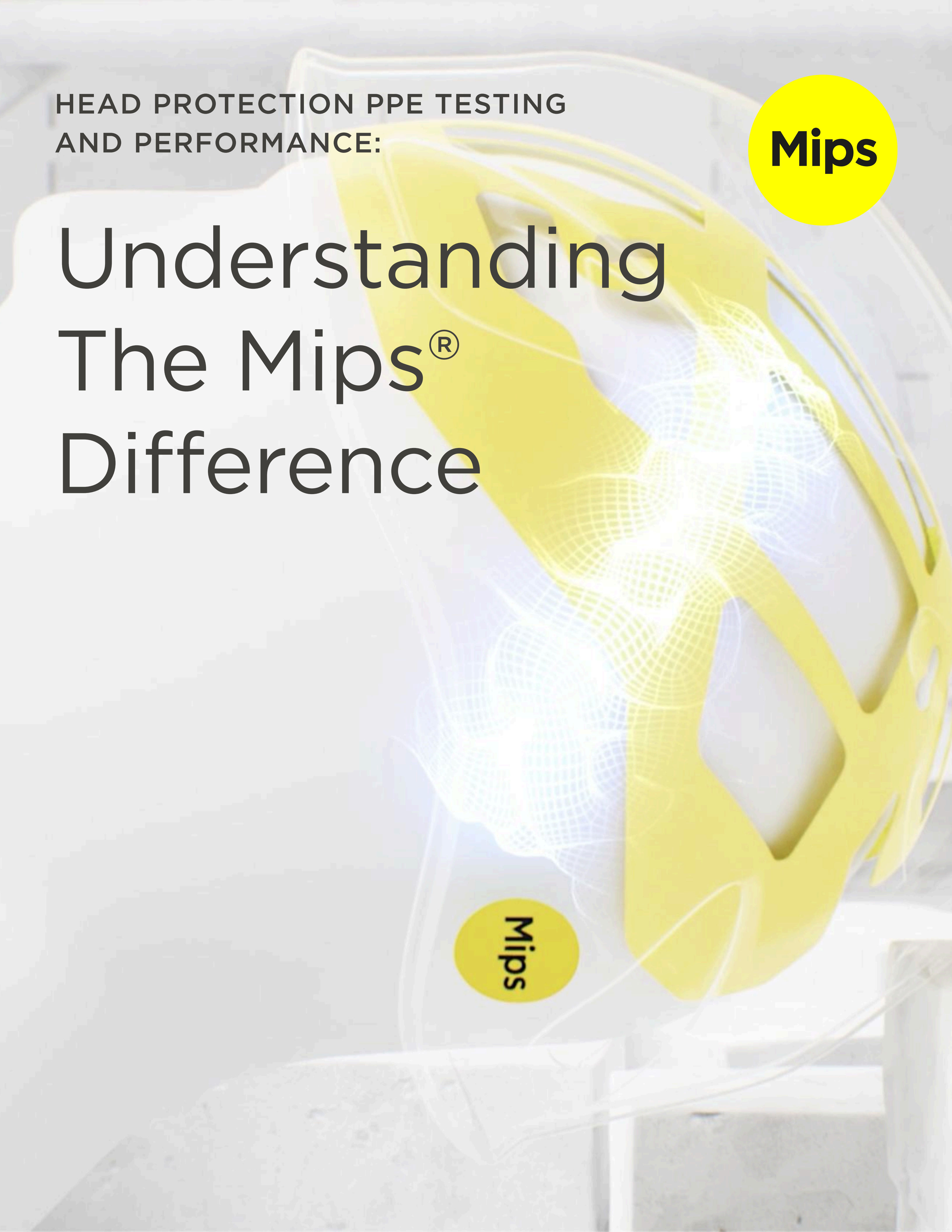
HEAD PROTECTION PPE TESTING AND PERFORMANCE:

Understanding The Mips® Difference

Mips



UNDERSTANDING THE MIPS® DIFFERENCE

Why choose Mips® brain protection system for industrial safety helmets

It has been shown that rotational motion of the head in industrial work settings can potentially lead to Traumatic Brain Injuries (TBIs),) including concussion.[1234] Today, different hard hat and safety helmet manufacturers offer solutions to help address angled impacts and rotational motion; but how the technologies mitigate rotation and how they are tested differs significantly. This white paper will review the differences in test methods used and available technologies to explain the benefits and advantages of Mips' safety system to help reduce rotational motion that might be transferred to the user's head.

Testing for reduction in rotational motion

Background on rotational testing

To evaluate the protection related to rotational motion, how the motion is transferred from the helmet to the brain must be understood. During an angled impact the helmet could grab hold of the head and force the head into a rotational motion. This rotational motion may be transferred to the brain.

Testing for rotation is complex and requires equipment developed for the purpose and a set-up that allows for the headform to move as realistically as possible. There are several aspects to consider when choosing a good test protocol such as test set-up, impact direction, test head, what to measure for, impact angle, and inclusion of a neck or not.

Mips has unique knowledge in this area after over 25 years of research and development in the field. It took 15 years to develop the complete Mips test environment. Mips' first test machine was built in 1997, and since then it has evolved into what Mips uses today.

25

Years experience

Mips has more than 25 years of experience in managing angled impacts to the head and developing head protection solutions.

50

Engineers

Mips employs more than 50 engineers including 5 PhDs that are 100% dedicated to developing and helping improve head protection solutions.

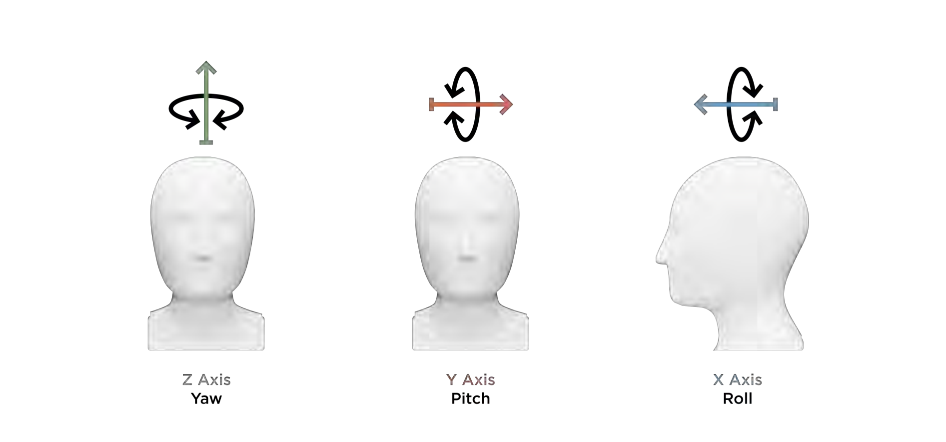
90,000

Rotational tests

Mips has performed more than 90,000 rotational tests in its own state-of-the-art test lab, and the Mips system is a leading helmet technology for rotational protection, used by millions of helmet wearers worldwide.[5]

Test set-up

To capture the rotational protection of a helmet, the test set-up must include a headform that is free to rotate and an anvil that induces a rotational motion. The most common way to do this, and the one employed by Mips, is to use a free headform impacting an anvil angled 45° towards the impact direction. This method is also adopted in the European test standard EN17950 and the ASTM F3555–22.[6] The impact is intended to represent a reality-based accident scenario where the head impacts the ground with a horizontal velocity component or an obstructing object at an angle. The impact angle of 45° generates high translational forces on the helmet that give rise to angular motion and is a good way to evaluate the functionality of a rotational protection system. The method allows for measurement of both the linear and the rotational motion transferred to the headform.



Impact directions

An impact can occur in any area of the helmet. The Mips test protocol includes four test impacts—front, side, rear, and pitch—allowing the helmet to be verified for functionality in all three major rotational components (see picture).

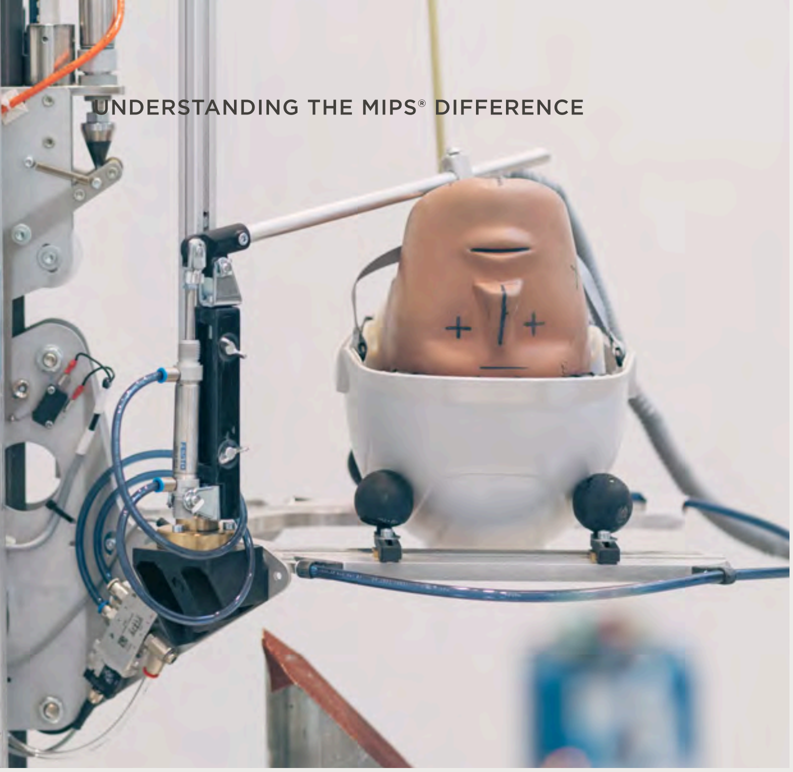
Test headform

A critical aspect of the test set up is that a proper headform is used. There are several different test headforms on the market such as Hybrid III, EN960, NOCSAE, and the newly developed EN17950.

The traditional headform for linear impact helmet testing used in Europe is the EN960. This is a robust metal headform that was developed for testing Type I (linear top impact) and Type II (linear side impact) helmets. It was not designed to test oblique impacts or rotational motion, and thus lacks biofidelity (how well it represents a human head) in both rotational inertia properties and surface friction. The Hybrid III headform was not developed for helmet testing but has improved biofidelity when it comes to inertia and is often used in helmet testing when rotation is evaluated.[7] In the U.S. the NOCSAE[8] headform is used in many helmet test facilities. →

Important parameters of the headform that will affect the resulting kinematics:

- FRICTION OF THE SURFACE
- HEAD SHAPE
- MASS
- CENTER OF GRAVITY
- INERTIA



→ Since 2024, the European standardization committee CEN has developed specifications for a new headform, designed for testing rotational motion in oblique (non-linear) impacts. It is called the EN17950 and is designed to have a more biofidelic inertia, centre of mass, and friction than previous headforms.

Depending on what headform is used, the resulting head accelerations and velocities will be affected. The Hybrid III headform, which Mips has been using in its helmet tests, the NOCSAE, and the EN17950 headform all have a rubber skin material and have a higher friction than the EN960 headform. Therefore, they will result in higher rotational motion than the EN960, in otherwise similar tests. Also, the inertia differs significantly between the headforms.[9]

The Mips system has been validated by third-party studies and internal tests to reduce rotational motion independently of which headform is used[10] and even when additional layers are added such as a wig or stocking[11] that alters the head-helmet friction. The risk in using a headform with less biofidelic properties is that the protection against rotational motion may not be as accurately evaluated, and the injury risks may be underestimated. It is Mips' position that the EN960 headform, while appropriate for evaluating protection against linear impacts, should not be used for the evaluation of rotational protection.

Neck – Why Mips does not use a neck surrogate in its tests

In current standard test methods, either a free head drop or a guided head drop is used. In the free drop, the head is dropped unrestrained onto the impact surface (European test standards). In the guided drop, the head is constrained to a monorail via a rigid arm (U.S. test standards). The latter test method does not allow for any rotations of the headform and cannot be used to evaluate rotational motion from oblique impacts.

In real accidents the head is constrained by a soft and flexible neck. Due to the short duration of a typical head impact and the compliance of the head-neck joint in a human, the head-neck interaction only has a small effect on the initial load transfer to the head.[12] However, looking at longer time intervals, the peak rotational velocity may be affected by the boundary of the neck. There are alternative test set-ups available that include a dummy neck to constrain the headform.[13] Dummy necks are designed by the automotive industry to simulate car crash scenarios and are not designed for the study of impacts to the head.

These necks are documented to behave in a non-biofidelic way,[14] [15] especially during oblique impacts that include vertical or torsional components, which is generally what we see in headfirst impacts. The risk when using a stiff dummy neck during rotational testing is that it is the neck determines the rotation of the head rather than the impact, both in amplitude and direction.[16] Thus, it is Mips' position that it is preferable to test rotational head protection without a non-biofidelic neck. If a dummy neck is included when conducting rotational testing, care should be given to analyze the data appropriately to avoid inclusion of inaccurate head kinematics.

What to measure for (PAV, PAA, BrIC, Strain) and how the data is presented

During an oblique impact test, sensors inside the headform capture both the linear and the rotational motion. This includes, e.g., Peak Linear Acceleration (PLA), Peak Angular Acceleration (PAA), and Peak Angular Velocity (PAV).

Research supports that strain in the brain is one of the preferred predictors of brain injuries such as concussion, shown both in experiments on living animal tissue[17] and in comparison, of numerical models with injury statistics.[18] Mips uses a complex method to measure strain in the brain, requiring a Finite Element (FE) computer model of the human brain. Mips has an exclusive license to use the FE brain model developed by the Royal Institute of Technology in Stockholm, for all rotational testing in this regard.

Though less precise than a FE brain model, the Peak Angular Velocity (PAV) or the Brain Injury Criteria (BrIC)[19] has been shown to predict brain injury fairly well in head impacts of a short duration nature (<20ms). Peak Angular Acceleration (PAA) does not correlate as well with brain strain as PAV or BrIC for short-duration helmet impacts. PAA is more accurate at predicting injury for longer duration impacts, such as car crashes.[20]

It is important to point out that the chosen measured parameter is the result of the specific test performed, with impact location, impact angle, test headform, and impact velocity. As an example, a value of BrIC 0.39 would only be relevant for the specific test set-up evaluated. Just a change of headform, or any of the parameters listed above, would result in another BrIC value.

It is Mips' position that, for helmet impact testing, strain is the best predictor of brain injury, followed, due to its simplicity, by PAV and criteria based on PAV, such as BrIC.

Mips' low friction technology vs deforming materials

The majority of technologies addressing rotational motion on the market are trying to redirect rotational energies away from the head by making the helmet move in relation to the head.

So, what differentiates Mips' technology from the rest?

The Mips system is designed to allow the helmet to slide relative to the head, ~10-15mm, during an angled impact. This relative motion is intended to reduce the harmful peaks of rotational motion. Mips is using a patented low friction layer to allow this sliding motion. Many other available technologies designed to address rotational motion, including 3D-structures and collapsing pods, need to deform in order to make the helmet move on the head. There are some disadvantages with deformation technologies:

1. They may not allow the helmet to move as much as the Mips low-friction layer, i.e., 10-15mm, relative to the head at impact. More movement generally means more energy is being redirected and less is transferred to the head.

2. Deformation takes time. The sliding motion of the Mips technology is nearly instant, whereas deformation takes time so that harmful rotational motion may have already been transferred to the head before the deformation has occurred.

3. While deformation technologies may lower the peak acceleration of the impact (i.e., reducing the PAA), they may prolong the impact, keeping constant the total amount of rotational energy transferred to the head. As noted above, reducing the PAA does not correlate as well with reduced injury risk compared to reducing the PAV.

Sources:

[1] Meaney et al. J of Biomechanical Engineering 2014
[2] Holbourn, A. H. S. British Medical Bulletin 1945
[3] Holbourn, A. H. S. Lancet 1943
[4] Gennarelli, T. A., et al STAPP 1972
[5] Over 50 000 000 helmets equipped with the Mips safety system has been sold per July 2024.
https://www.linkedin.com/feed/update/urn:li:activity:7219332582033809408
[6] STM F3555-22 Standard Test Method for Measuring Impact Attenuation Characteristics of Helmets Under Induced Rotational Loading Using an Inclined Anvil. Figure 1
[7] Willinger et al., prox. International Cycling Safety Conference 2014
[8] National Operating Committee on Standards for Athletic Equipment, The NOCSAE headform – https://nocsae.org/the-nocsae-headform/
[9] Stark et al., Annals of Biomedical Engineering 2024
[10] Mips press-release: How we use headforms in our helmet testing - Mips (mipsprotection.com)
[11] Bonin et al., Annals of Biomedical Engineering 2022
[12] Fahlstedt et al. Ircobi 2016
[13] Whyte et al., Journal of Biomechanical Engineering 2019
[14] Wang et al., Ircobi 2021
[15] Begonia, et al. Ircobi 2018
[16] Rödlund., Influence of the Neck on Head Kinematics in Impacts to the Head, Master thesis, KTH, 2024
[17] Bain & Meaney, J Biomech Eng. 2000
[18] Kleiven, Stapp Car Crash Journal 2007
[19] Takhounts, Stapp Car Crash Journal 2013
[20] Gabler, Annals of Biomedical Engineering 2016

Disclaimer:

No helmet or impact protection system can protect a user from all injuries. Although the Mips® system has been designed to reduce rotational energies to the head, which may lead to brain injuries, there are limits to the protective capabilities of all helmets, including helmets with the Mips® system.