Bicycle helmet test
2015
by Folksam

Folksam

This is why we test bicycle helmets

Every day three cyclists in Sweden sustain head injuries, which are some of the most severe injuries a cyclist can experience. Data from real-life crashes show that bicycle helmets are very effective to reduce injuries. Two out of three head injuries from bicycle accidents could have been avoided if the cyclist had worn a helmet.

We are committed to what is important to our customers and to you. When we test and recommend safe bicycle helmets we believe this can help to make your life safer and we provide tips on how to prevent injury.

How does a bicycle helmet obtain our good choice label?

Helmets which obtain the best overall results in the bicycle helmet test by Folksam are given our good choice label. The good choice symbol may only be used by products which have obtained the best scores in one of our tests.

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Summary

Folksam has tested 18 bicycle helmets on the Swedish market for teenagers and adults. All helmets included in the test have previously been tested and approved according to the CE standard, which means that the energy absorption of the helmets has been tested with a perpendicular impact to the helmet. This does not fully reflect the scenario in a bicycle crash. In a single-bicycle crash or in collision with a motor vehicle, the impact to the head will be oblique towards the ground or the car. The intention was to simulate this in the tests since it is known that angular acceleration is the dominating cause of brain injuries.

In total four separate tests were conducted: a test to evaluate the shock absorption of the helmets and three tests to evaluate the helmets' protective capacity in cycle crashes with varying impact angles; an oblique impact to the upper part of the helmet, an oblique impact against the side of the helmet and an oblique to the rear part of the helmet. Computer simulations were also conducted for all oblique impact directions to evaluate the risk of injury. In these simulations an FE model of the brain developed by researchers at the Royal Institute of Technology (KTH) was used. Since the FE model is based on the brain's tolerance levels, the simulation output was used to compare and rate the helmets.

In total five helmets obtained the Folksam good choice label: Bell Stoker MIPS, Giro Savant MIPS, Hövding 2.0, POC Octal AVIP MIPS and Spectra Urbana MIPS. The Hövding 2.0 head protector, which protects the head with an airbag in the event of an accident, showed the overall best result. The conventional bicycle helmets Bell Stoker MIPS, Giro Savant MIPS, POC Octal AVIP MIPS and Spectra Urbana MIPS, which are all fitted with MIPS (Multi-directional Impact Protection System), also showed good test results. In general helmets fitted with the MIPS reduced the rotational energy better than other conventional helmets without the system. However, there is no guarantee that a helmet with the MIPS is good. Two helmets, Giro Sutton MIPS and Scott Stego MIPS, showed lower protection than the average good helmet even though these were equipped with rotational protection.

Folksam's tests show that bicycle helmets need to absorb energy more effectively. The helmet safety standard of today is no guarantee for a high helmet safety level. Our study shows that a conventional helmet that meets today´s standards does not prevent from getting a concussion in case of an accident. The EU helmet standard limits the acceleration to the head to be under 250g. This level corresponds to a 40 % risk of skull fractures. Based on the shock absorption test, all helmets except from five (Abus S-Force Peak Official Vasalopp-helmet, Carrera Foldable, Giro Sutton MIPS, Occano Urban Helmet and Yakkay) showed a linear acceleration lower than 180 g, which corresponds to a 5 % risk of skull fractures. The Hövding 2.0 helmet performed almost three times better than all the other conventional helmets (48 g vs. other helmets that were around 175 g). The most important is that this helmet also reduced the rotational energy to the head better than conventional helmets. In the oblique impact tests helmets equipped with MIPS preformed better than helmets without the system. The difference was higher in the oblique impact with contact point on the upper part of the helmet (y-rotation) and contact point on the side of the helmet (x-rotation) than in the oblique impact with contact point on the back side of the helmet (z-rotation). All helmets need to more effectively reduce rotational energy.

The greatest difference between a good and a bad helmet is how well it protects the head during oblique impacts. To prevent helmets from being sold without rotational protection the legal requirements should also include such oblique impacts. Since 2012 Folksam has conducted helmet

tests to help consumers to choose a safe helmet and to encourage helmet manufacturers to design safer helmets. The proportion of helmets with rotational protection has increased significantly during this period, which shows that consumer tests are important in driving development forwards.

Background

Every day three cyclists in Sweden sustain head injuries, which are some of the most severe injuries a cyclist can experience[1]. Over 70 percent of the head injuries occur in single-bicycle crashes. However, generally head injuries are more severe in crashes involving motor vehicles than in single bicycle crashes. Data from real-life crashes show that bicycle helmets are very effective in reducing head injuries. Two out of three head injuries from bicycle accidents could have been avoided if the bicyclist had worn a helmet (Rizzi et al, 2013). In the event of more severe brain injuries the protective effect is even higher (Thompson et al, 2009). Real-life data indicate that the most common impacts to the head are impacts against the temple or the back of the head (Björnstig et al, 1992). Oblique impacts result in rotation of the head, to which the brain is most sensitive to (Margulies and Thibault, 1992).

In the current certification tests in which the helmet is dropped straight onto a flat anvil and onto a kerbstone anvil only the energy absorption in a perpendicular impact is evaluated. An approved helmet should comply with the 250 g limit (Swedish standard SS-A 1078, 1997). The acceleration which the head form is exposed to must therefore be less than 250 g, a limit that corresponds to a 40% risk of a skull fracture. According to Zhang et al (2004) concussion with or without loss of consciousness can occur at approximately 60-100 g. Researchers (Marguelies and Thibault, 1992, Kleiven, 2007) have also shown that the brain is much more sensitive to rotational movement than to linear forces. The risk of concussion or more serious injuries such as Diffuse Axonal Injury (DAI), bleeding or contusion are caused by the rotational acceleration and/or the rotational velocity (Gennarelli et al, 1987, Holbourn, 1943, Löwenhielm, 1975). Despite this, translational acceleration is widely used today to optimise helmets and safety systems in the automotive industry.

Objective

Folksam’s bicycle helmet test is intended to evaluate the energy absorption of current helmets both regarding perpendicular impacts and oblique impacts against the head in order to cover different injury-generating accident scenarios better than the legal requirements. This is to provide consumers and shop owners with better data when choosing bicycle helmets. In addition, we hope to be able to encourage helmet manufacturers to make better helmets as a result of Folksam’s tests.

Method

A total of 18 bicycle helmets have been included in the test; Table 1. When choosing helmets, we looked at the range available in bicycle/sports shops and web shops. This was in order to choose the helmets most readily available on the Swedish market, but also to choose models with special protective features.

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[1] Based on data from STRADA [Swedish Traffic Accident Data Acquisition] which contains hospital records of road crashes in Sweden, year 2014

Table 1. *Helmets included in the study*

Cycle helmets 2015	Type of helmet	Price (SEK)
Abus S-Force Peak Official Vasaloppet Helmet	Classic	700-900
Bell Stoker MIPS*	MTB	1000-1400
Biltema cycle helmet	Classic	100
Carrera Foldable	Classic	700-900
Casco Active-TC	Classic	700
Giro Savant MIPS*	Classic	1000-1300
Giro Sutton MIPS*	Skate	1000
Hövding 2.0	Collar	2700
Limar Ultralight	Classic	1200-1500
Melon Urban Active	Skate	600
Occano U MIPS Helmet	Classic	500
Occano Urban Helmet	Classic	350
POC Octal	Classic	2700
POC Octal AVIP MIPS*	Classic	3500
Scott Stego MIPS*	MTB	1700
Smith Forefront**	MTB	2000
Spectra Urbana MIPS*	Classic	650
YAKKAY with and without cover	Skate	600-700 + 400 cover

** The helmet is fitted with a MIPS system, an extra protection aimed at lowering rotational acceleration in the event of an oblique impact*

*** Smith Forefront is partly made of material with a honeycomb structure.*

Seven helmets, *Bell Stoker with MIPS, Giro Savant MIPS, Giro Sutton MIPS, Occano U MIPS Helmet, POC Octal AVIP MIPS, Scott Stego MIPS and Spectra Urbana MIPS, were equipped* a Multi-directional Impact Protection System (MIPS), which is intended to reduce the rotational acceleration of the brain caused by oblique head impacts. The protection is based on a low friction shell on the inside of the helmet that can slide on the inside of the helmet. The Smith Forefront helmet was selected because it is claimed to be extremely light and impact resistant since the material in the helmet is partly made up of a honeycomb structure[2]. The Yakkay helmet was selected since it is sold with a cover as additional equipment. The intention was to evaluate its effect on the test results. The skate helmet Melon Urban Active was selected because it was of a much lighter construction (up to 30% lighter) in comparison with other skate helmets, for which it was awarded the international bicycle industry prize Eurobike Award 2013. Skate helmets have generally performed worse in Folksam's previous helmet tests (Stigson et al, 2012, Stigson et al, 2013). Since the outer shell of Melon Urban Active is thinner the hypothesis was that it should therefore absorb more impact energy than the skate helmets tested previously. The Limar Ultralight helmet was selected since it was marketed as the world's lightest bicycle helmet. Folksam has already tested the Hövding head protector previously (Stigson et al, 2012).

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[2] Previous studies have shown that the honeycomb structure reduces the translational acceleration by 14% and the rotational acceleration by 34% (Hansen et al 2013)

At that time it was only possible to test the Hövding's energy absorption in the perpendicular impact procedure. In addition, the head protector is available in a new updated version, Hövding 2.0. In this year's test Folksam along with SP developed a test method in which it was also possible to test Hövding 2.0 in oblique impacts. All helmets in the test are CE marked in accordance with the European safety standard (Swedish standard SS-EN 1078, 1997) or Directive 89/686/EEC[3]. Helmets included in the test fall within a price range of SEK 100 to SEK 3500.

The four impact tests are designed to compare the potential of the helmets ability to absorb impact energy and to evaluate the protective effect of the helmets in bicycle crashes. The method used in Folksam helmet testing 2015 differs from our previous helmet tests (Stigson et al. 2012; Stigson et al. 2013; Stigson et al. 2014; Stigson et al. 2014). The test set-up has been modified to correlate with the proposal from some of the members in the CEN Working groups 11 "Rotational test methods" (CEN/TC158-WG11 2014; Willinger et al. 2014). In total four separate tests were conducted, Table 2 and Figure 1. The acceleration pulses measured from these tests have then been applied to a validated data-simulated model of the human brain (Kleiven, 2003, Kleiven, 2006b, Kleiven, 2007) to compare the helmets.

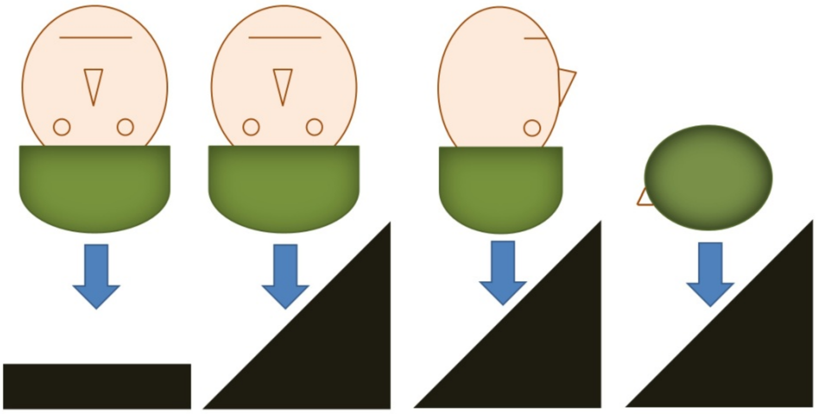

Figure 1. *Test from the left: 1) Shock Absorption 2) oblique impact to the side of the helmet 3) oblique impact to the upper part of the helmet 4) oblique impact to the rear part of the helmet*

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[3] CE marking covers some thirty product areas such as toys and personal protective equipment. In order for a product to be approved, the product needs to comply with certain basic requirements. Either the product is tested according to one or more harmonised standards such as EN1078, which applies to bicycle helmets or the company engages a Notified Body (e.g. SP), which has to evaluate the product in relation to the basic requirements for CE marking. Then accreditation of independent technical experts takes place at an authority. In Sweden accreditation is carried out by SWEDAC (Swedish Board for Accreditation and Conformity Assessment). The test method for cycle helmets is limited in design terms since the current standard (EN 1078) is designed for conventional helmets and is unfortunately not applicable to Hövding since it requires a neck for support during the inflation phase. SP has developed the test method for evaluating the Hövding head protector and this method is accredited by SWEDAC.

Table 2. Included tests

Test	Velocity	Angle	Description
Shock Absorption	5.6 m/s	0°	The helmet was dropped from a height of 1.5 m to a horizontal surface in the same way as in the regulation test of shock absorption.
Oblique impact A. Contact point on the upper part of the helmet.	6 m/s	45°	A test that simulates an actual bicyclist-vehicle-crash or a single bicycle crash. Rotation around the x-axis.
Oblique impact B. Contact point on the side of the helmet.	6.0 m/s	45°	A test that simulates an actual cyclist-vehicle-crash or a single bicycle crash. Rotation around the y-axis.
Oblique impact C. Contact point on the side of the helmet.	6.0 m/s	45°	A test that simulates an actual cyclist-vehicle-crash or a single bicycle crash. Rotation around the z-axis.
Computer simulations	-	-	As input into the FE model, x, y and z rotation and translation acceleration data from the HIII head in the three tests above were used

Shock Absorption

The helmet was dropped from a height of 1.5 m to a horizontal surface according to the European standard (EN1078), which sets a maximum acceleration of 250g, Figure 2. The shock absorption test is the only partial test included in our test that is mandatory by law when testing helmets. The ISO head form was used and the test was performed with an impact speed of 5.42 m/s. The helmets were tested in a temperature of 15°C. The impact test was only performed in a helmet position in which the initial angle of the helmeted head was 0 degrees. The test was performed by SP, which is accredited for testing and certification in accordance with the bicycle helmet standard EN 1078.

Figure 2. *The method used in shock absorption test*

Three Oblique Tests

In three oblique tests the ISO head form was replaced by the Hybrid III 50th Male Dummy head, figure 3-4. The reason was that a Hybrid III 50th male dummy head has much more realistic inertial properties. The helmeted head was dropped against a 45° inclined anvil with a friction similar as asphalt. The impact velocity was 6.0 m/s.

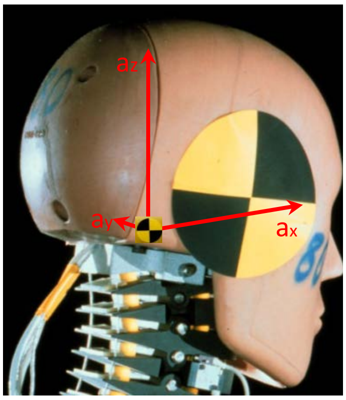


Figure 3. *Translational acceleration*

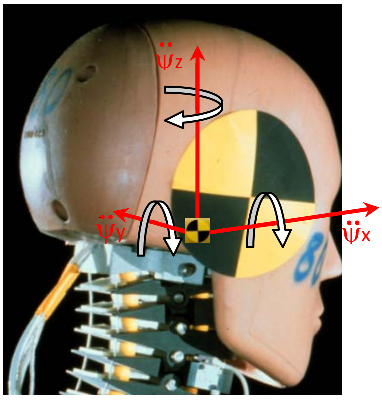


Figure 4. *Rotational acceleration*

The impact to the side of the helmet was located at parietal level and the impact was applied in the frontal plane, resulting in rotation around the X direction. The head was dropped 90° horizontally angled to the right resulting in a contact point on the side of the head, Figure 5. The impact to the upper part of the helmet resulted in rotation around the Y direction, Figure 6. This impact simulates a crash with oblique impact to the front of the head. The third impact was located at parietal level and was applied in the frontal plane, resulting in a rotation around the Z direction. The head was angled to the side which resulted a contact point on the side of the head, Figure 7. All three oblique tests were simulating a single-bicycle-crash or bicycle-to-car-crash with an oblique impact to the head.

Figure 5. *Oblique test with rotation around the x-axis.*

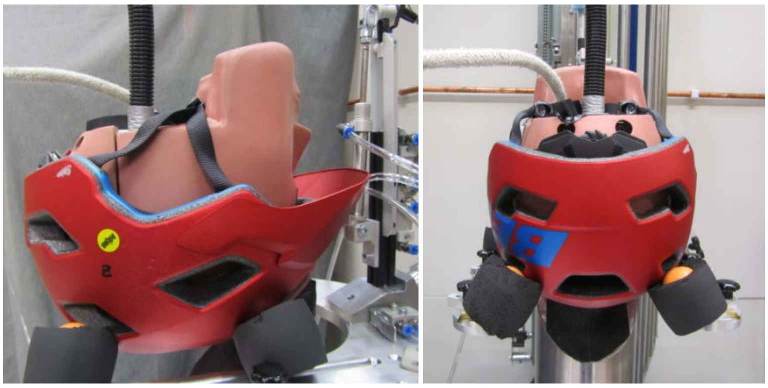


Figure 6. *Oblique test with rotation around the y-axis*

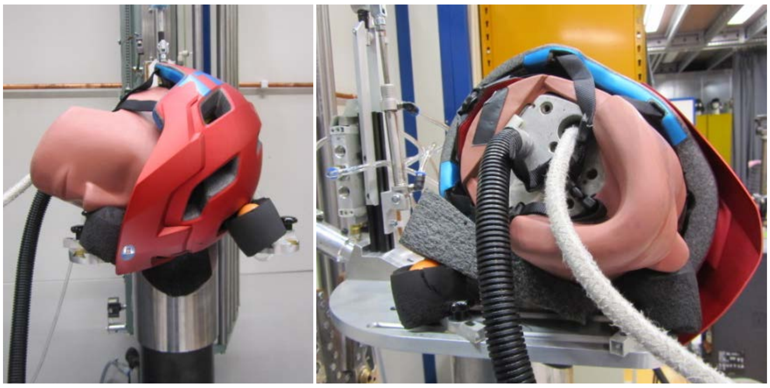


Figure 7. *Oblique test with rotation around the z-axis (head pre position: 20 ° in x and 35° in z)*

The Hövding 2.0 helmet

The test with the Hövding 2.0 was conducted in similar principles as the standard EN1078, *5.1 Shock Absorption*. However, in both the shock absorption test as well as in the three oblique tests, an anvil with larger dimensions was used, Figure 8. If Hövding 2.0 would have been tested against the anvil used for a conventional helmet it would have been a risk that it would get in contact with the edges of the anvil. The airbag of the Hövding 2.0 had a pressure of 0.55 bar.

Figure 8. *The Hövding2.0 and the larger anvil*

Computer simulations (FE model)

Computer simulations were conducted for all the three oblique impact tests. Table 3-5 shows the results from the simulations, which gave the brain tension ratio caused by rotation of the brain. The strain was between 6-44%. A strain above 26% corresponds to a 50% risk for concussion (Kleiven, S. and W.N. Hardy 2002, Margulies, S.S. and L.E. Thibault 1992).

The simulation was conducted by KTH (the Royal Institute of Technology) in Stockholm. As input into the FE model, x, y and z rotation and translational acceleration data from the HIII head were used. The FE model of the brain (Figure 9) which was used in the tests is described by Kleiven (2006 and 2007). The researchers at KTH did not know the brand and model of the helmets they were doing the

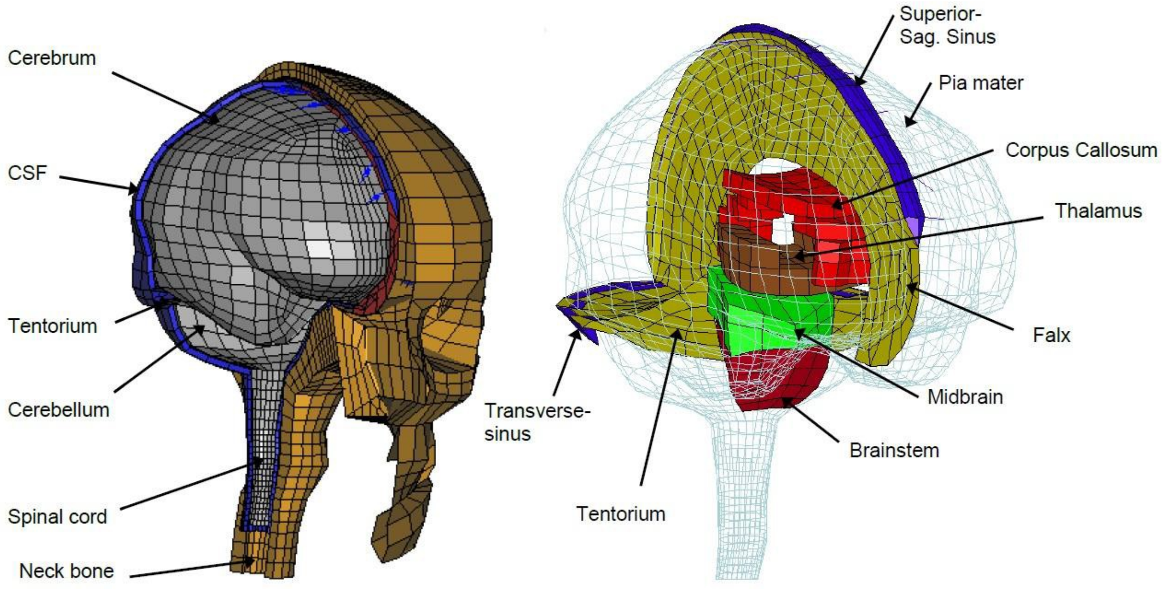


Figure 9. Finite element model of the human brain

Injury criteria

The mathematical model predicts a 50% risk of concussion in the event of strains of 26% in the grey matter of the brain. The simulation shows the maximum strain that occurs in the brain matter during each test, which in turn can be translated into a risk of injury.

Results

The results of four crash tests are reported below: a shock absorption test performed on a basis similar to that in the legal requirements, and three oblique impacts.

Shock Absorption

All helmets in the shock absorption test showed accelerations lower than 250 g, Table 2. Five helmets (Abus S-Force Peak, Carrera Foldable, Giro Sutton MIPS, Occano Urban Helmet and Yakkay) got a linear acceleration lower than 180 g, which corresponds to a 5 % risk of skull fracture (Mertz et al. 1997). The Hövding 2.0 helmet performed almost three times better than all the other conventional helmets (48 g vs other helmets that were around 175 g). The POC Octal performed best and Yakkay preformed worst of the conventional helmets.

Table 2. *Shock Absorption - Linear acceleration*

Manufacturer	Translational acceleration (g)
Abus S-Force Peak Official Vasaloppet	202
Bell Stoker MIPS	155
Biltema cycle helmet	189
Carrera Foldable	225
Casco Active-TC	170
Giro Savant MIPS	153
Giro Sutton MIPS	212
Hövding 2.0	48
Limar Ultralight	169
Melon Urban Active	173
Occano U MIPS Helmet	178
Occano Urban Helmet	192
POC Octal AVIP MIPS	140
POC Octal	135
Scott Stego MIPS	166
Smith Forefront	231
Spectra Urbana MIPS	168
YAKKAY with cover	242
Average/Median	**175/172**

Oblique Test – rotation around the x-axis

In the test, which reflects the helmet's protective effectiveness in a bicycle crash with oblique impact to the side of helmet (rotation around the x-axis), the translational accelerations were in average 129 g, which is considerably lower than the threshold for the current helmet standard (250 g), Table 3 and Appendix A. The lowest translational acceleration was measured in Hövding 2.0 (42 g), and the highest value was measured in tests of Carrera Foldable (180 g). The mean value of the rotational accelerations was 6,406 rad/s^2. The lowest rotational acceleration was measured in Hövding 2.0 (1,546 rad/s^2). The mean rotational velocity was 27.5 rad/s. The maximum value was measured in Scott Stego MIPS (35.4 radians/s) and the lowest value was measured in Hövding (24.3 rad/s). When simulations were conducted, the strain in the grey matter of the brain varied from 6% to 22%. All the values measured were below the limit for a 50% risk of concussion (26% strain). The lowest strain was measured when testing the Hövding 2.0 head protector. The illustrations below show the point at which the maximum strain in the brain is measured when testing the best or worst conventional bicycle helmets and the Hövding 2.0; Figure 10 and Figure 11. The protective potential of the helmets has been ranked based on the strain calculated from the FE model, which is presented in Table 4.

Table 3. *Oblique test 1 (rotation x)*

Helmet	Tran. acceleration (g)	Rot. acceleration (krad/s^2)	Rot. velocity (rad/s)	Strain (%)
Abus S-Force Peak Official Vasalopp's Helmet	175	7.5	29.9	16
Bell Stoker MIPS	112	4.2	23.2	11
Biltema cycle helmet	124	5.1	29.3	15
Carrera Foldable	180	7.9	27.6	16
Casco Active-TC	123	7.8	31.3	20
Giro Savant MIPS	120	5.3	24.7	12
Giro Sutton MIPS	124	4.5	23.8	11
Hövding 2.0	42	1.5	26.9	6
Limar Ultralight	132	8.5	31.5	18
Melon Urban Active	138	6.1	29.2	16
Occano U MIPS Helmet	121	5.1	23.9	12
Occano Urban Helmet	161	7.5	31.6	17
POC Octal	102	7.6	32.2	19
POC Octal AVIP MIPS	95	5.3	23.2	12
Scott Stego MIPS	94	6.8	35.4	19
Smith Forefront	136	8.1	31.5	18
Spectra Urbana MIPS	155	6.1	21.9	12
YAKKAY with cover	150	5.8	19.2	14
YAKKAY without cover	174	10.8	33.8	22
Average/Median	**129/124**	**6.4/6.1**	**27.5/29.2**	**15/16**

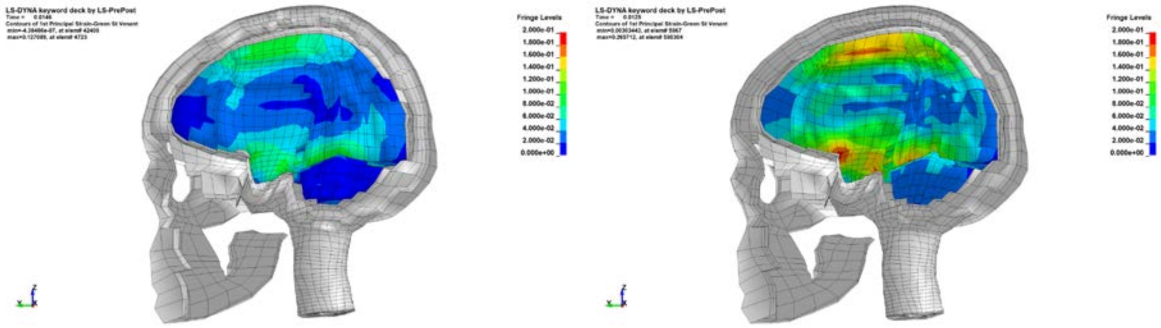


Figure 10. *Maximuml strain in the brain, rotation in x – impact to the side of the helmet. To the left one of the best and to the right one of the worst outcomes.*

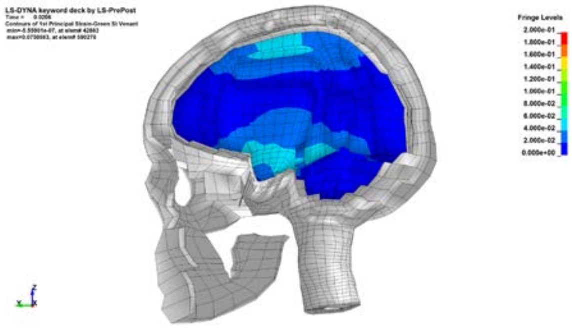


Figure 11. *Maximum strain in the brain,. rotation in the xaxis - Hövding 2.0*

Oblique Test – rotation around the Y-axis

In the test that reflects the helmet's protective effectiveness in a bicycle crash with an oblique impact to the upper part of helmet (rotation around the y-axis), the translational accelerations was in average 119 g, which is considerably lower than the threshold for the current helmet standard (250 g), Table 4. The minimum translational acceleration was measured in Hövding 2.0 (37 g), and the highest value was measured in tests of YAKKAY (174 g). The mean value of the rotational accelerations was 12.854 rad/s^2. The lowest rotational acceleration was measured in Hövding 2.0 (1.735 rad/s^2). The mean rotational velocity was 33.1 rad/s. The maximum value was measured in YAKKAY without a cover (39.4 rad/s), and the lowest value was measured in Hövding (24.3 rad/s). When simulations were conducted the maximum strain in the brain matter varied from 7 to 35%; Table 5 and Appendix A. The lowest strain was measured in the Hövding 2.0. Among the conventional helmets the lowest strain was measured when testing the YAKKAY helmet with cover and the highest strain was measured in the YAKKAY without cover. In six tests (Casco Active-TC, Limar Ultralight, Melon Urban Active, Smith Forefront and YAKKAY without cover) values which are above the 26% limit were measured, which corresponds to a 50% risk of concussion in those regions in the grey matter of the brain where the highest strain was measured (Kleiven. 200b. Kleiven. 2007). The illustrations below show the point at which the maximum strain in the brain is measured for the best and worst scoring helmets; Figure 12. There was a considerable difference between the strain in the helmets with the best and worst outcomes. The strain is shown from 0 (Blue) to 39%. The red areas in the illustration show the parts of the brain that run a 50% risk of concussion.

Table 4. *The values measured in an oblique impact on the upper part of the helmet (rotation around Y)*

Helmet	TRANS. ACC. [g]	ROT. ACC. [krad/s2]	ROT. VEL. [rad/s]	Strain (%)
Abus S-Force Peak Officiella Vasaloppshjälmen	131	7.2	33.4	23
Bell Stoker MIPS	100	6.2	31.8	23
Biltema cykelhjälm	115	7.1	36.4	25
Carrera Foldable	147	7.8	32.9	25
Casco Active-TC	116	8.0	38.8	29
Giro Savant MIPS	100	4.2	28.3	17
Giro Sutton MIPS	116	6.1	34.2	23
Hövding 2.0	37	1.7	28.6	7
Limar Ultralight	121	7.0	36.9	26
Melon Urban Active	131	8.2	34.5	26
Occano U MIPS Helmet	126	5.3	29.1	20
Occano Urban Helmet	121	7.6	35.8	27
POC Octal	90	6.2	35.6	24
POC Octal AVIP MIPS	87	4.5	30.5	19
Scott Stego MIPS	103	6.7	32.7	24
Smith Forefront	166	10.0	38.9	30
Spectra Urbana MIPS	115	5.8	27.2	19
YAKKAY with cover	156	5.1	24.3	16
YAKKAY without cover	174	12.9	39.4	35
Mean/Median	**119/116**	**6.7/6.7**	**33.1/33.4**	**23/24**

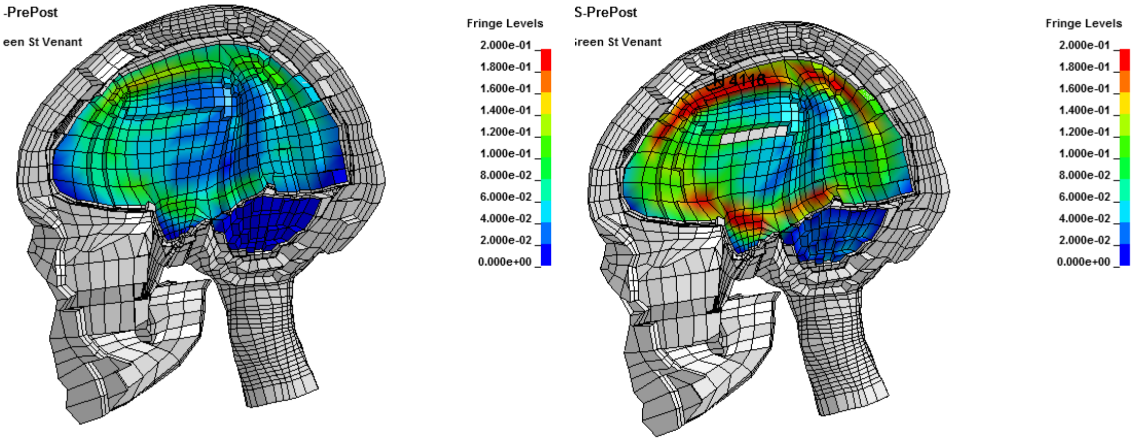


Figure 12. *The maximum strain in the brain. rotation in the y-axis. To the left the helmet with the lowest value and to the right the one with the highest value.*

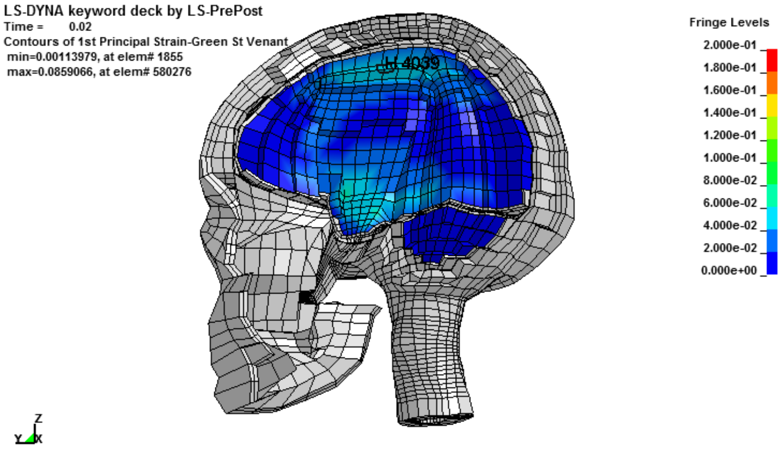


Figure 13. *Maximum strain in the brain, rotation in y - Hövding 2.0*

Oblique Test – rotation around the z-axis

In the test that reflects the helmet's protective effectiveness in a bicycle crash with oblique impact to the rear part of the helmet (rotation around the z-axis), the translational accelerations was in average 117 g, which is considerably lower than the threshold for the current helmet standard (250 g) . Table 5. The minimum translational acceleration was measured in Hövding 2.0 (27 g), and the highest value was measured in tests of YAKKAY (167 g). The mean value of the rotational accelerations was 12.042 rad/s^2. The lowest rotational acceleration was measured in Hövding 2.0 (2828 rad/s^2). The mean rotational velocity was 40.9 rad/s. The maximum value was measured in YAKKAY without a cover (46.6 rad/s), and the lowest value was measured in Hövding (33.7 rad/s) . When simulations were conducted the maximum strain in the brain varied from 31 to 44%; Table 6 and Appendix. When testing the Hövding 2.0 head protector a strain of 19% was measured, which is below the limit for a 50 % risk of a concussion, Figure 14-15.

Table 5. *The values measured in oblique impact on the rear part of the helmet (rotation around z)*

Helmet	TRANS. ACC. [g]	ROT. ACC. [krad/s2]	ROT. VEL. [rad/s]	Strain (%)
Abus S-Force Peak	145	14.4	39.5	33
Bell Stoker MIPS	114	10.5	39.1	31
Biltema cykelhjälm	126	13.8	42.1	34
Carrera Foldable	157	15.5	42.3	35
Casco Active-TC	76	10.1	44.4	35
Giro Savant MIPS	103	9.5	38.7	31
Giro Sutton MIPS	139	13.7	41.0	33
Hövding 2.0	27	2.8	37.1	19
Limar Ultralight	111	12.4	43.2	34
Melon Urban Active	128	12.6	40.5	33
Occano U MIPS Helmet	156	14.7	39.5	32
Occano Urban Helmet	131	13.9	42.6	35
POC Octal AVIP MIPS	77	9.2	43.5	33
POC Octal	74	10.2	42.1	33
Scott Stego MIPS	86	9.4	42.8	33
Smith Forefront	149	13.5	40.0	33
Spectra Urbana MIPS	109	10.5	40.2	32
YAKKAY with a cover	167	14.1	36.0	30
YAKKAY without a cover	142	18.1	46.6	44
Mean/Median	**117/126**	**12.0/12.6**	**40.9/41.0**	**33/33**

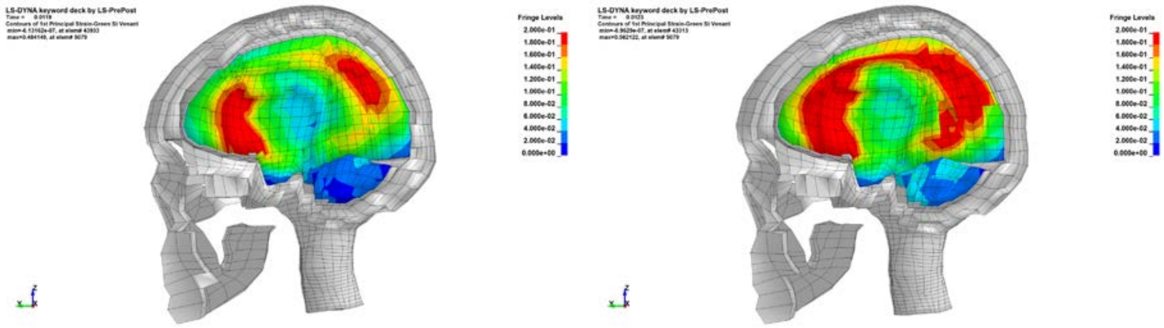


Figure 14. *The maximum strain in the brain. rotation in the zaxis. To the left the helmet with the lowest value and to the right the one with the highest value.*

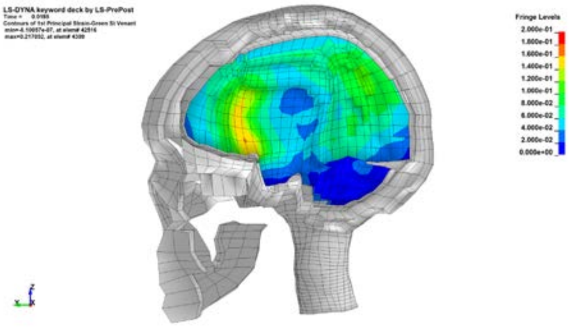


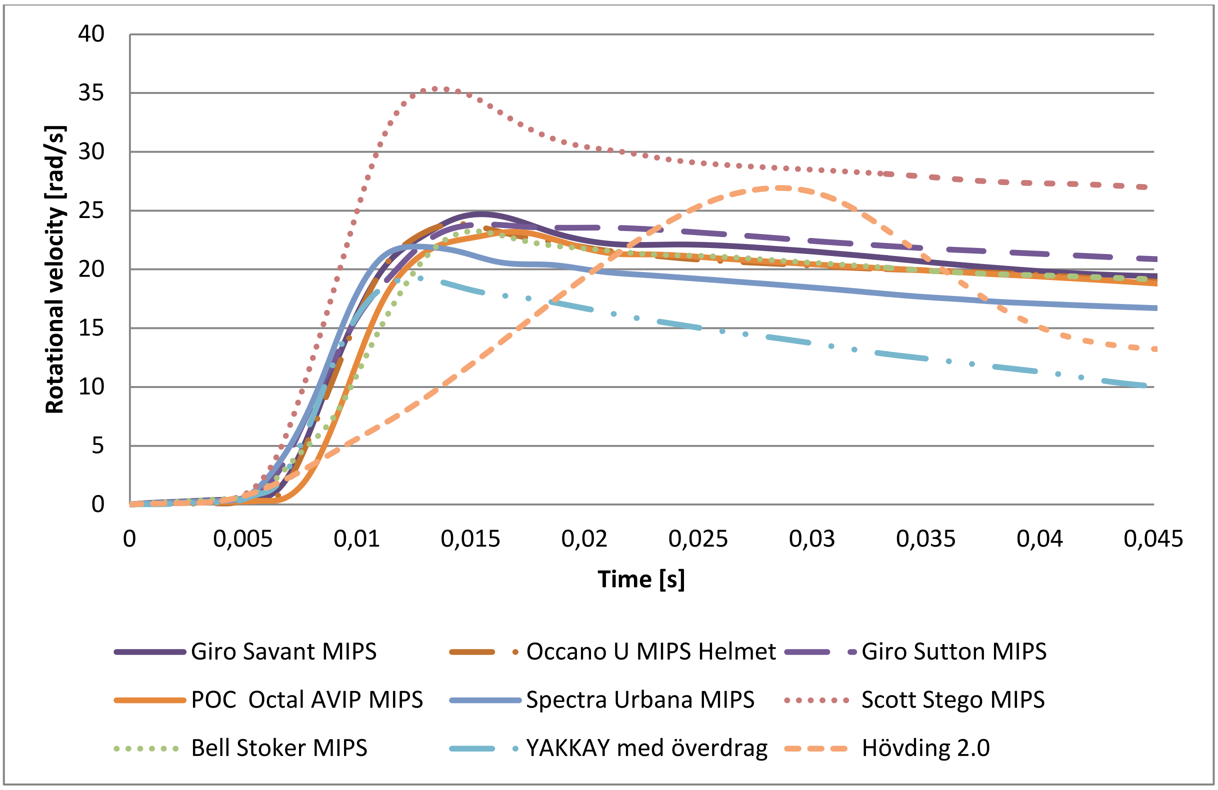
Figure 15. *Maximum strain in the brain, rotation in the z-axis - Hövding 2.0*

Discussion and conclusions

All the helmets included in the test comply with the legal requirements for a bicycle helmet. The legal requirements do not cover the helmets' capacity to reduce the rotational force. i.e. when the head is exposed to rotation due to the impact. The Folksam test shows a relatively large variation in the test comparing the helmets' capacity to absorb impact energy (48-242 g). Experience from American football indicates that head injuries start to occur at 60-100 g (Zhang et al 2004). In addition, the risk of skull fractures could be dramatically reduced (from a 40% to a 5% risk) if the translational acceleration would be reduced from 250 g to 180 g (Mertz et al. 1997). Helmets should therefore be designs to reduce the translational acceleration well below the legal requirement (250 g), provided that they also take into account the rotational forces to avoid brain injuries. The translational acceleration is mainly associated with the risk of skull fracture whereas the rotational acceleration and rotational velocity are associated with brain injuries. The results from the Folksam helmet test clearly show that it is possible to design a helmet that meets the legal requirements with a wide margin. The conventional helmet POC Octal reduced the energy that the head form was exposed to with almost half of the threshold of the requirements (135 g compared with 250 g). However, the Hövding 2.0., a head protector that is inflated during an accident situation and acts as an airbag for the head, obtained the best results. The translational acceleration was 48 g, a value almost 3 times better than the best conventional helmet, POC Octal. The tests indicate that the impact absorbing materials in today's helmets are far too stiff. In order to obtain lower head acceleration softer impact absorbing materials would be required, which probably need to be somewhat thicker (Mills and Gilchrist. 2006, Asiminei et al 2009, Fahlstedt. 2005). At the same time there are requirements to spread the force in connection with the legal requirement test against a kerbstone. A hard outer shell is required to meet this requirement simultaneously. By using different materials and concepts the helmets should be able to be more efficient to absorb the energy during a head impact. When developing a standard many different limits are set based on the assumed protective capacity of the existing materials. Most helmets have been of a similar design for a relatively long period and few improvements have been made even though new impact-absorbing materials have been developed. One of the helmets, Smith Forefront, is constructed with a honeycomb design. It has previously been shown that honeycomb design is effective in reducing both translational and rotational accelerations (Hansen et al. 2013). However, the Smith Forefront was too stiff and was shown to be one of those with the highest values measured.

Few helmets provide good protection against oblique impacts (rotational combined with translational acceleration), which is probably the most common accident scenario for a bicycle accident with a head impact. An oblique impact to the head means high risk of severe injury such as concussion with a loss of consciousness and diffuse axonal injury (DAI). Several of the helmets, Bell Stoker with MIPS, Giro Savant MIPS, Giro Sutton MIPS, Occano U MIPS Helmet, POC Octal AVIP MIPS, Scott Stego MIPS and Spectra Urbana MIPS, are designed to absorb rotational force. These helmets generally perform well in the rotation tests. However, the fact that a helmet has rotational protection is notany guarantee for a good protection. The tests clearly show a large variation between the 18 helmets and there is also a large variation between helmets with rotational protection; Figure 16.

Figure 16. Rotational velocity for helmets with rotational protection during oblique impact against the side of the helmet (rotation around the x-axis)



One of the helmets, Yakkay, which is available in a version in which it is possible to fit a cover in the form of a hat/cap, was tested both with and without the cover. A major difference was measured in the oblique tests between the Yakkay with and without the cover, which indicates that this cover provides good protection against rotational forces, similar to MIPS; Figure 17 and Figure 18. The difference is that the sliding shell in the case of the Yakkay is fitted on the outside of the shell of the helmet. It is probably not an intentional rotational protection, but shows that a surface-mounted layer can provide similar protection as a sliding layer fitted on the inside. There is a similar concept among motor cycle helmets, known as SuperSkin, which has been shown to reduce the rotational forces in oblique impact tests (PhillipsHelmets. 2015). Another example is the 6D helmet that consists of two layers of EPS linked with “dampers” that allow energy absorbing shear between the layers (6D Helmet. 2015). The Hövding did also obtain very good results in the rotational tests; Figure 17. When it is inflated, the exterior fabric can slide sideways in relation to the fabric on the inside against the head. Thus two shearing layers are created that considerably reduces the rotational acceleration. The above examples clearly demonstrate that there are several ways to design a helmet to absorb rotational forces.

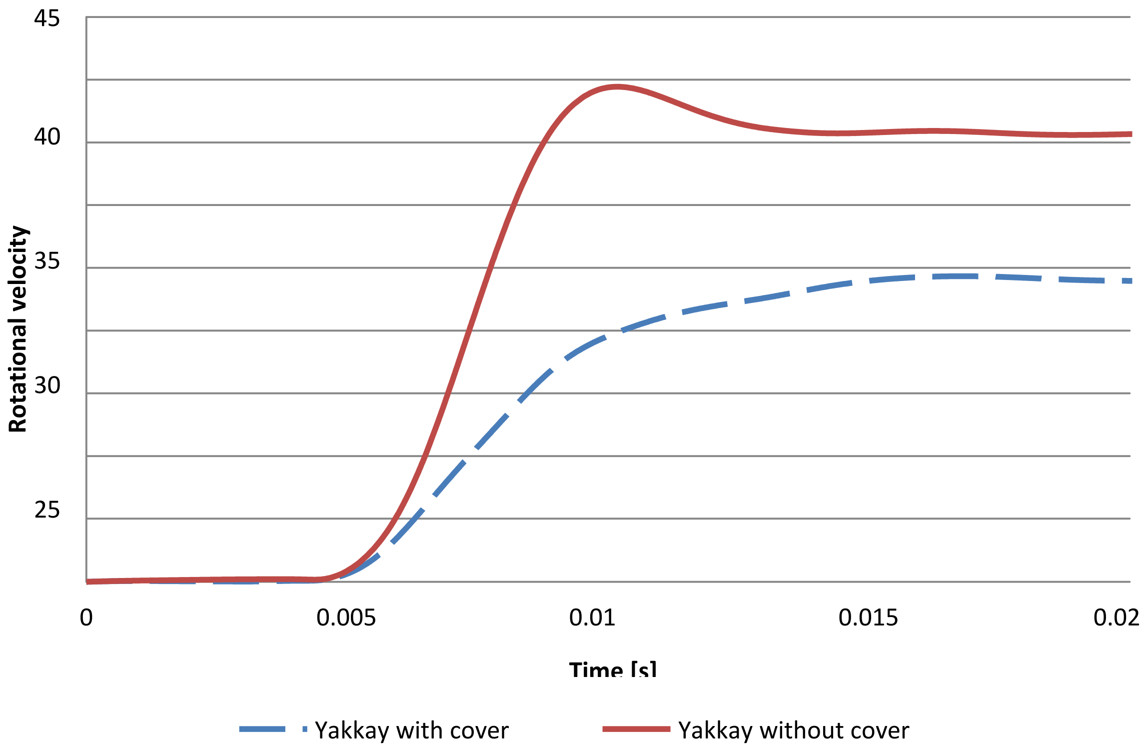


Figure 18. Rotational velocity during an oblique impact against the upper part of the helmet (Rotation in the y-axis)

One explanation for the variation in the helmet test results is also the difference in geometric design. A bicycle helmet design with many holes to achieve good ventilation and many edges in the outer shell is more likely to have a larger variation depending on the point of impact. When the Scott Stego MIPS is compared with the Bell Stoker MIPS, for example, the Bell helmet is round and smooth, whereas the Scott helmet has relatively marked design edges. The skate helmets are smoother but often have a harder outer shell and therefore generally obtain higher values. In addition, the variation may be caused by the fact that the helmet was not fitted equally firm on the crash dummy head. It was hard to check this. The helmets were fitted on the head with the intention that the neck adjustment system should be adjusted as similarly as possible using the same procedure as in the certification tests. The variation of the results reflects the variation in energy absorption, but also the fact that several helmet manufacturers do not develop the helmets for oblique impacts.

All the helmets included in the test comply with the legal requirements for a cycle helmet. However, the legal requirements do notcover the helmet's potential to reduce rotational forces. The results from Folksam's tests clearly indicate that a bicyclist using a helmet that meets the current legal requirements of 250 g can still get a concussion in case of an accident. Concussion or what is known as Mild Traumatic Brain Injury (MTBI) with or without loss of consciousness occurs in many activities, often as a result of the brain being subjected to rotational forces in the event of either direct or indirect forces against the head. Concussion can result in long-term or permanent symptoms such as memory disorders, headaches and other neurological symptoms. Eight per cent of the cases reported to Folksam in which a person suffers a head injury in connection with an accident lead to long-term symptoms with medical impairment (Malm et al. 2008). Rotation of the head may also lead to to more serious injuries such as diffuse axonal injury (DAI). To evaluate this risk a data simulation model was used.

In spite of the relatively high limit of 250 g in the legal requirements, studies indicate that current helmets have a good protective effect with a 60% reduction of head injury risk (Rizzi et al 2013). But the protective effect could be considerably higher if oblique impacts similar to those conducted in this study would be included. For a number of years the introduction of oblique impacts into the bicycle helmet standard (CEN/TC158-WG11, 2014) similar to the one used in the present study has been discussed. However, changing legal requirements is a long process and cannot be expected to be implemented within the next coming years. Therefore consumer test like this are important to increase consumer awareness when choosing cycle helmets and to influence helmet designers.

Thanks

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Conflict of interests

Peter Halldin is also actively involved in MIPS AB and is one of the founders of the company behind the MIPS helmet. During the simulation the researcher did not know which helmets had been tested.

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Appendix A – Graphs of test values from the three rotation tests

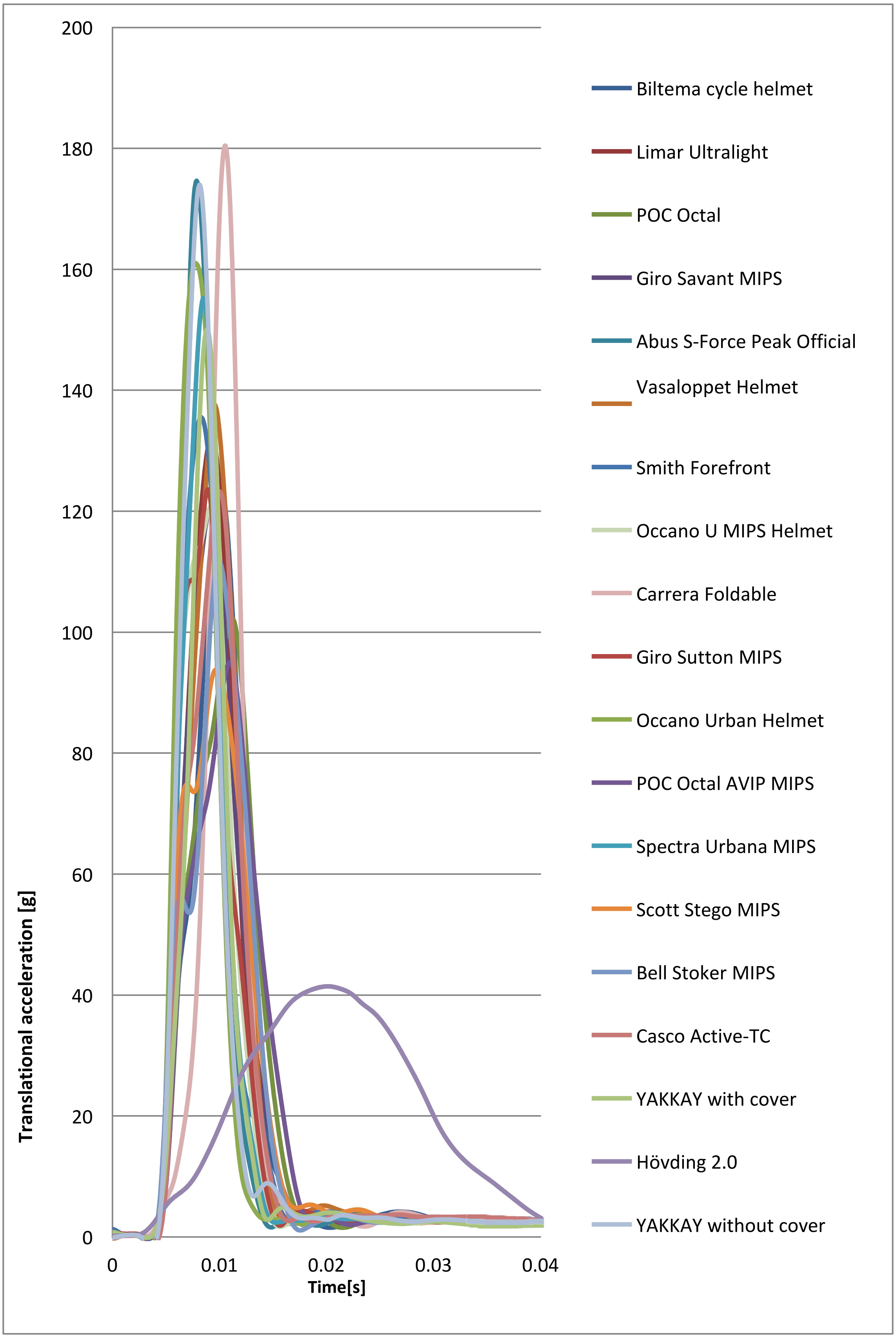

Figure A. Translational acceleration during oblique impact against the side of the helmet (rotation in the x-axis)

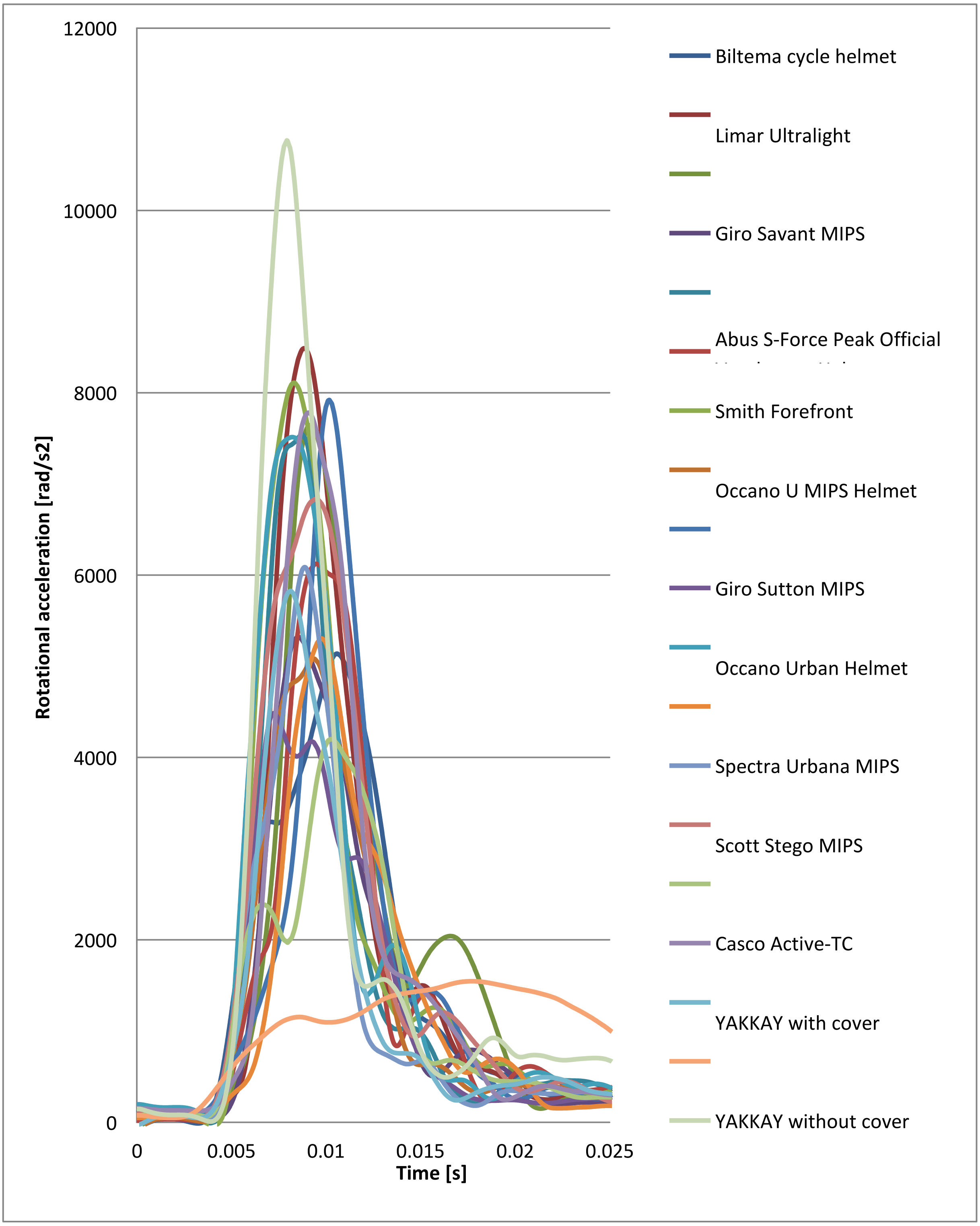

Figure B. Rotational acceleration during oblique impact against the side of the helmet (rotation in the x-axis)

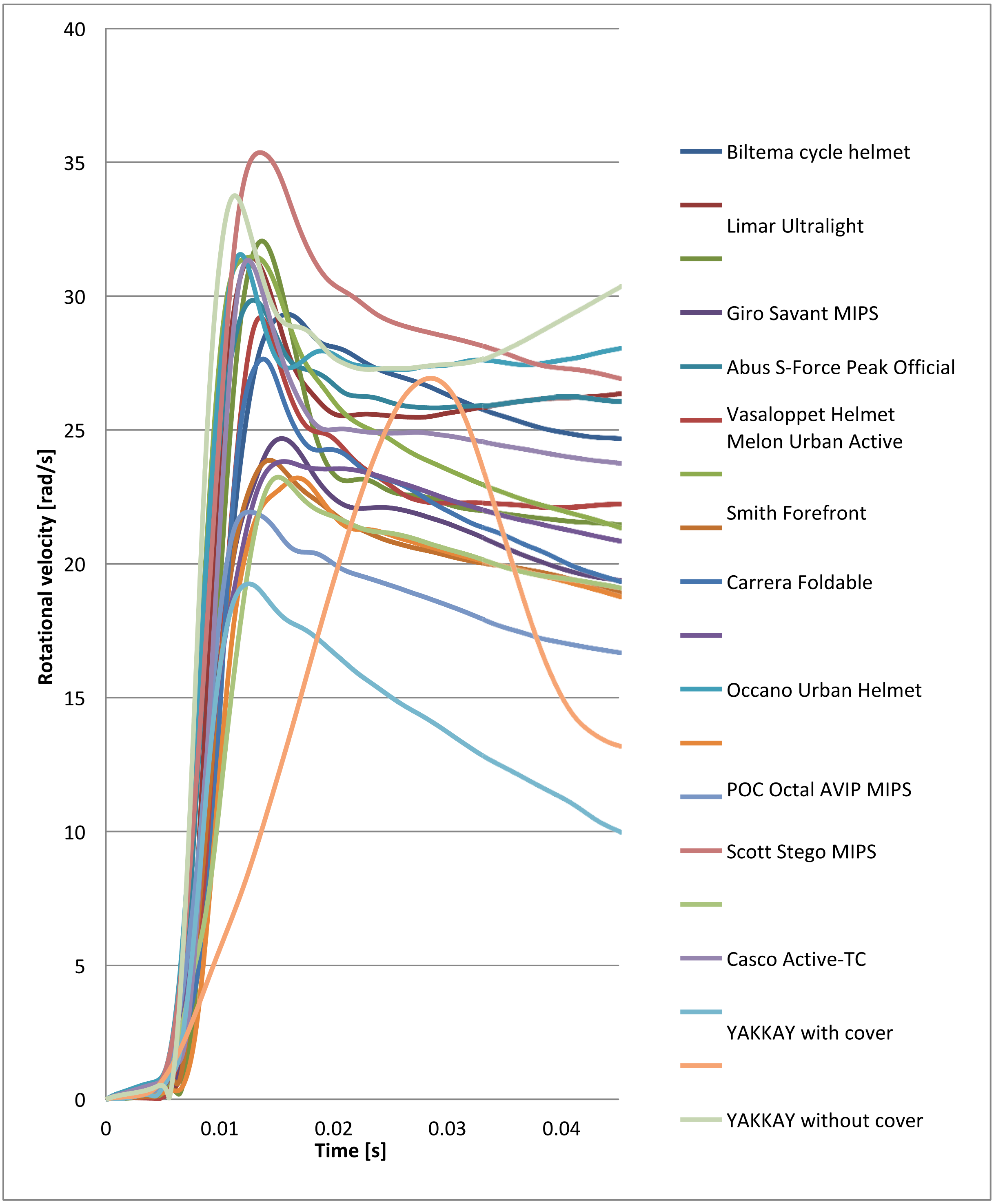

Figure C. Rotational velocity during oblique impact against the side of the helmet (rotation in the x-axis)

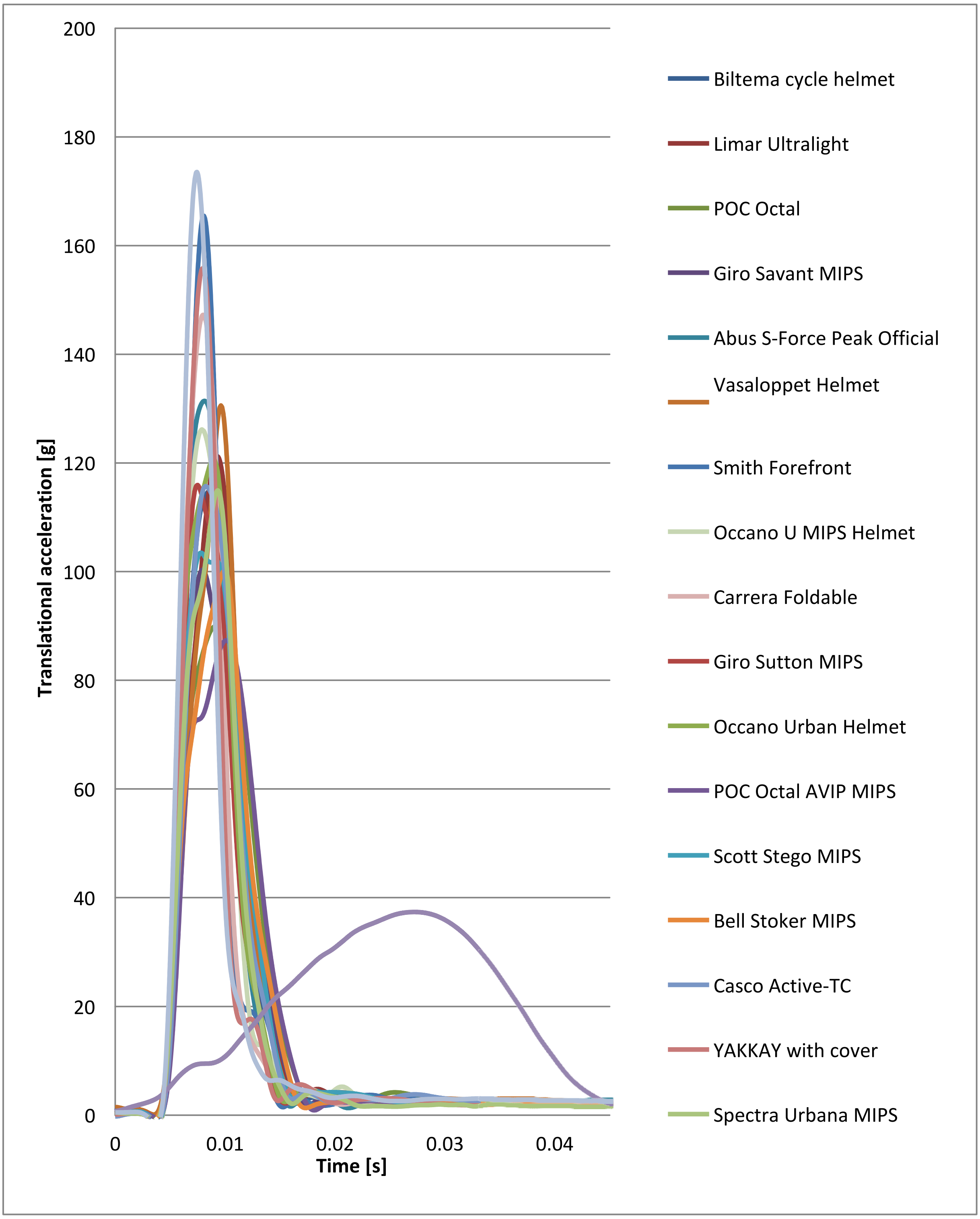

Figure D. Translational acceleration during oblique impact against the upper part of the helmet (rotation in the y-axis)

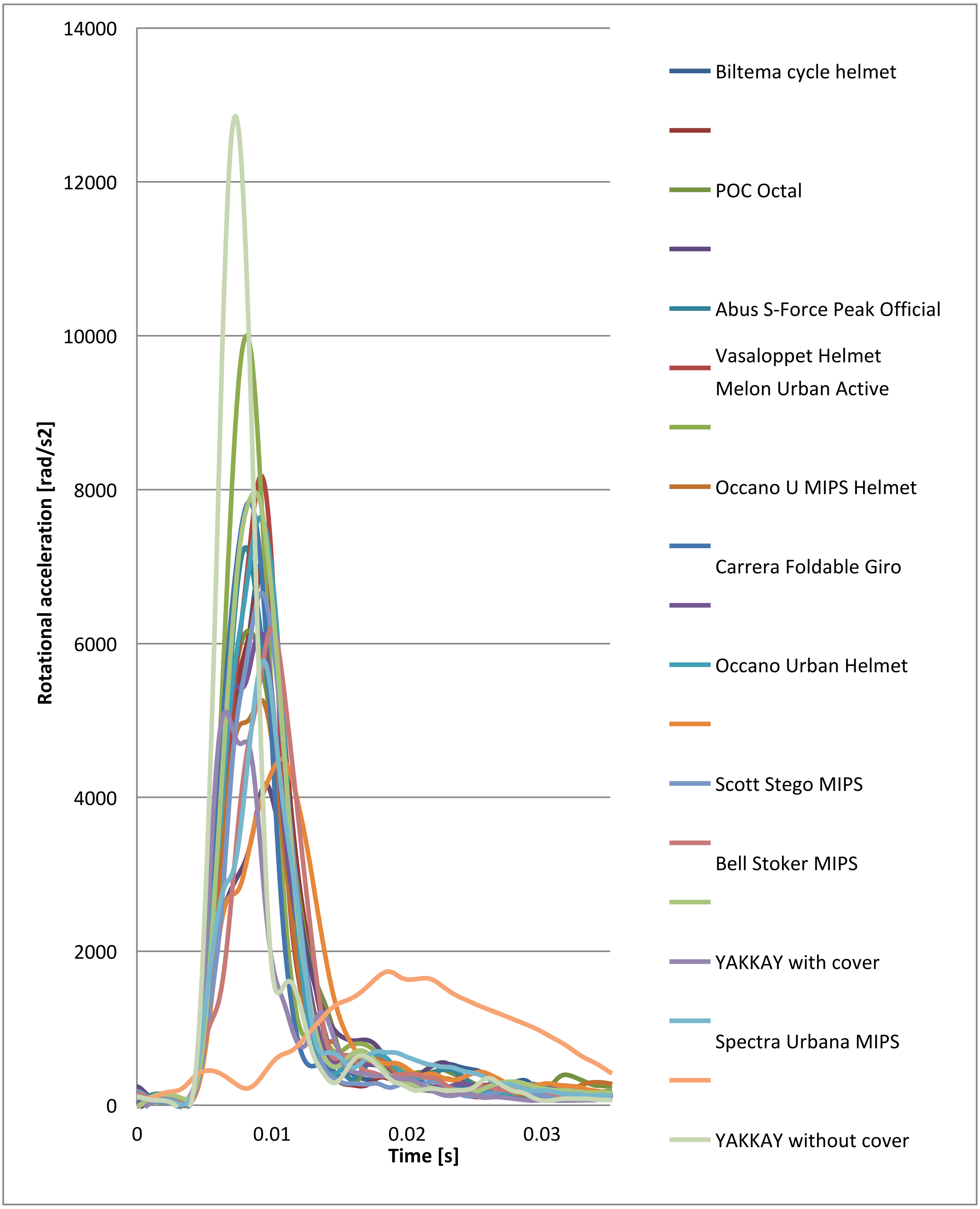

Figure E. Rotational acceleration during oblique impact against the upper part of the helmet (rotation in the y-axis)

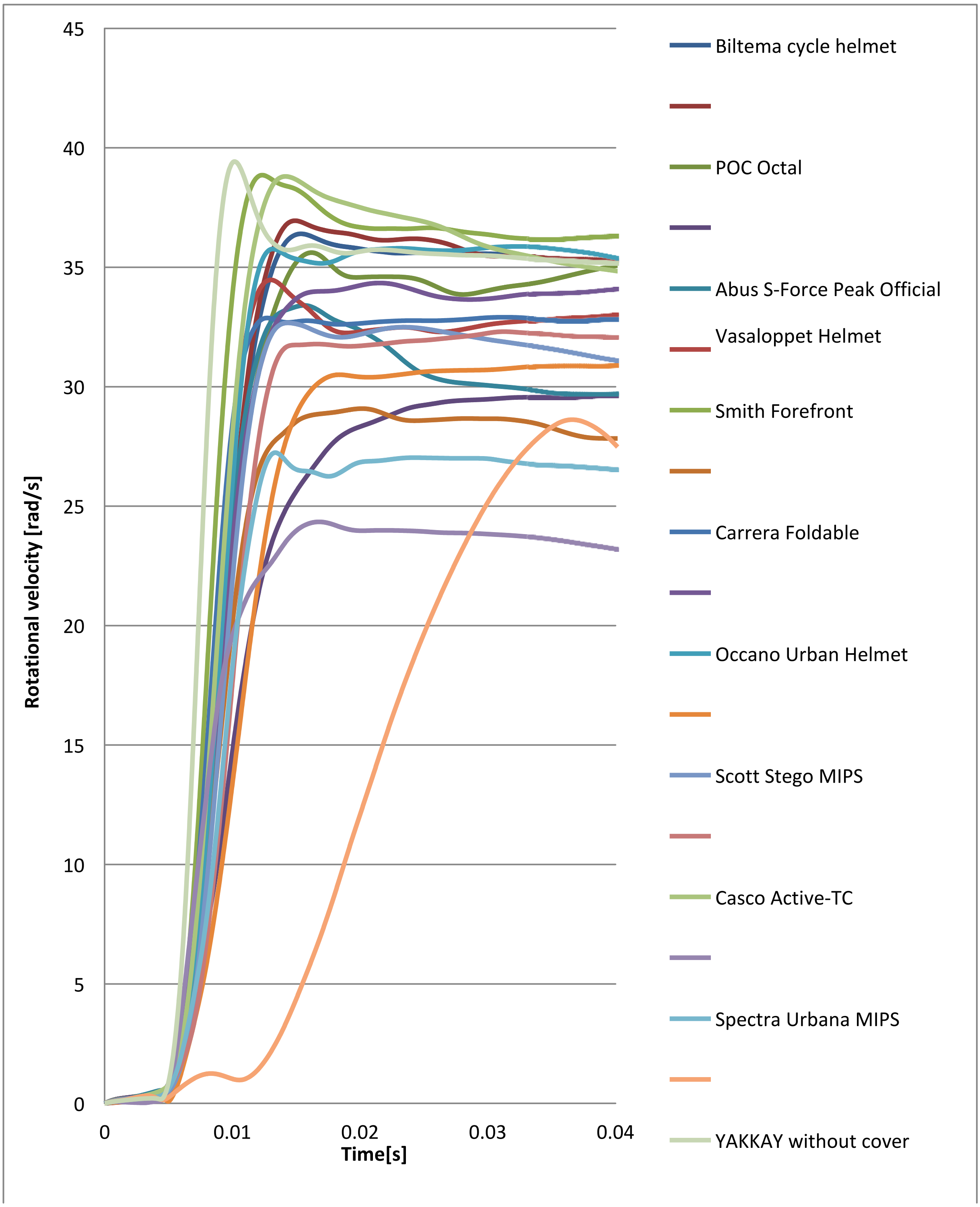

Figure F. Rotational velocity during oblique impact against the upper part of the helmet (rotation in the y-axis)

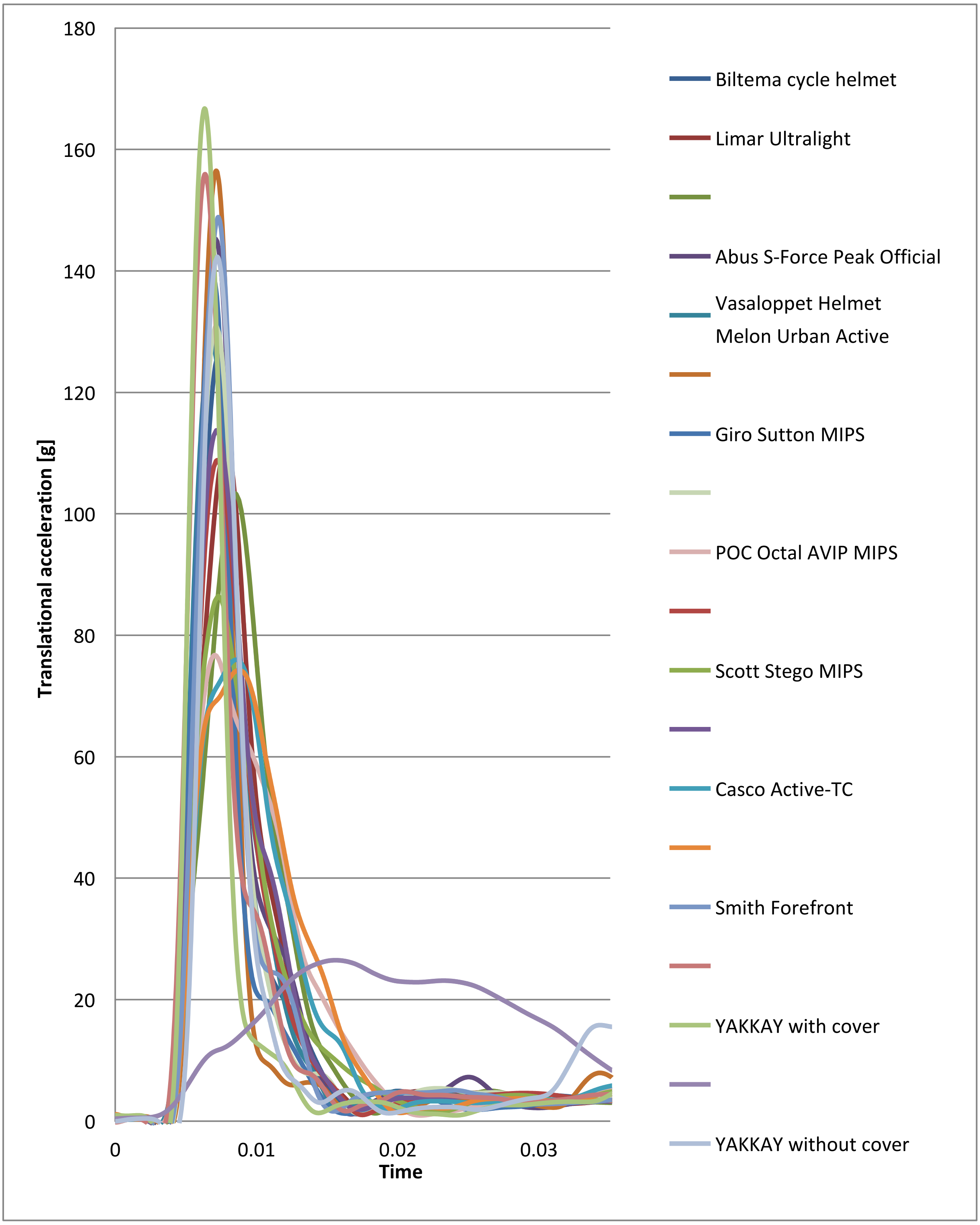

Figure G. Translational acceleration during an oblique impact against the rear part of the side of the helmet (rotation in the z-axis)

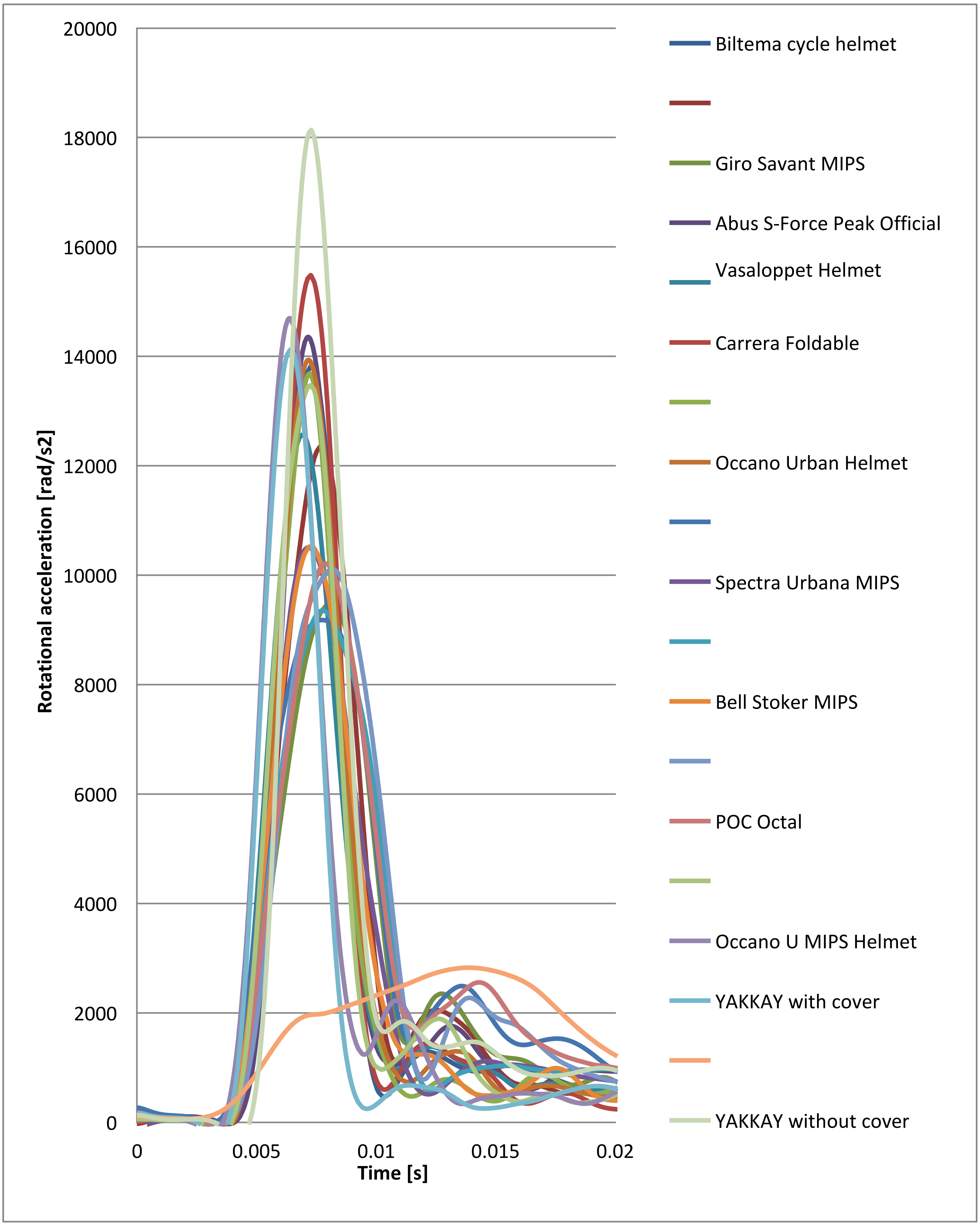

Figure H. Rotational acceleration during an oblique impact against the rear part of the side of the helmet (rotation in the z-axis)

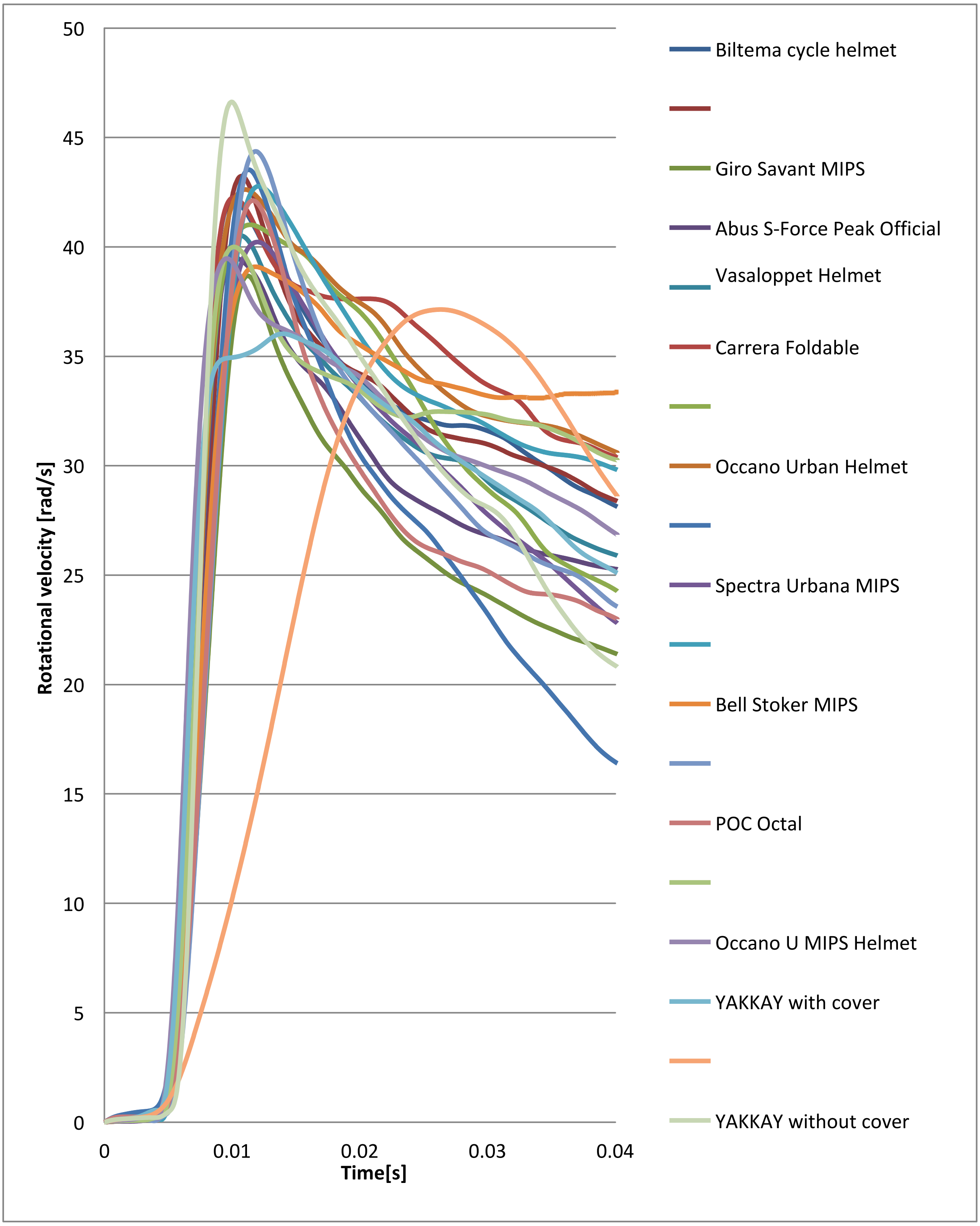

Figure I. Rotational velocity during an oblique impact against the rear part of the side of the helmet (rotation in the z-axis)

Appendix B – Hövding

Hövding 2.0 is a bicycle helmet in the form of a collar, which contains an airbag protecting the head in case of an accident. The movements of the bicyclist are continuously recorded by sensors and if an abnormal pattern of movement is detected the airbag inflates. Inflation takes a tenth of a second. The pressure in the airbag is maintained for several seconds. The Hövding's capacity to detect an accident or critical situation was not included in the test. However, during the development of the product and during CE marking the company itself performed crash tests at SP and VTI to ensure that it is activated. During these procedures they used both crash test dummies and stuntmen.

A limitation with the Hövding is that it does not provide protection when the head is struck directly by an object when cycling, i.e. without falling off the bicycle. This can occur if the head strikes a branch or post during cycling.

Impact of a neck on the test head

Since a neck is expected to provide the necessary support for the Hövding in the rotation tests, comparative tests were conducted both with and without a neck on the test head. A Hövding 2.0 with a neck only had a slightly higher rotational velocity than one without; Figure A and Table A. The test results for the Hövding 2.0 without a neck are reported in the study. The reason for this is that for a conventional helmet it has a significant effect on the test results if it is tested with a neck, see Figure A. The accident scenario and also the test scenario are very short (10-20 ms) for a conventional helmet and previous studies have shown that the neck is only rotated 10 degrees during this procedure. It is therefore probably a completely realistic scenario for the conventional helmets not to use a neck. Several researchers have highlighted that this should be investigated further (Fahlsted, 2015) and that it is particularly important to investigate the impact the neck has on longer impact durations, such as for the Hövding 2.0 head protector.

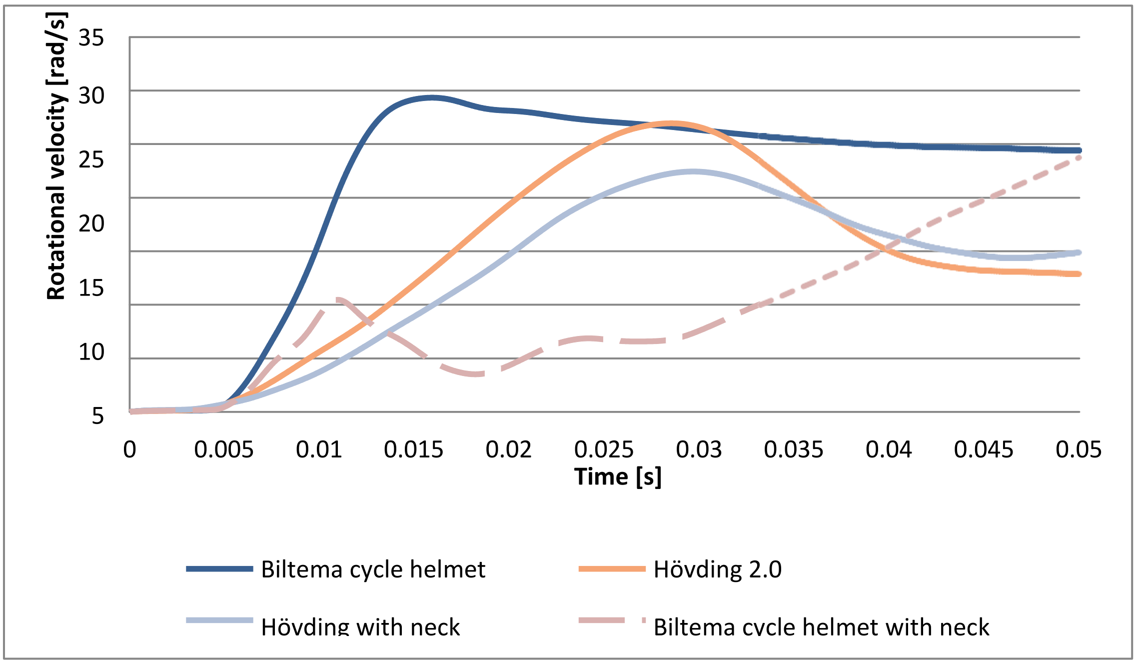

Figure A. Rotational velocity with and without neck for a conventional helmet and the Hövding 2.0

Table A Strain values from simulation with and without neck

	Strain (%)		
Simulation	Rotation around x-axis	Rotation around y-axis	Rotation around z-axis
Hövding	6.2	7	19
Hövding with neck	6.8	10	18
Biltema	19.0	25	34
Biltema with neck	5.6	16	36