

# Improving blunt impact performance of combat helmets

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**Abstract.** TNO performs research on soldier survivability to support the Ministry of Defence (MoD) in the procurement of materiel. The in service combat helmet is primarily designed to protect against ballistic threats, which does not by definition protect against other types of relevant injury risks for the soldier. Recently, protection against blunt impact to the head in the military context has gained attention, because blunt impact injury accounts for a substantial portion of incidents. The loading as a result of blunt impact, either from falling debris or due to accidents during activities such as parachuting, mountaineering or operating open motorized vehicles, differs from ballistic loading and as such protection requirements differ. The search for a solution that improves the blunt impact performance adds to the traditional trade-off for a solution between minimal burden for the soldier and maximal protection. In addition, the constraints on this trade-off due to legislation may differ between peacetime and wartime. This paper provides an overview of the mechanical loadings that are relevant to military activities. A novel helmet add-on prototype was evaluated, showing that a combat helmet's blunt impact performance can be substantially upgraded, reducing the risk of injury. The add-on concept allows soldiers to 'train-as-you-fight' during peacetime scenarios, whilst benefiting from increased blunt protection.

## 1. INTRODUCTION

The soldier presents probably the most versatile fighting system of any army. Soldiers are tasked with a wide variety of objectives and are given an equally wide variety of tools to achieve those. Whilst the 'job' of a soldier inherently carries a higher risk of injury, the MoD has the obligation to provide the tools and training to minimize those risks where possible. In this context, consequences of investigate blunt impact loadings on the combat helmet were investigated. TNO aids the MoD in this goal by performing research and analyses and has recently started to.

Soldiers are taught to 'train-as-you-fight' to replicate a scenario as realistically as possible. However, training, during peace-time, requires that soldiers must also adhere to civil law (unless exempted). For example, as a combat helmet is not certified for use on motorized vehicles, switching to wearing a certified motor helmet is mandatory when they operate a motor vehicle (such as a quad, see Figure 1) during the training. This is neither 'train-as-you-fight', nor a practical solution. However, the adherence to these regulations provides essential worker safety during peace-time activities. For reference, in the Iraq and Afghanistan campaign, motor vehicle crashes were the second leading cause (Afghanistan: 26%; Iraq: almost 18%) for Type 2 Traumatic Brain Injury hospitalizations [1].



**Figure 1.** NLD KCT operating a quad (Mali, Africa) wearing a combat helmet with night vision goggles.

The aim of the present research was to compare the performance of the Team Wendy combat helmet and improvements in situations posing risks of blunt impact, to that achieved by helmets designed for use in such contexts. This approach intends to provide input for certification of the combat helmet, or support a request for exemption to the relevant law.

The results highlight the requirements for protection of the head against blunt impacts that are compatible with the military's motto to train-as-you fight, and the evaluation of a blunt impact add-on for the combat helmet.

## 2. OVERVIEW OF BLUNT IMPACT RELATED RELEVANT STANDARDS

Several civil standards, regarding blunt impact to the head, were compared to assess the variation in loading and thresholds employed by the different standards. Table 1 shows the selected helmet certification standards based on the potential relevance to military applications.

**Table 1.** Military activity and corresponding selected (helmet) standard

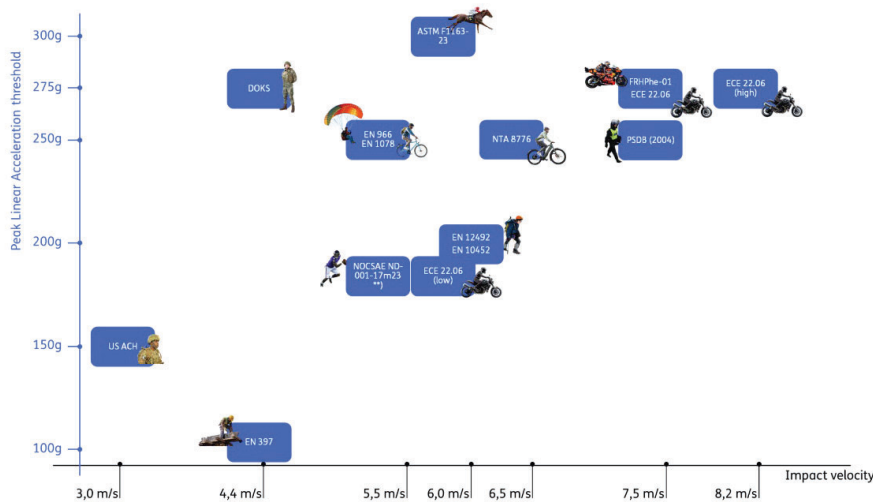
Military activity	Relevant Standard
Operating a motor vehicle	Motor cycle (ECE 22.06 [2]) Racing helmet (FRGPhE-01 [3])
Riot control	PSDB 2004 [4]
Climbing	Mountaineering EN 12492 [5]
Parachuting	Airborne sports EN 966 [6]
Construction	Industrial Helmets EN 397 [7] Protective Helmets EN 13087 [8] High Performance Industrial Helmet EN 14052 [9]
Miscellaneous	Equestrian (ASTM F1163-23) [10] Bike (EN 1078) [11] Speedelec (NTA 8776) [12]

The blunt impact loading in helmet standards is generated in two ways; either by dropping the helmet with headform onto an anvil, or by dropping an impactor onto the helmet. The variables measured in the tests are compared to the thresholds defined in the respective standards (see Table 2)

**Table 2.** Overview of thresholds used in blunt impact standards

Threshold	Loading type	Standard
Peak Linear acceleration (PLA)	Linear	ECE22.06 [2], PSDB(2004) [4], FRHPhe-01 [3]
Maximum transmitted force	Linear	EN 397 [7], EN 12492 [5] , EN14052 [9]
Severity index (SI)	Linear	NOCSAE ND-001-17m23 [13]
Head Injury criterion (HIC)	Linear	ECE22.06 [2], FRHPhe-01 [3]
Peak rotational acceleration (PRA)	Oblique	ECE22.06 [2], NOCSAE ND-001-17m23 [13]
Brain Injury Criterion (BrIC)	Oblique	ECE22.06 [2]

In order to get an initial impression of similarities between standards, the linear impact velocity and corresponding thresholds (PLA) were compared. Where no PLA was specified, the threshold was converted to a PLA using assumptions as specified in the caption of Figure 2. The resulting overview is presented in Figure 2.



**Figure 2.** Overview of head blunt impact standards and corresponding PLA or force threshold.

\*) Conversion from force threshold to PLA is done using  $F = ma$ , using a mass of 5 kg

\*\*) Conversion from Severity Index to PLA assumes triangular pulse of 10ms

Current military helmets do include blunt impact requirements. For example, the Netherlands DOKS helmet specifies a maximum PLA of 275g for an impact at 4,4m/s and the US ACH helmet [14] specifies an impact velocity of 10 ft/s (3 m/s) with a maximum PLA of 150g.

This overview of activities, standards and thresholds provides a reference frame that can be used to judge blunt impact loadings and thresholds. Notable observations in this overview are that higher loadings generally coincide with a higher level of accepted risk. A risk associated to occupational hazards (e.g. EN397 industrial helmets) has a lower threshold (and thus a lower accepted risk) than a voluntary sport (e.g. EN966 paragliding).

A choice of loading and threshold depends on the institution that issues the standard and it will reflect the risk acceptance regarding the intended activities, as well as a maturity of the products at hand. Sometimes new requirements (or standards), opt for relatively easier to reach thresholds so that a minimum level of protection is achieved faster whilst also giving producers a chance to adapt their products. As the requirement matures, a more critical threshold can be chosen to incentivize producers to improve the performance of their products.

### 3. EVALUATION OF BLUNT IMPACT ADD-ON

#### 3.1 Methodology

##### 3.1.1 Helmet and add-on description

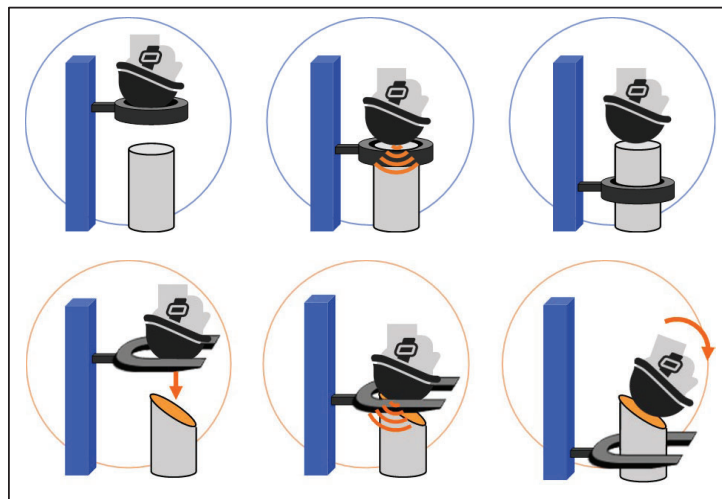
An add-on prototype for the Team Wendy helmet was evaluated that was designed to improve the blunt impact protection (see Figure 2). The add-on consists of an additional shell that attaches to the helmet using Velcro and has a separate element to cover the front-facing mount. The side rails are not yet covered by the current prototype. The intended goal of the add-on is to improve blunt impact protection by redistributing the impact force over a larger area and absorbing and dissipating impact energy.



**Figure 3.** Team Wendy combat helmet (above) and blunt impact add-on (below), from left to right: front-, right-, back- and left side.

### 3.1.2 ECE22.06 drop test

An analysis was performed to assess the blunt impact performance of this prototype, evaluate the added protected, and identify necessary improvements. The ECE22.06 drop test was selected as the test methodology due to its relevance for the operation of motorized vehicles.



**Figure 4.** Linear (above) and oblique (below) impact test procedure

The ECE22.06 drop test includes both linear and oblique impacts (see Figure 3), where accelerations are measured in the headform. From these accelerations, the Head Injury Criterion (HIC) for linear impacts and the Brain Injury Criterion (BrIC) for oblique impacts are determined.

The HIC and BrIC are metrics used to assess the severity of head injuries in impact scenarios. By linking them to established injury risk scales, they help estimate the probability of specific types of brain injuries.

Unlike PLA, which only considers the instantaneous maximum acceleration, HIC accounts for both the magnitude and duration of linear acceleration. A higher HIC value indicates a greater risk of head injury. The calculation integrates acceleration over a specific time window (up to a maximum of 36 ms) to capture the most critical phase of the impact.

BrIC is used for oblique impacts and focuses on rotational kinematics, particularly angular velocity. Since brain injuries such as concussions and diffuse axonal injury are strongly linked to rotational forces, BrIC complements HIC by providing a broader assessment of head injury risk. However, as the inclusion of oblique impact testing is relatively new in ECE 22.06 [2], the current thresholds for rotational acceleration and BrIC are generally considered less constraining compared to those for linear impacts, which is not reflected in epidemiology studies [15].

The ECE22.06 specifies three impact velocities and corresponding thresholds for the Peak Linear Acceleration (PLA) and HIC, and one impact velocity for the Peak Rotational Acceleration (PRA) and BrIC. These thresholds are provided in Table 1.

For the linear impact test, four impact points are defined, that are all tested one helmet: Frontal area (B), Left or right lateral area (X), Top (P) and Rear (R). For the oblique impact test, the ECE22.06 prescribes five impact points to be tested on two helmets, out of which the following three impact points were selected for this study: Rear (180°), Lateral left (270°) and Front (0°). All impact locations must meet the thresholds defined according to ECE 22.06.

**Table 1.** Thresholds prescribed by ECE22.06 for linear (top table) and oblique (bottom table) tests.

Test	Impact velocity	PLA threshold	HIC threshold
Linear blunt impact	6,0 m/s	≤ 180 g	≤ 1300
Linear blunt impact	7,5 m/s	≤ 275 g	≤ 2400
Linear blunt impact	8,2 m/s	≤ 275 g	≤ 2880

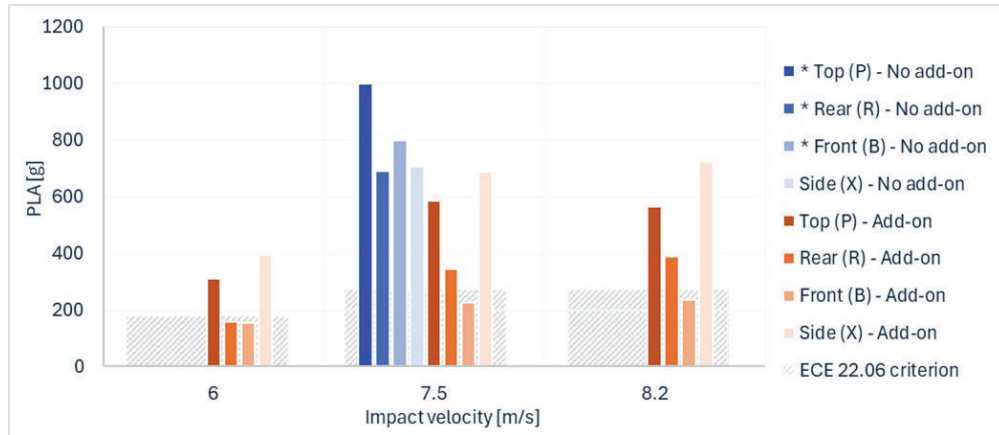
Test	Impact velocity	PRA threshold	BrIC threshold
Oblique blunt impact	8,0 m/s	≤ 10400 rad/s <sup>2</sup>	≤ 0,78

The tests were performed by TASS International, where a total of five helmets was tested. The helmet without the add-on was only subjected to the linear impact test, as this represents the most critical impact loading condition. The test was conducted at the standard velocity of 7.5 m/s. Helmets with the add-on were tested at all three linear impact velocities (6.0 m/s, 7.5 m/s, and 8.2 m/s) as well as in the oblique impact test at a velocity of 8.0 m/s.

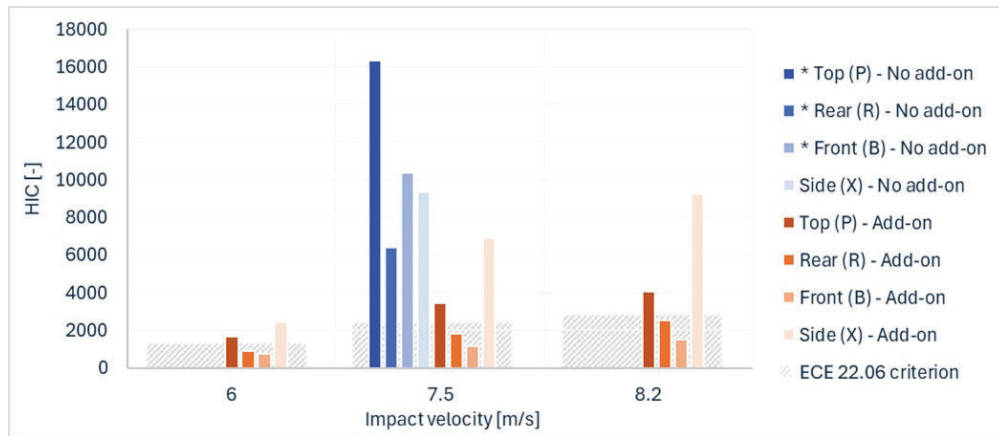
### 3.2 Results

Figure 5 and Figure 6 show the PLA and HIC results for linear impacts on the helmet with and without add-on. The oblique drop tests were also performed, but since the results with the add-on were well below the ECE22.06 thresholds those results have not been included in this publication. In contrast, the ECE22.06 thresholds for the linear impact tests appear to be harder to satisfy which is in line with other results [15].

Note that (for the tests without the add-on) TASS indicated that some of the measured accelerations exceeded their equipment specifications. In accordance with ECE22.06 the raw accelerometer signals are filtered, leading to the results presented here. However, the unfiltered signals may contain peaks that exceed sensor limits. Where applicable, those results have been indicated in the results.



**Figure 5.** Peak Linear Accelerations (PLA) measured during drop tests with and with-out the blunt impact add-on. \* indicate measurements exceeding test equipment specifications



**Figure 6.** Head Injury Criterion (HIC) values based on accelerations measured during drop tests with and with-out the blunt impact add-on. \* indicated measurements exceeding test equipment specifications.

### 3.2.1 Helmet without add-on

The helmet without the add-on, serving as a reference for comparison of the add-on performance, was tested in a linear impact at the standard velocity of 7.5 m/s. The measured PLA and HIC values can be found in Figure 5 and Figure 6 respectively. In 3 out of the 4 tests, the measured acceleration exceeds the capacity limit of the accelerometers. The capacity limit of the accelerometers used is 500 g per direction, with a theoretical limit of 866 g, and any values reported above this limit are unreliable and should be treated with caution. For the top, rear and front impact locations, the measured accelerations exceed the equipment limit and cannot be used for calculations. These measurements are indicated in the label of the figures with an asterisk.

The ECE22.06 PLA threshold is well below the capacity limit. The exceeding of this limit during the helmet test with the available equipment strongly indicates the poor blunt impact performance of the helmet without the add-on, reinforcing the need for additional protective measures.

Only the acceleration for the side impact location could be reliably measured. However, with a PLA of 709 g and a HIC of 9355, the performance still exceeds the threshold values provided in ECE 22.06 (indicated by the hatched areas in the figures).

### 3.2.2 Helmet with add-on

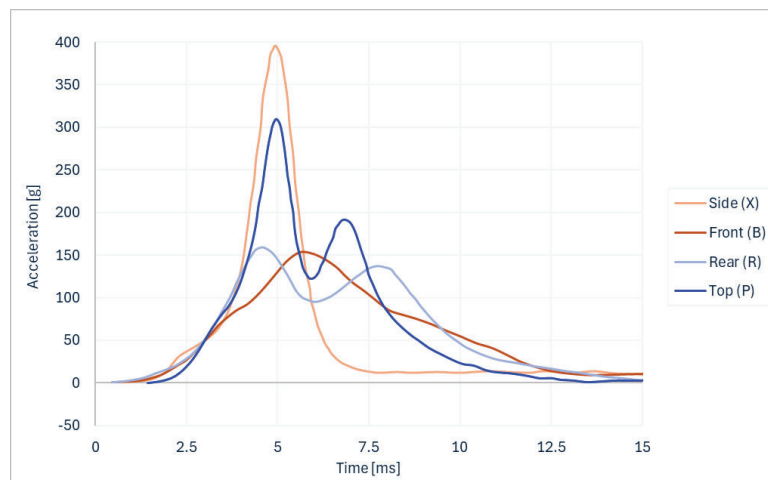
Linear impact tests with the add-on were conducted at three different velocities (as specified in ECE22.06), with the results presented Figure 5 and Figure 6. The performance of the helmet add-on varied depending on the impact location.

The top location demonstrated the worst performance. At all tested velocities, the helmet did not meet the thresholds set by the ECE 22.06 standard. The measurement of acceleration over time, presented in Figure 7 for the impact velocity of 6 m/s, shows two peaks in the acceleration experienced by the headform. The first peak is likely attributed to the outer shell of the add-on that deforms, and dampens the impact. Damage on the outer shell of the add-on is observed after testing (see Figure 8). The second peak is hypothesized to originate from either the contact of the outer shell with the inner foam of the add-on, or the contact of the add-on with the helmet.

Similar behaviour with double peaks in acceleration is observed for the rear impact location. However, the acceleration is significantly lower at this location, and it meets the ECE 22.06 standard threshold for HIC at all impact velocities and the PLA threshold for the 6 m/s impact.

In contrast, the front location demonstrated the best performance with a single, spread-out peak. The helmet with the add-on met the ECE 22.06 standard thresholds at all tested velocities. Plastic deformation of the add-on was observed at the front location after the tests, which likely contributed to its superior performance due to additional energy absorption through crushing. The front is also the only location that meets the PLA requirements set in the ECE 22.06 standard at all impact velocities.

The side impact location was not covered by the add-on. Results are (as expected) similar to the results without the add-on. The results showed a single peak in the headform acceleration.



**Figure 7.** Acceleration of the headform over during the linear impact test at 6 m/s with the add-on



**Figure 8.** Damage to add-on shell after linear impact at 6 m/s at top location.

A comparison of the helmet's performance with and without the add-on at an impact velocity of 7.5 m/s clearly demonstrates an improvement in blunt impact protection. The add-on dampens the impact

and spreads out the acceleration to enhance protection. The most substantial improvement was observed at the front location. For the top and rear, there is still a substantial improvement, but the acceleration peak is less spread out and instead a double peak behaviour is obtained, indicating room for improvement.

#### 4. CONCLUSIONS

This paper presents a pilot evaluation of the blunt impact performance of a prototype for a blunt impact add-on for a military combat helmet. Without the add-on, drop tests (according to the ECE 22.06) with the military helmet result in PLA and HIC values that far exceed the ECE22.06 criteria. With the add-on there is a significant improvement and shows some values that meet the ECE22.06 criteria.

Thus, the current add-on improves the blunt impact protection of the helmet and thereby reduces risks of blunt impact injuries. It is not sufficient yet to pass the requirements outlined in the ECE 22.06, but it is expected that further engineering can result in a next iteration that meets the ECE22.06 criteria. At this moment critical points to address are impact performance at the top (P) location and a solution that covers the side (X) locations without significantly impeding the functionality of the side rails.

This study shows that a fairly simple add-on construction can substantially improve a military helmet's performance against blunt impact. Improving the blunt impact performance can potentially reduce a substantial number of TBI related injuries that occur through e.g. motor vehicle accidents. This is especially relevant in training scenario's where military personnel is expected to adhere to civil laws and regulations. In peacetime conditions, balancing the motto to train-as-you-fight, with the safety of personnel might lead to different decisions regarding the utilized personal equipment. At the moment this leads to scenarios in which military personnel, operating motor vehicles, are expected to use a separate combat helmet and a motor helmet during training. An add-on, such as the one evaluated in this paper, is a solution that removes the need for two separate helmets.

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