8	16	330
Arc	F 60°	129	6.2	1.0	-3.7	-3.5	14	390
Arc	R 70°	138	6.5	0.5	3.2	2.1 *	14	480
Avanti	R 70°	135	6.3	0.3	5.5	1.5 *	13	510

* x axis rotational acceleration

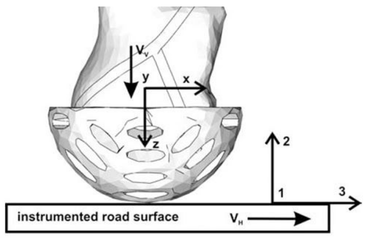


Source: Oblique impact testing of bicycle helmets [19]

Oblique impacts with tangential velocity 3.6 m s-1 and normal velocity 4.5 m s-1:

helmet	Impact site	Max. Accel. G	Max. F_N kN	Max. F_T kN	Max. z axis rot. acc. krad s^{-2}	Max. y axis rot. acc. krad s^{-2}	max. liner crush mm	Loading slope N mm^{-1}	$\frac{F_T}{F_N}$
Aventicum	Left 70°	114	5.2	0.5	3.9	3.6	17	320	0.21
Arc		129	6.0	0.8	4.0	4.9	15	420	
Avanti		121	5.6	0.7	3.7	3.0	16	340	0.25
Indicator		115	5.5	0.7	3.9	2.8	16	340	0.23
Indicator *	right 70°	109	5.1	0.5	-4.3	6.2	19	250	
Specialized	Left 70°	129	5.9	0.7	4.7	5.6	13	490	0.18
Avanti	Front 90°	106	4.8	0.9	< 1.0 & > -1.0		19	230	
Aventicum		105	4.8	0.4	< 1.5 & > -1.5		15	340	0.20
Arc		117	5.5	0.5	< 1.0 & > -1.0		Two stage		0.22

*The impact surface was 100 grade SiC paper



Source: Oblique impact testing of bicycle helmets [20]

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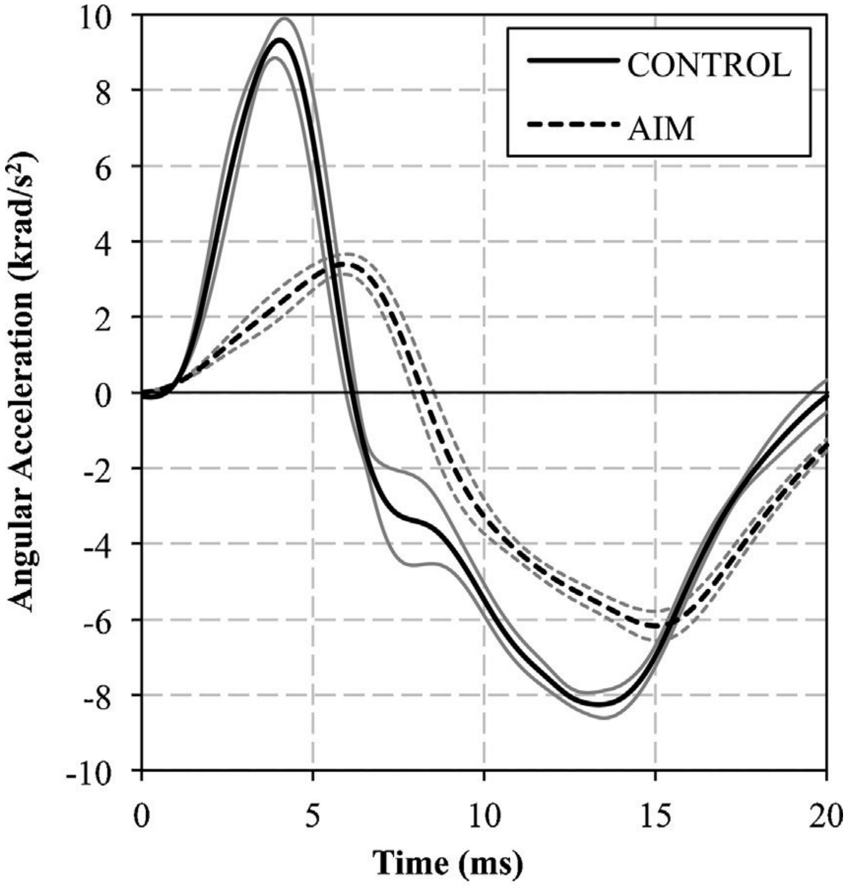
18 http://www.birmingham.ac.uk/Documents/college-eps/metallurgy/perg/Documents/p156obliqueimpacttestingofbikehelmetsfweb150dpi.pdf. Accessed october 6th, 2017.

19 http://www.birmingham.ac.uk/Documents/college-eps/metallurgy/perg/Documents/p156obliqueimpacttestingofbikehelmetsfweb150dpi.pdf. Accessed october 6th, 2017.

20 http://www.birmingham.ac.uk/Documents/college-eps/metallurgy/perg/Documents/p156obliqueimpacttestingofbikehelmetsfweb150dpi.pdf. Accessed october 6th, 2017.

Averaged angular acceleration signals from oblique impact tests:



Source: Angular Impact Mitigation System for Bicycle Helmets to Reduce Head Acceleration and Risk of Traumatic Brain Injury [21]

21 https://www.researchgate.net/publication/239732270_Angular_Impact_Mitigation_System_for_Bicycle_Helmets_to_Reduce_Head_Acceleration_and_Risk_of_Traumatic_Brain_Injury. Accessed october 10th, 2017.

Impact and testing

Scenarios

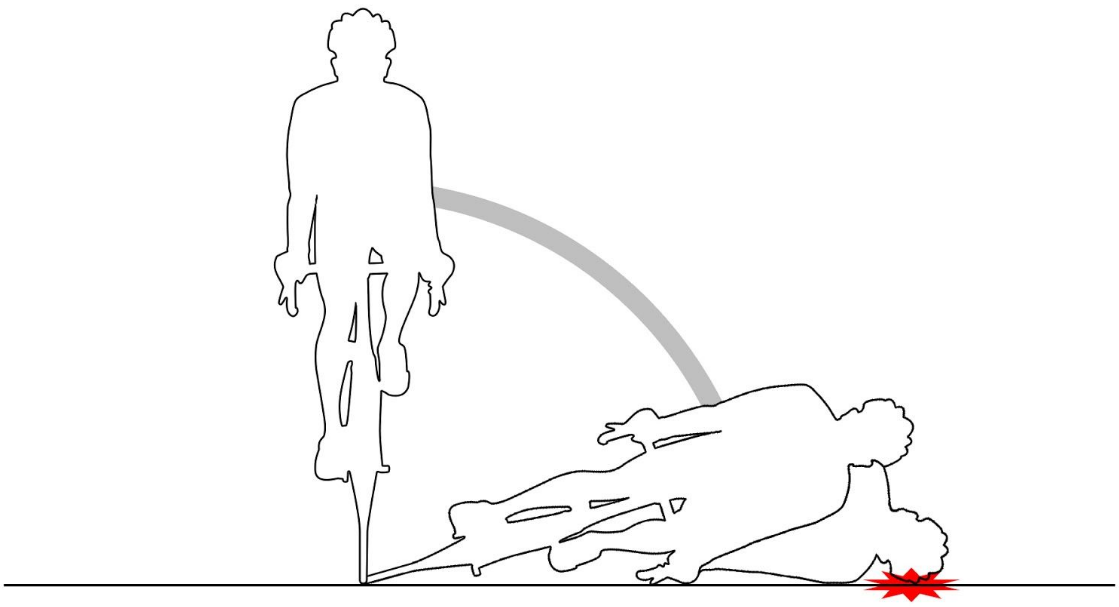
To get a better (visual) sense of what kind of impacts occur, crashes are classified in three different scenarios: high speed impact, low speed impact and oblique impact.

High speed impact

These are impacts that helmets currently protect against and are tested for. Even though most impact scenarios are oblique, helmets are tested only for linear high speed impacts, and therefore need protection against this type of impact.

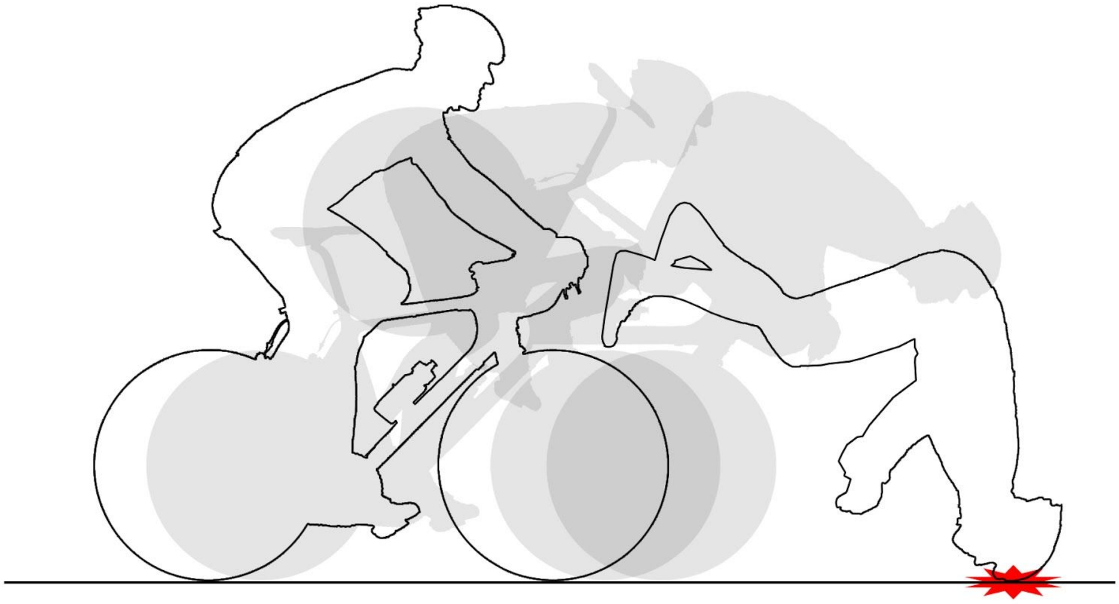
Low speed impact

This is the scenario where a person impacts the ground with a relatively low speed (compared to for example an impact while riding), but still high enough to cause damage. This speed is considered at around 3.0 m s^{-1}, compared to the EN 1078 test speed of 5.42 m s^{-1}.



Oblique impact

The oblique impact is tough to classify, as there is a large amount of crashes possible that can lead to it. In this example the over the bar type crash is used, to illustrate the impact. Because the rider impacts the ground under an angle at speed, both linear and angular accelerations occur.



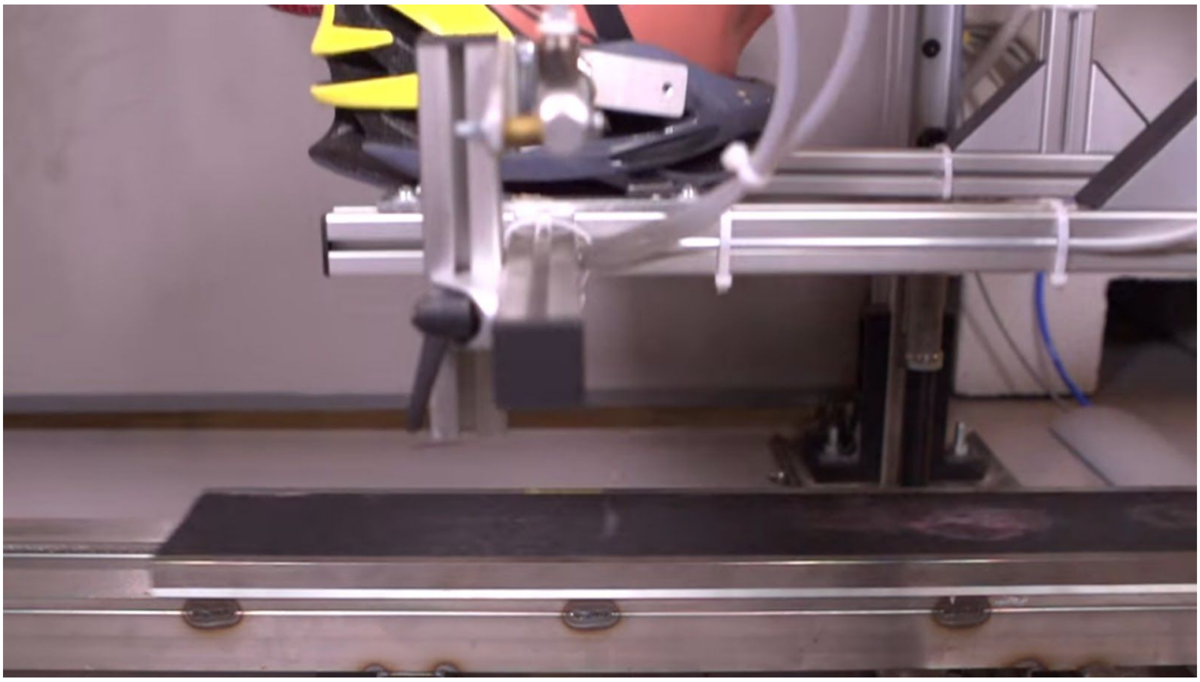
Testing

Giro

The second way is how Giro test their helmets, by using a pendulum. The helmets are placed on a bare headform attached to a weighted torso, which is then swung against a surface which is under an angle.

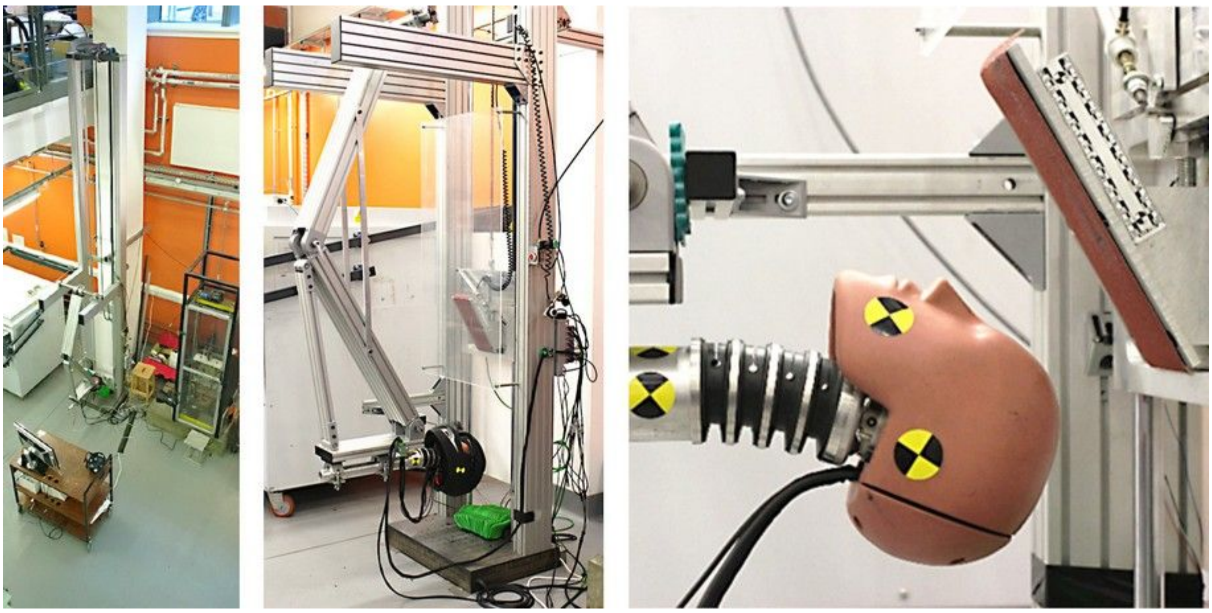
Moving surface

The third way is by dropping the helmet on a surface that moves underneath the helmet, simulating the speed at which the cyclists moves.



Kali Protectives

Kali Protectives have developed their own way of testing oblique impacts, which is similar to MIPS's way. The difference compared to MIPS's way is that the helmet is stationary in Kali's set up, whereas the platform is the part that is moving. Furthermore they make use of a neck form, which is able to move and rotate.

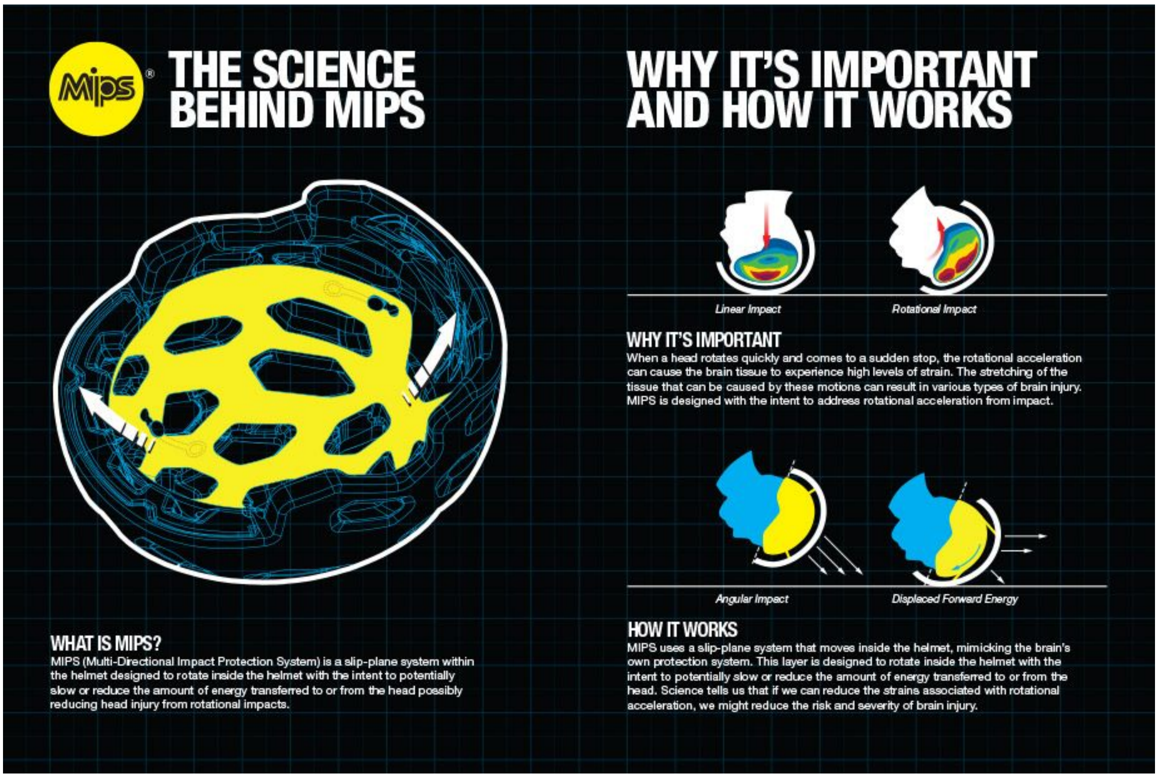


Competitors

Bicycle industry

MIPS

MIPS is a very thin plastic liner that attaches to the inside of a regular helmet. It is hooked at four points to the EPS liner, and is able to slide back and forth, claiming to reduce (part of) the rotational accelerations.



Patent summary

Recently is has been announced that MIPS AB is taking legal action against helmet manufacturer POC[22], stating POC's Spin technology is infringing on MIPS AB's patent(s) (EP15154710NWB1[23]). The full patent POC is supposedly infringing on can be found in appendix 16.10.

To avoid risking the same faith, it is vital to investigate these patents and to steer clear of the main claims. The claims are as follows:

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22 http://www.cyclingweekly.com/news/product-news/mips-take-legal-action-poc-359567. Accessed november 27th, 2017.

23 https://data.epo.org/publication-server/rest/v1.0/publication-dates/20170816/patents/EP2896308NWB1/document.pdf. Accessed november 24th, 2017.

Claims

1. A helmet comprising:

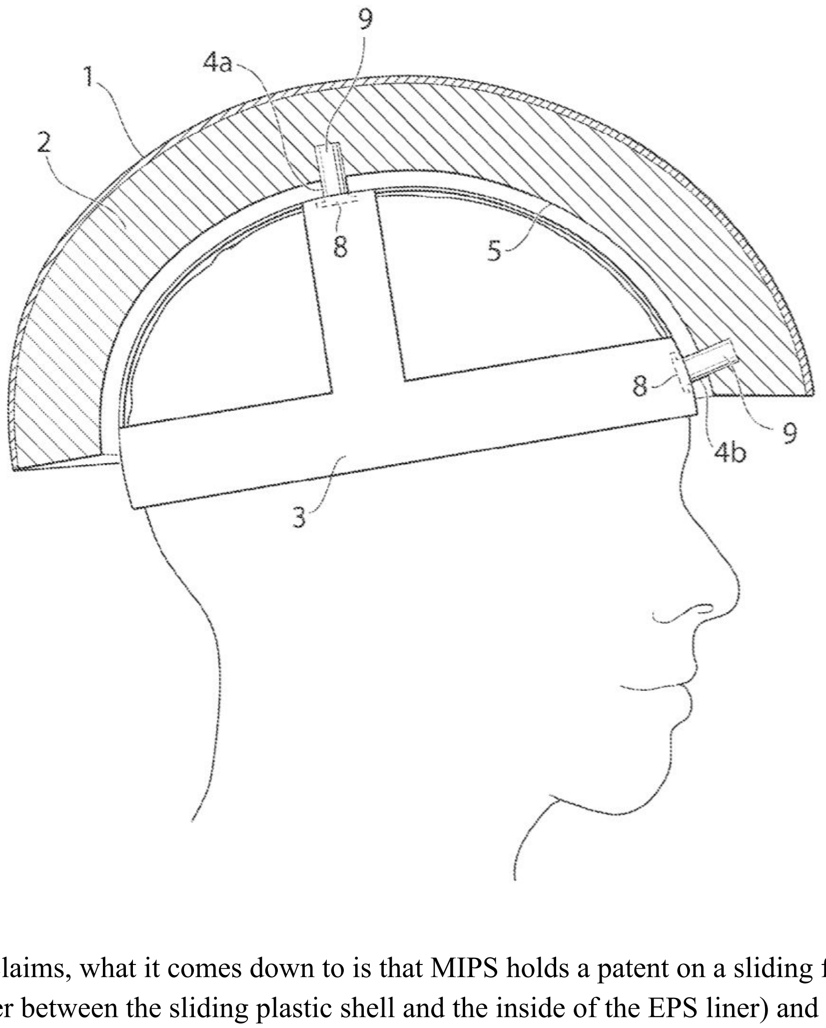
   an energy absorbing layer (2);
   an attachment device (3) provided for attachment of the helmet to a wearer's head;
   characterised by:

   a sliding facilitator (5) configured to allow sliding between the attachment device (3) and the energy absorbing layer (2) during an impact, wherein the sliding facilitator (5) is a low friction material provided on the outside of the attachment device (3) facing the energy absorbing layer (2) or on the inside surface of the energy absorbing layer (2) facing the attachment device (3).

2. The helmet according to claim 1, wherein the low friction material is a waxy polymer, such as PTFE, PFA, FEP, PE and UHMW PE, or a powder material which could be infused with a lubricant.

3. A helmet according to any one of the previous claims, wherein the attachment device (3) comprises tightening means for adjustment of the attachment device (3) to the wearer's head.

4. A helmet according to any one of the preceding claims, wherein the energy absorbing layer (2) is formed from a polymer foam material or a honeycomb structure.



Looking at the claims, what it comes down to is that MIPS holds a patent on a sliding facilitator (the low friction layer between the sliding plastic shell and the inside of the EPS liner) and the attachment device as they called it. Basically a sliding shell part that moves along the surface of the inside of the helmet, in their case attached to the four elastic strings.

POC

Size

POC is able to sell a bigger helmet to consumers, without them becoming unattractive to them. In fact, their size has become somewhat of a trademark, arguably even attracting certain customers to them.

SPIN technology

SPIN tries to absorb angular accelerations with comfort padding. Normally this padding is soley meant as a way to make the fit and comfort of a helmet better, but with the gel inside, POC claims it also has impact absorbing qualities.

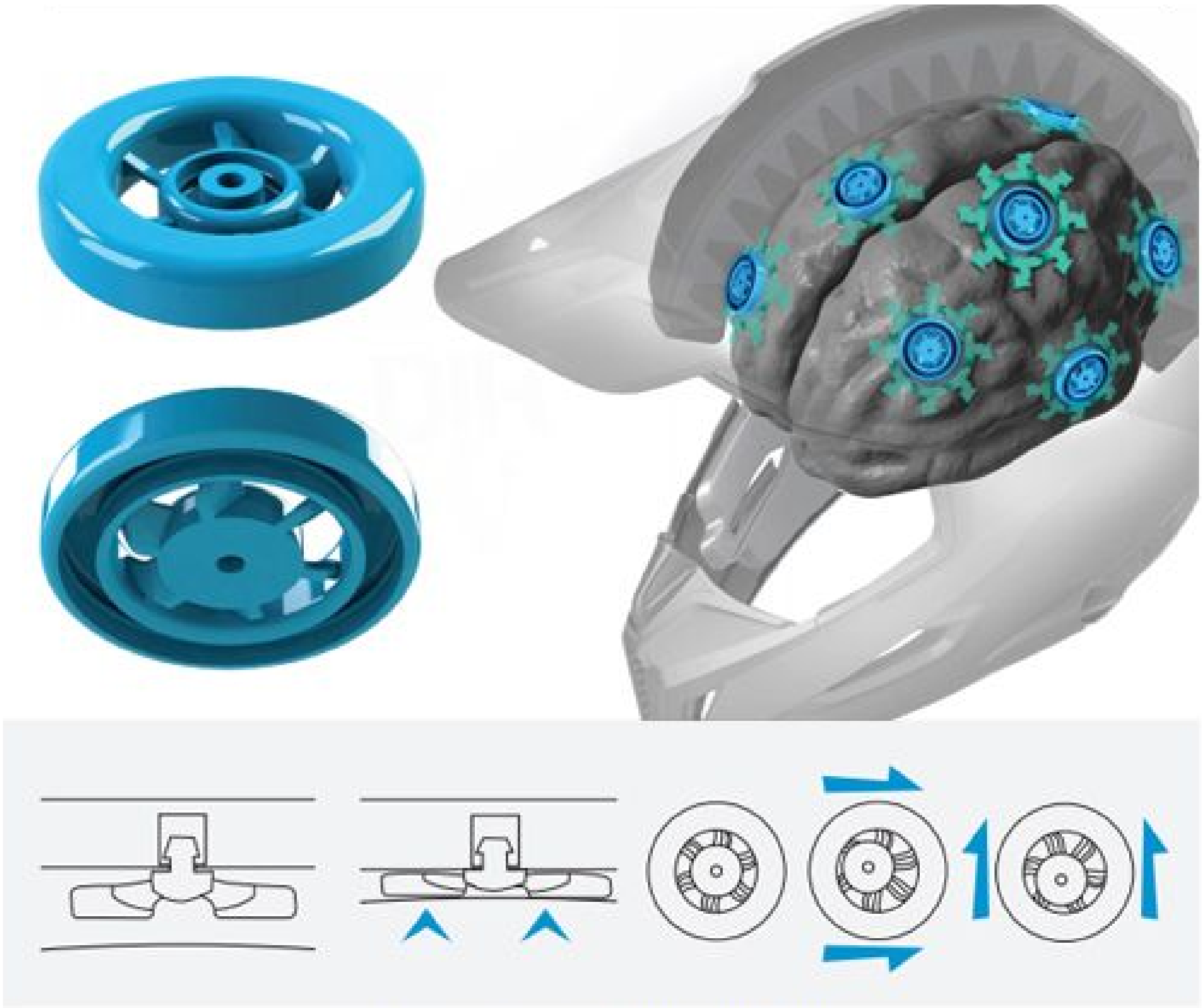
6D

ODS

The ODS system revolves around two EPS liners that are separated from each other by flexible polymer shapes. This configuration allows the two liners to rotate along each other, but also compress due to the polymer shapes in between.

Turbine technology

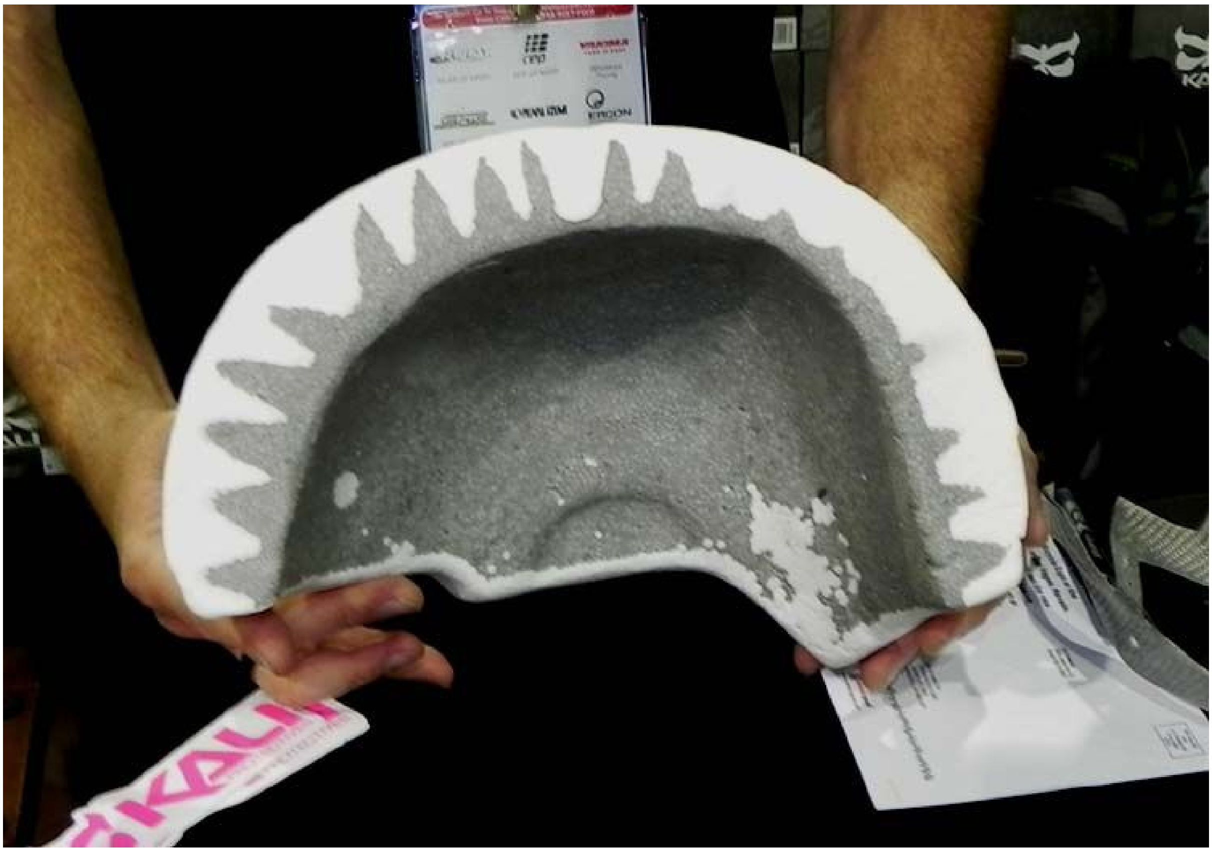
Turbine technology consist of carefully placed cylinders that can be both compresses as well as moved in every direction. They sit directly on the head, allow the helmet to compress slightly during low speed impacts and rotate during oblique impacts.



Kali

Conehead

Conhead is a combination of two different densities of EPS. The idea is that the low density EPS (white) absorbs the impact if it is low speed, but when the impact becomes too large, the high density EPS (gray) kicks in.



Flex liner


EPS
Expanded Polystyrene
EPO
Expanded Polyolefin
EPP
Expanded Polypropylene
BELL
FLEX
Available Instore Now

Analysis conclusions

Angular accelerations

Folksam helmet impact data

Helmet	OBLIQUE IMPACT A (X-AXIS)					OBLIQUE IMPACT B (Y-AXIS)					OBLIQUE IMPACT C (Z-AXIS)				
	T. ACC. [g]	R. ACC. [krad /s2]	R. V [rad/s]	BrIC	Strain [%]	T. ACC. [g]	R. ACC. [krad /s2]	R. V [rad/s]	BrIC	Strain [%]	T. ACC. [g]	R. ACC. [krad /s2]	R. V [rad/s]	BrIC	Strain [%]
Abus Urban-I 2.0	136.4	9.42	33.5	0.96	25.2	131.6	8.88	37.6	1.03	35.5	120.2	7.12	28.3	0.79	29
Bell Event XC MIPS	102.6	5.11	21.3	0.59	14.1	107.4	4.92	27.9	0.73	24.5	101.7	5.69	25.3	0.69	25.3
Bell Super 3 MIPS	102.9	4.9	24.3	0.65	17.1	96.8	5.42	32.2	0.83	25.1	92.2	4.58	23.2	0.62	20.7
Bern Brentwood	138.8	10.02	34	0.99	28.3	135.1	8.7	39.2	1.06	34.3	133.4	8.17	29.5	0.84	31.4
B'TWIN MTB 500	138.1	9.74	24.6	0.78	21.3	143.5	8.42	34.9	0.96	33.5	133.9	8.2	31.9	0.89	31.7
Giro Trinity MIPS	111.1	4.5	21.5	0.58	17.7	134.7	7.13	27.6	0.77	31.4	113.6	5.76	28.1	0.75	28.2
Occano U Mips Inmold HLM	120.5	6.49	24.7	0.7	16.2	121	6.35	34.5	0.9	26.9	107.4	5.89	27.5	0.74	24
Specialized Ambush	119.7	8	28.5	0.82	20.9	109.8	6.6	34.8	0.92	27.9	103	6.84	29.9	0.82	27.5
Specialized Prevail II	113	8.25	30.7	0.87	18.5	85	5.37	35.8	0.91	27.6	87.8	4.92	28.8	0.74	24.2
Spectra Urbana Ev1 MIPS	120.6	4.69	17.2	0.49	13.2	130.4	7.16	24.5	0.71	30	127.1	5.32	20.2	0.57	25.8
Tec Umbra Ev1 MIPS	113.8	6.44	25.3	0.64	21.7	130.3	7.73	29.4	0.83	30.9	111.8	5.78	20.8	0.59	24.7
Medel	119.8	7.05	26	0.73	19.5	120.5	6.97	32.6	0.88	29.8	112	6.21	26.7	0.73	26.6
Median	119.7	6.49	24.7	0.7	18.5	130.3	7.13	34.5	0.9	30	111.8	5.78	28.1	0.74	25.8

Low speed impact testing

Low speed impact testing data

Data provided by one of BBB Cycling's helmet manufacturers.

test setup	CPSC device		impact positions:
procedure for conditioned samples:	1	take samples out of conditioning chamber	top
	2 – to be discussed	do as many tests as you can **in 5 min**	
	3	Put sample back in conditioning chamber and condition it according to the	
	4	after full reconditioning, go	

actions to take according to the values:				
under	199			continue testing
between	200	–	249	continue testing
between	250	–	274	continue testing
above	275			stop testing

		drop height [m]	speed [m/s]	sample #	max. G value [g] #3	#4	#5	#6	#7	#8	#9	#10	LAST: STANDARD TEST	Proposal for # of tests	
Vivo, m, CE	ambien	0.8	4.0	p-5	210	220	234	250	255	258			259	2	max 200
		0.8	4.0	p-6									267		
		1.2	4.9	p-7	258	284							294	1	max 200
		1.2	4.9	p-8	259	278	294	321					273		
		1.2	4.9	p-9	255	272	295	310					269		
		1.5	5.4	p-10										1	
	cold	0.2	2.0	p-11											
		0.4	2.8	p-12											
		0.8	4.0	p-13											
		1.2	4.9	p-14			do not test these impacts								
		1.5	5.4	p-15			with black background!								
	hot	0.2	2.0	p-16											
		0.4	2.8	p-17											
		0.8	4.0	p-18											
		1.2	4.9	p-19			do not test these impacts								
		1.5	5.4	p-20											

Assignment

Initial design brief

Graduation Assignment | Tijs Marcus
Company | BBBCycling
University | Delft University of Technology, Industrial Design Engineering

Project Subject: Bicycle helmets

Project Title: "Improve bicycle helmet safety by developing a system that reduces forces on the brains caused by low speed and oblique impacts"

Research

Head injuries

In the past 10 years science gained a lot of insights on this field and especially the last few years it gets more attention. Not only in cycling but also in other hazardous sports like American football and rugby, where head injuries are common. Understanding what happens to the human brain as a result of an impact is the basis knowledge for this project.
Literature research – Interview Neurologist - ..

Crash tests helmets

There is a lot information on how helmets behave on impact because of the mandatory helmet impact tests. A research into available data will give a better understanding where helmets need to be improved. We can provide all out test data and we can arrange some additional testing with our helmets at our manufacturer.
Analysis crash test data - Impact tests – Regulations - ..

Production techniques

Basic understanding how helmets are produced is necessary to gain insight for what are the possibilities and what are the limitations of current production technologies.
Interview product designers – Materials - ..

Helmet concepts and existing products

There are some existing solutions like MIPS, and Kali bumperfit, 6D ODS. And also concepts for other sports helmets. What can we learn from these systems and what can we do better.
Market Research – Available test/research

Design challenges

Implementation

Developing a system that can be implemented in current helmets is the main design challenge. With minimal effort/investments/mold modifications it must be implemented in existing helmets and with minimal impact on the headform shape and size, ventilation properties and

Producibility:

The system must be producible and also the combination of helmet + system needs to be possible for production.

Costs:

The costs are important and are highly dependent of the design. The system must be produced and implemented at relatively low cost otherwise it would effect the helmet price to much

Goal

At the end of this graduation project we expect a design that:

- Meets the requirements of implementation, producibility, etc.
- Theoretically will work. Thus improves test values at low speed impact and rotational acceleration.
- Is made into a testable prototype.

The testing and final optimization of the design is outside the scope of this project.

List of Requirements:

Functionality

- Improve functionality at Low speed impacts
    - o Reduced G-values measured in the head on drop tests compared with normal helmets significantly.
- Improve functionality at Oblique impacts (rotational accelerations)
    - o Reduced accelerations measured on the head compared with normal helmets significantly.
- Ventilation
    - o The ventilation of the helmet may not, or only very minimal, be compromised by the system.
- Fitting
    - o The headform, both shape and size may not or only very limited be compromised by the design.

Applicability

- Reverse engineering
    - o The system can be implemented in existing helmets. The aloud modification on these helmets is making a new inner EPS mold.

Costs

- Unit price
    - o The system may add max. €30,-?? to the retail price.
- Tooling
    - o Tooling cost must …..

Weight

- It must be possible to develop a helmet with this system <300 grams.
- Preferably the weight of the system is similar or even less than the weight of the EPS it can replace.

Adapted design brief

It has been shown that current helmets do not offer adequate and all round protection in case of a crash, mainly due to the way helmets are tested. Testing helmets at high speed linear accelerations causes companies to optimize their designs for this specific type of impact, and this impact alone. The lack of low speed and oblique impact protection however has called for a safer helmet; one that offers protection against angular accelerations, and low speed linear accelerations, on top of the currently available high speed linear acceleration protection.

Assignment

Design a system that can be implemented in current helmets than increases the protection against consequences of low speed and oblique impacts. Low speed impact protection leading to linear accelerations should focus at the sides of the helmet, whereas oblique impacts causing angular accelerations should work in both the front-to-back direction, as well as the side-to-side direction. Helmets with said system should still pass the EN 1078 norm and should not negatively influence the high speed protection already provided by current helmets.

Prototyping and validation

Manufacturing of a prototype of the design proposal (if possible) will be done by BBB Cycling's manufacturer to ensure a realistic prediction of an actual production model. Validation of oblique impact protection should be done with the MIPS test setup, since this is currently the main way to test angular accelerations reliably. Another reason is so results can be compared to competitors also using this test setup.

Validation of low speed impact protection can be done with the regular straight drop test, measuring linear accelerations (albeit at lower speeds than the EN 1078 norm).

Press release

Why a press release

Recently companies have been using internal ‘fake’ press releases at the start of their product development process. By making these press releases, you start thinking about the core problem, how it should be solved and other questions. Therefore to end the analysis phase, a press release of TOTAL IMPACT, the system that addresses the problem at hand, is presented.

TOTAL IMPACT press release

TOTAL IMPACT™
Protect your brain better against a broader set of bicycle crash impact types.

Total Impact™ is a system that increases the protection of current bicycle helmets, by adding impact protection on top of the protection already provided by modern helmets. It is a system that has a double functionality: absorbing low speed impacts that current helmets are not designed for, and reducing rotation of the head, a new phenomenon that is believed to cause great injury.

Current helmets only offer protection against one specific type of impact. In reality, there are multiple other types of impacts that can result in serious brain damage. Because governmental regulations only focus on this one type of impact, modern helmets are optimized merely pass these test. This means that although helmets are sold as ‘safe’, they’re not as safe as they could and should be.

Total Impact™ aims to solve this problem by providing a way to better protect cyclists against a variety of impacts.

“BBB has proven that they care more about the people using their products than the absolute minimum that is required. By offering a helmet that on top of the mandatory impact tests also provides greater protection against other types of impacts, we have taken a big step toward making cycling safer.”

- Product designer at BBB

Helmets with Total Impact™ integrated function exactly like normal helmets do. The technology is inside the helmet, without you having to do anything. So there is nothing stopping you from using it like you are using your current helmet. Easy!

“I’ve been following the latest developments regarding bicycle helmet safety, but wasn’t really impressed with what’s on offer so far. This helmet not only looks great, but it also seems a lot safer than others. Which is why you wear a helmet in the first place!”

- User

Watch the videos on the BBB Cycling YouTube channel about how it works or visit your local dealer for extra information!

Q&A

Q: Why does this helmet have the same safety rating as other helmets?
A: Currently the rules on helmet safety are a little bit one dimensional: only linear impact forces are measured. With TOTAL IMPACT, we tried to also account for angular forces that can occur during an impact. Impact standards used today don't account for these, yet.

Q: Is this helmet safer than other helmets?
A: In the eyes of the law, all helmets sold are 'equally safe', because they have the same required safety certification. However, we have worked hard to go above and beyond this standard requirement with the TOTAL IMPACT system, researching and developing ways to try to reduce the chance of injury even further.

Q: Why is this helmet more expensive than other, equally safe helmets?
A: The TOTAL IMPACT system aims to add another layer of safety to existing helmets, both figuratively as well as literally, creating the best helmet we have ever made. This is reflected in the price, as we think it is of higher quality than other helmets.

Q: How much bigger/heavier is the helmet than other helmets?
A: Obviously the helmet the TOTAL IMPACT system is a little bit heavier and also slightly thicker, but we feel this is worth the benefits.

Q: I've heard of MIPS helmets. Which system is better?
A: Our testing shows that MIPS reduces rotational forces by around 10%. Helmets with the TOTAL IMPACT system we are able to achieve a reduction of 15%, in some cases even up to 20%, compared to helmets without the system.

4. Synthesis

Starting point

AED project summary

Ch. 01

EXECUTIVE SUMMARY

1.1 Problem & mission

Traditional bicycle helmets are designed to protect against the consequences of a high speed impact crash. However, other types of impacts also occur, namely so called low speed and rotational acceleration impacts. Unfortunately current helmets are not accounting for these types of impacts, making the modern helmet unsafe for these situations. Thus, the mission for this project is to design such a helmet for road cyclists, which improves safety by protecting against high speed, low speed and rotational acceleration impacts. Also, a larger part of the head should be covered to protect a greater area of the head. All this should be achieved, while the helmet should still remain well ventilated, comfortable, attractive and feasible in terms of manufacturability and profit.

1.2. Approach

To succeed in such a mission, the project is divided into six challenges. When these are solved, an answer is found to the main problem.

▲ Symbols per challenge

1.2.1. Safety

Safety is mainly improved by adding another layer to the already existing road cycling helmet. For this project, it is called the Wonder Liner. After testing different materials and structures, the best outcome is a Marilon® EVA foam (Immotus B.V.) (more information on the material is found in appendix 1.0), cut into a series of cylindrical structures (height 10 [mm], diameter 8 [mm]). Drop tests show that implementing this Wonder Liner significantly improves the safety of the helmet.`

1.2.2. Extra head coverage

Extra head coverage is realized by adding coverage at the occipital area and pterion. Being aware of the positioned geometry, the aesthetics and usage of the retention system has been taken into account. Although the extra head coverage makes the helmet more 'bulky', clever aesthetic lines distract the eye from these areas and strategically placed holes enable easy retention system fastening.

1.2.3. Ventilation

A compromise is sought between ventilation properties of the BBB Tithon and Icarus helmets, and the design of the Daedalus has been adjusted likewise. Ventilation tests have been done and results are somewhat disappointing. However, it has to be noticed that the materials used and the prototype quality of the Daedalus testing prototype are not similar to those of the real Tithon and Icarus helmets, and thus a fair comparison cannot be made. However, it has given a benchmark

▲ **Figure 1**
Racing cyclists

1.2.4. Comfort

The addition of extra materials to the occipital area and pterion might block sight or the helmet might feel heavy due to the added Wonder Liner. The hypothesis for the outcome of the comfort testing with the Daedalus prototype on a real road bike, is that the Daedalus design does not negatively compromise on these areas. It will be slightly heavier and bigger but not perceived as a negative emotion, compared to the Tithon and Icarus helmets.

1.2.5. Aesthetics

In the end, users should want to buy the helmet. From the basis of the Icarus helmet, a new design is created. This includes the extra head coverage, new ventilation and the added Wonder Liner. Aesthetic lines and colors are strategically chosen to draw away attention to the bulky areas of the helmet. A 'faced' and modern look is chosen, making the helmet a unikum in its kind but still recognizable as a cycling helmet.

1.2.6. Feasibility

The helmet will be placed in the A-brand helmet sector, and thus it will have a similar pricing. In the end, it is questionable if the investment costs and expected market success will make the helmet a profitable one.
Due to the additional layers (EVA structure layer and inner PC layer), the cost would be increased. While the new implemented material itself are not extremely advanced and superior; the functionality of the absorption is decided by structure dimensions and placement. In addition, the structures are designed based on producibility and manufacturability. Therefore no complex and advanced manufacture methods are needed to make these structures. The cost increase in material and their manufacture process would not be dominant.

Presumably, the cost increase might mainly appear on the assembly process. To fix the structure into certain positions and connection of different layers in different material would need too much manual work, or a new-build assembly line.

1.3. Conclusion

After 20 weeks, the AED group CHI has researched, designed and delivered a new road cyclist helmet that is more safe and is feasible, cost wise speaking. Both the added Wonder Liner and the extra head coverage are unique selling points in this regard. This liner accounts for low speed and rotational acceleration impacts, and differs itself from the rest of the road cyclist helmets. From scratch, the group has been able to realize a new road cyclist helmet, that could become the new standard in the field, on every aspect that has been researched.