Optimized protective clothing for motorcyclists: Which safety benefit can airbag-clothes deliver?

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Introduction

Motorcyclists still have a significantly higher risk than car occupants of being injured or even killed in an accident. Over 18% (583) of all road users killed in Germany in 2017 were motorcyclists. In the same year, almost 10,000 motorcyclists were seriously injured in road accidents, which is almost a third of the number of seriously injured car occupants. This also represents an increase on the share seriously injured ten years ago (Destasis, 2018). The total annual distance covered by motorcyclists in Germany amounts to only around 2% of the distance covered by cars (BASt, 2018). That means, in relation to the covered distance, motorcyclists have a considerably higher risk of being killed in a road accident than car occupants. In 2017 the risk was higher by a factor of 20. Moreover, the level of risk is constantly increasing. The accidents of motorcyclists are often serious collisions, since they do not have the benefit of the protective crumple zones or highly developed safety systems that have become standard in virtually all cars. Depending on the circumstances of the impact, the motorcyclist's body may have to absorb most of the energy involved, which often results in severe and fatal injuries. Accordingly, there is significant scope for optimizing the protective clothing of motorcyclists. In particular, new developments such as airbags in protective clothing are highly promising. However, a detailed analysis of the injury patterns and protective mechanisms is essential so that solutions can be developed and their effectiveness assessed. There has been insufficient research carried out into this so far. The aim of this project is to study the accidents that occur in order to identify typical accident situations and impact scenarios. In addition, a list ranking the regions of the body most badly affected will be produced. Based on these findings, selected "optimized protective clothing" will be thoroughly assessed in terms of its potential to prevent injuries and mitigate the severity of any injuries.

Underlying data and methodology

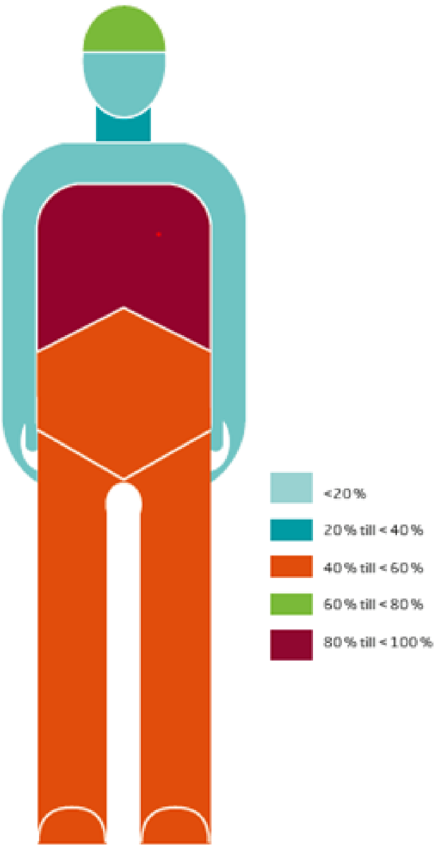
The regions of the body most often affected in motorcycle accidents were identified initially following an analysis of the available accident data. In addition, typical accident situations involved in motorcycle accidents, any relevant impact parameters of the motorcyclist and the characteristics of the object involved in the impact (including its geometry) were obtained from the accident data. The motorcyclist's speed of impact was of particular interest here in order to be able to calculate the force expected to be transferred to the motorcyclist.

Three samples were available, which largely account for the serious accidents. On the one hand, there were 76 fatal motorcycle accidents from the years 2004 to 2014 provided by the institute for forensic medicine at Ludwig-Maximilians-Universität München (LMU). In addition, there were a further 55 fatal motorcycle accidents (from the years 2003 to 2016) provided by a firm of experts. Autopsies of these motorcyclists or pillion passengers were carried out at the institute for forensic medicine at LMU. The motorcycle accidents were selected if they met the criteria of involving a motorcycle of the EU category L3e or L4e and a motorcyclist or pillion rider who had died as a result of the accident. Detailed records were available for the accidents in the form of technical and medical documents. These included accident analysis reports, technical reports and autopsy reports. The documented injuries were categorized on the basis of the Abbreviated Injury Scale© or AIS (2015). This case material was complemented by accidents involving motorcycles taken from the UDV accident database (UDB). 156 accidents were available involving at least one motorcycle belonging to the category L3e. 213 motorcyclists/pillion passengers were injured to varying degrees in these accidents. However, detailed medical information was available only on the 42 who were seriously injured and the 23 who were killed.

The circumstances of accidents involving two-wheelers are generally relatively complex, and when they are reconstructed, uncertainties often cannot be eliminated. In particular, the impacts of motorcyclists are difficult to describe because they often involve more than one object. This is also clear from the literature (COST, MAIDS). In order to be able to circumscribe the impact parameters of the motorcyclist during the accident without having to carry out a very time-consuming and detailed reconstruction of all accidents, the fatal accidents of LMU and the firm of experts were subjected to simplified kinematic encoding. In particularly complex scenarios and for some particularly relevant accident situations, multi-body system simulations (PC-Crash and Madymo) were carried out to complete the picture. Finally, based on these results, detailed finite-element model (FEM) simulations were carried out in order to assess and categorize the injury risk and the potential of optimized protective clothing to provide protection.

Injuries and most often involved body regions

As far as injury severity is concerned, it is clear that the available data largely concerns very serious accidents. Just over 30% of the motorcyclists on whom autopsies were carried out at LMU had an injury severity of MAIS 5, and just over 40% had an injury severity of MAIS 6, which is currently considered to be untreatable. 94% of all motorcyclists or pillion passengers on whom an autopsy was carried out at LMU had serious thoracic injuries at the level of MAIS 3+ (figure 1). The high prevalence of thoracic injuries tallies with the findings of other studies (COST, MAIDS, MOSAFIM). Frequent injuries included haemothorax, fractured ribs and lung injuries. Injuries to the thoracic aorta were found in around a third of the motorcyclists involved in these accidents.



MAIS Head 3+	87	63,8%
MAIS Face 3+	11	8,0%
MAIS Neck 3+	44	32.1%
MAIS Thorax 3+	129	94.2%
MAIS Abdomen 3+	66	48.2%
MAIS Upper Extremities 3+	8	5.8%
MAIS Lower Extremities 3+	75	54.7%
MAIS External 3+	3	2.2%

Figure 1: Percentage of people killed who had at least one serious injury (AIS 3+) in the regions of the body shown (LMU, n=137)

In addition to the motorcyclists killed in accidents, less seriously injured motorcyclists were also investigated using the UDB. This was done in order to address less serious injuries as well and get a better impression of all the accidents taking place. 78 motorcyclists from the sample taken from the UDB were categorized as “slightly injured” or “uninjured”. 112 people suffered injuries with a MAIS 1+ degree of severity. 42 of the motorcyclists had injuries with a MAIS 3+ degree of severity. Among the 44 motorcyclists and pillion passengers with MAIS 2 injuries, injuries to the extremities were most common, and thoracic injuries were of only secondary relevance (figure 2, multiple responses possible).

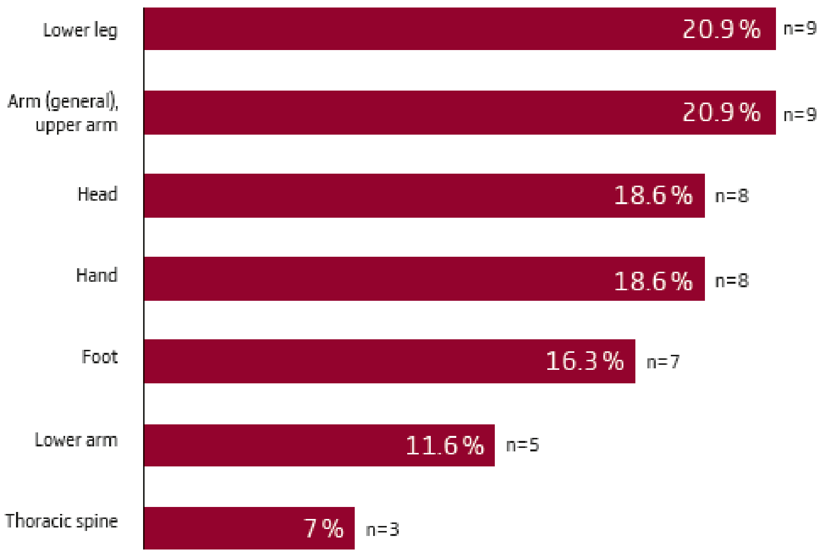


Figure 2: Region of the body with the highest AIS value (motorcyclists with AIS 2 injuries in the UDB, n=43)

This tallies with the analyses of minor motorcycle accidents in the literature. In the MAIDS study, for example, it was found that around 32% of the motorcyclists involved in accidents had AIS 1+ injuries to the lower extremities. This was the most commonly injured region of the body, followed by the upper extremities (around 24%). In Malczyk's dissertation, around 71% of the motorcyclists with AIS 1+ injuries had fractures in their lower extremities (MAIDS). Around 36% had a fractured femur, and 29% had a fractured tibia/fibula (Malczyk). It should also be mentioned that the percentage of head injuries in the samples studied was also high. In the current project, however, it was decided not to study this region of the body in any depth. Other studies (COST, MAIDS) have already addressed head protection for motorcyclists in depth. When all the findings obtained from the analysis of the injuries are compiled, it becomes clear that the thorax is by some distance the most relevant and very often the most seriously injured region of the body, particularly in serious and fatal accidents. Consequently, this project addresses thoracic impacts and analyzes the potential of optimized protective clothing.

Kinematic analysis and typical impact parameters

The kinematic analysis and advance categorization carried out before the detailed calculations enabled the subsequent grouping and identification of particularly frequent and relevant impact parameters. These were then analyzed in detail by means of simulations.

In each case, the available technical and medical documents were examined, and based on these the possible course of the accident, including the mechanical impact parameters, was described. In addition, rough calculations were carried out, and attempts were made to link the thoracic injuries with specific objects involved in the impacts. The objects involved in the impacts were categorized based on factors such as their radii and rigidity. It was found that the objects were largely highly rigid. The radius of the object or whatever the victim comes into contact with plays a key role in the mechanical analysis of the injuries and the protective clothing. For example, the impact forces can be transferred to the relevant part of the motorcyclist's body at particular points or distributed over a larger area. When the force is transferred against a particular point, there is an increased risk of injury. On the other hand, when it is distributed over a larger area, the intensity of the load to be expected is lower assuming the impact parameters are otherwise the same. The speeds of the motorcyclist on impact, in particular the vertical portion of the speed in relation to the object, which is of particular relevance to the injury caused, were also studied.

Based on the results of the kinematic analysis, the following key areas of focus can be identified for the thorax in the relevant impact scenarios:

- Impact with the road (vertical speed of around 17 km/h)
- Impact with an object with a radius of around 0.075 m, impact speed of around 25 km/h
- Impact with an object with a radius of around 0.075 m, impact speed of around 60 km/h
- Impact with an object with a radius of around 0.25 m, impact speed of around 50 km/h

A small impact radius is typically found with car structures such as the edge of the roof or the sill or objects at the side of the road such as the posts of crash barriers. A somewhat larger radius is characteristic of components such as the corners of bumpers, for example, but also, in particular, of trees or other vegetation at the side of the road. Within these key areas of focus, typical accident scenarios were identified and analyzed in detail. The procedure is described below using the example of one particularly relevant impact scenario (motorcyclist collides with the side of a car crossing its path). The accident was initially assessed on the basis of relevant parameters and then simulated using multi-body simulation in Madymo (figure 3). A motorcycle model available to LMU and a freely available vehicle model from the NHTSA database were used for this. The purpose of the multi-body simulations was to calculate the impact parameters of the motorcyclist, in particular the speed, orientation and exact point of impact. These then serve as the initial parameters for the finite-element model (FEM) simulation of the loads and injury risks to be expected.

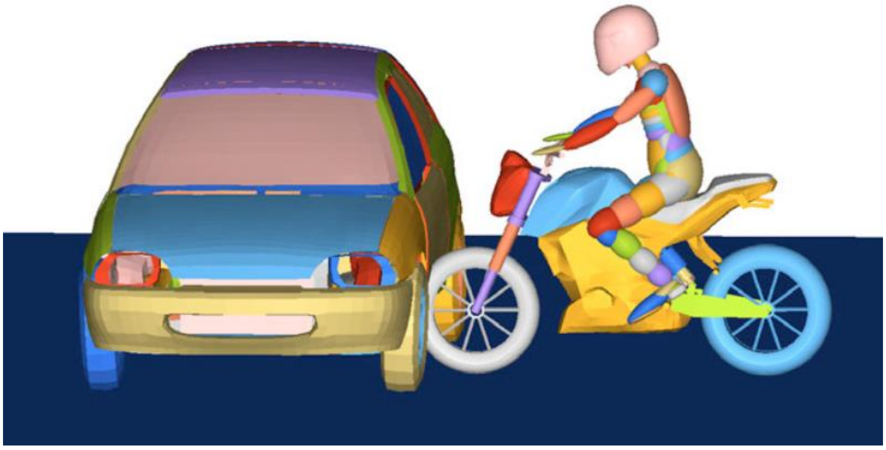


Figure 3: Multi-body simulation of the impact of a motorcyclist with the side of a car

Simulation of typical impact situations and injury-related mechanical assessment

The further simulation of the typical impact situations and the injury-related mechanical assessment was carried out by means of FEM simulations. The male 50th percentile of the Global Human Body Model Consortium (GHBMC) model was used for this. The model is being constantly further developed and has been adequately validated for the selected application scenarios.

The airbag concept was used as optimized protective clothing in this research project. In order to be able to ascertain the potential of the latest commercially available thorax airbags to offer protection, a corresponding generic (i.e. general) finite-element model was developed and adapted for the human body model (figure 4). To this end, a technical exchange was sought with well-known airbag manufacturers. In addition, in order to further circumscribe and examine the model parameters, a commercially available thorax airbag was tested multiple times on the basis of the valid test conditions specified by EN 1621-4. The generic model meets the requirements of safety level 2 of the EN 1621-4 standard.

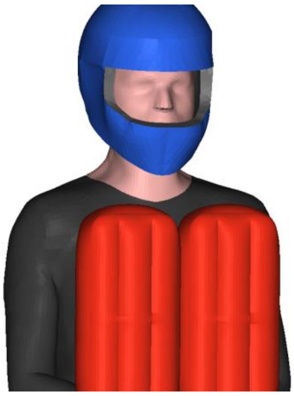


Figure 4: FEM human model (GHBMC) and generic thorax airbag model

An "optimized" airbag with a significantly greater volume was modelled for further investigations. However, this was merely a model concept intended to illustrate the potential and limits of future developments. It will not necessarily be easy to implement this concept technically. Based on the results of the kinematic analysis, the generic scenarios identified as key areas of focus were then simulated. To this end, the human model was propelled at the calculated speed against an object with the relevant radius and the calculated rigidity (figure 5). The simulations were run both with and without an airbag.

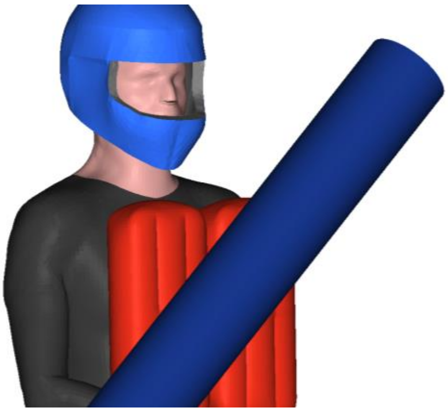


Figure 5: Essential setup of the FEM simulation of a generic scenario (radius of the object involved in the impact: 0.075 m)

In addition, a number of typical real accidents were replicated and simulated by means of FEM. The collision of a motorcyclist with the side of a car and the resulting impact of the motorcyclist's thorax with the edge of the roof is shown in figure 6.

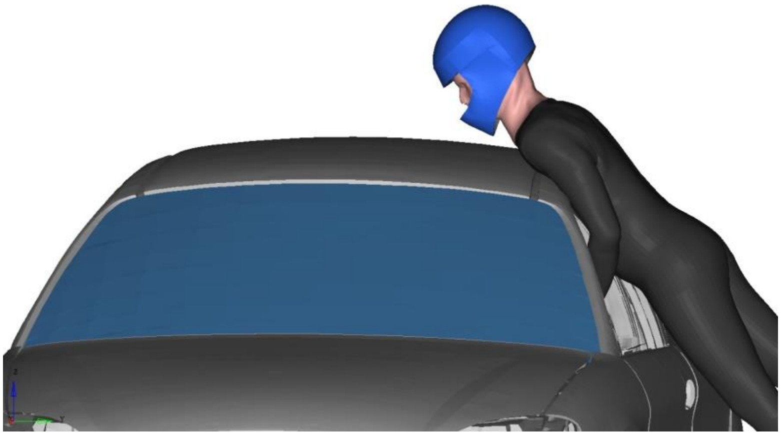


Figure 6: FEM simulation of the impact of a motorcyclist with the edge of a car's roof

On the basis of these simulations, the loads and the thoracic injuries to be expected were then ascertained and assessed. Thorax deformation and fractured ribs were used for this, in particular, since it seems possible with the model used to calculate real injury risks using these parameters.

For the example of the impact of a motorcyclist at 60 km/h against an object with a radius of 0.075 m (e.g. the edge of a roof), the thorax is shown with the heart, aorta and lungs in its initial state (in the images on the left) and at the point of maximum compression (in the images on the right) in figures 7 and 8. It is clear that this is a very serious impact and that very serious injuries would be expected from it. In addition to serial rib fractures on both sides, the expected injuries would include life-threatening injuries to the heart or aorta. In this example, a state-of-the-art airbag would reduce the load on the body only slightly, if at all. It is likely that there would be little difference in the severity of the injuries with or without an airbag.

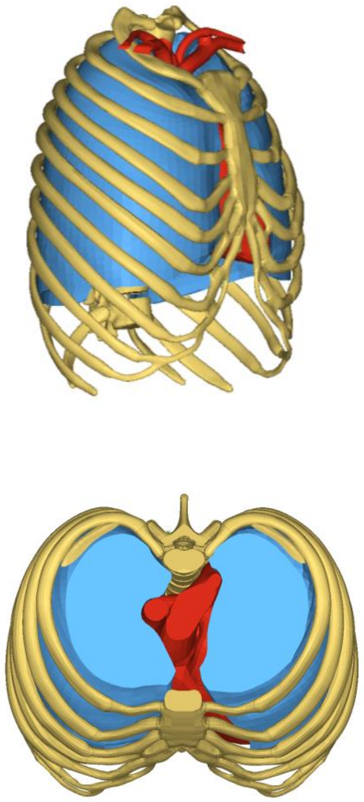


Figure 7: Condition before the collision

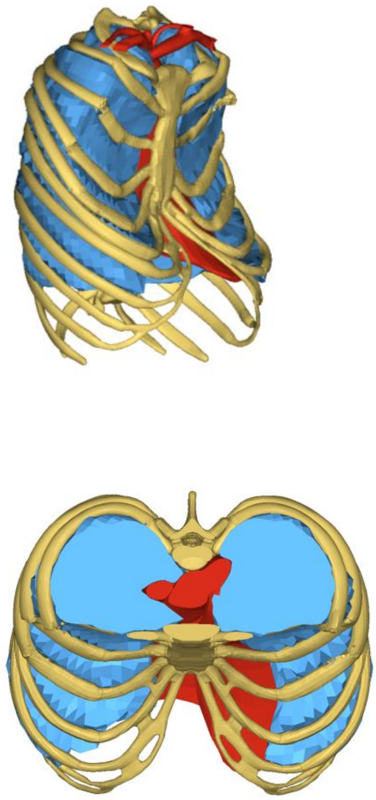


Figure 8: Deformation during the collision

The results of the mechanical analyses of the injuries make it clear that currently available thorax airbags can only offer protection at low speeds of impact. At a speed of impact of 25 km/h against the same object with a small radius (0.075 m), there are clear positive differences compared to an unprotected impact. Instead of the serial rib fractures on both sides that occur without an airbag, there are only two fractured ribs with an airbag. Thorax deformation is reduced from around 70 mm to around 45 mm, which would significantly mitigate injuries. In the case of an impact against a surface such as the road, which is most likely to occur as a result of a fall and generally happens at a speed of under 20 km/h (vertically to the surface), no serious injuries would be expected even without an airbag.

At speeds of impact of 50 km/h (radius: 0.25 m) and 60 km/h (radius: 0.075 m), current airbags reach their limits. No protective effect can be observed in terms of injury severity at these speeds. In these scenarios only an “optimized” airbag, which has not yet been implemented in this form, would help (figure 9). However, even a significantly optimized airbag comes up against its limits. It was possible to show by means of the simulations carried out that the protective effect decreases dramatically as of a speed of impact of slightly over 60 km/h. As of a speed of impact of 70 km/h, there is no longer an appreciable protective effect.

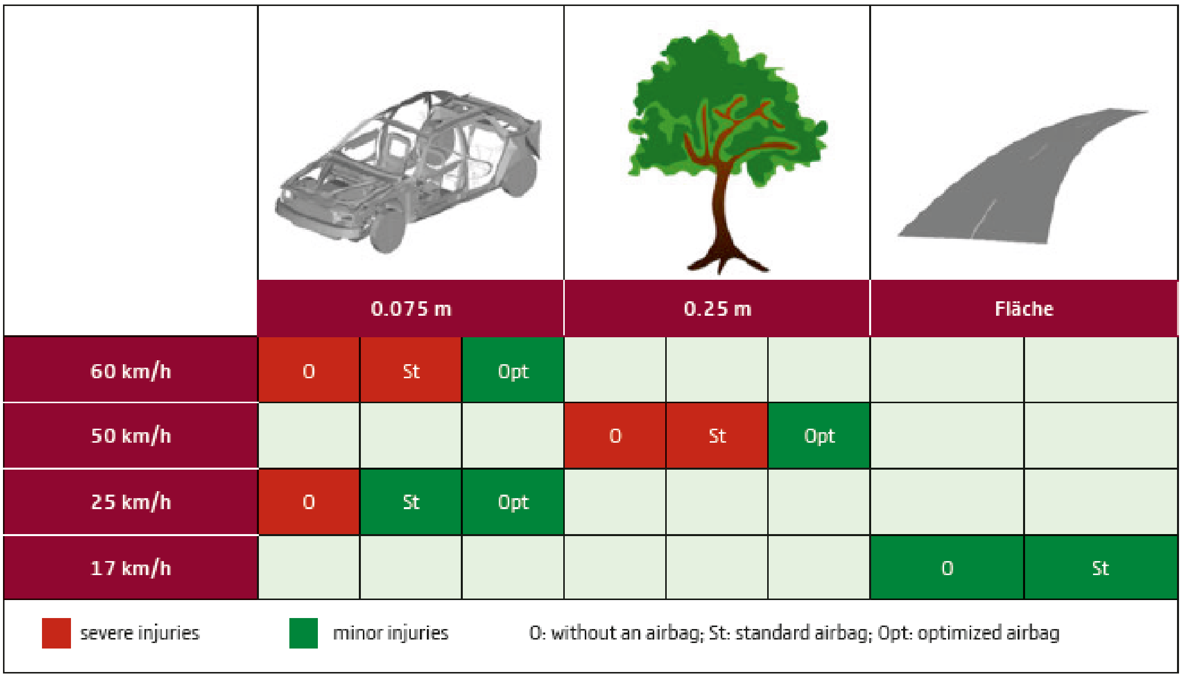


Figure 9: Simulation matrix and protection potential (red: severe injuries; green: minor injuries; O: without an airbag; St: standard airbag; Opt: optimized airbag)

Recommendations on the protection offered by optimized protective clothing

Taking the results of the analyses together, it is clear that today's commercially available thorax airbags can mitigate injuries at lower speeds of impact. The higher the speed of the impact and the smaller the radius of the object involved in the impact, the smaller is the protective effect that can be expected. As of a speed of impact of at most 50 km/h, no appreciable mitigation of injury severity can be expected. Even a significantly optimized airbag, which can still have a protective effect in this speed range, is no longer effective as of a speed of impact of at most 70 km/h.

What that means in terms of accidents is that a thorax airbag can offer good protection in minor accidents, in particular. In such accidents, however, no severe injury consequences would be expected even with conventional protective clothing (without an airbag). The typical impact conditions ascertained (approx. 25 km/h) are in the range for which today's motorcycling helmets are designed and offer good protection against injuries. However, the analysis of accidents reveals that thorax injuries do not occur often in this group of minor accidents and are also not always very serious. Injuries to the extremities are most common in these accidents.

In more serious accidents at higher speeds of impact, the relevance of serious thorax injuries increases significantly. However, the protective potential of airbags in protective clothing decreases to the same extent. The benefits of today's thorax airbags should therefore be rated as acceptable, but given the overall context, they should be viewed as controversial.

DIN EN 1621, parts 1 to 4, is currently applicable in Germany for the marketing of approved protective clothing with mandatory labelling for motorcyclists and the protectors and airbags it contains. The standard specifies test procedures for ascertaining the extent to which this clothing absorbs shock and distributes impact forces. For example, chest protectors must allow only certain residual forces in an impact with a test object with a weight of around 5 kg and at a speed of around 16 km/h.

Inflatable protectors for motorcyclists are treated separately on the basis of a variety of parameters (e.g. intervention time, service life) and, in terms of their protective effect or shock absorption, only have to meet the requirements of conventional protectors. There needs to be a discussion about adapting the test parameters for optimized protective clothing developed in the future. In particular, the test weight used and the test speed should be increased appropriately.

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