

Influences on the Risk of Injury of Bicyclists' Heads and Benefits of Bicycle Helmets in Terms of Injury Avoidance and Reduction of Injury Severity

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ABSTRACT

This study deals with the risk of injury to the bicyclist's head and the benefits of wearing a bicycle helmet in terms of reduction of injury severity or even injury avoidance. The accident data of 4,245 injured bicyclists as a randomized sample, collected by a scientific research team within the GIDAS project (German In-Depth Accident Study) were analyzed. Given that head injuries result in approximately 40% of bicycle-related crashes, helmet usage provides a sensible first-level approach for improving incidence and severity of head injuries. The effectiveness of the bicycle helmet was examined using descriptive and multivariate analysis for 433 bicyclists with a helmet and 3,812 bicyclists without a helmet. Skull fractures, severe brain injuries and skull base fractures were up to 80% less frequent for bicyclists wearing a helmet. Among individuals 40 years of age and older, a significant increase of severe head injuries occurred if no helmet was used compared to younger persons with helmet.

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INTRODUCTION

In the Federal Republic of Germany in 2012 a total of 406 bicyclists were killed (2011: 408), 13,853 bicyclists were severely injured (2011: 15,127) and 60,513 were slightly injured (2011: 66,535). The number of cyclists killed in traffic (Figure 1) has fortunately almost steadily decreased by about ¾ over the past 30 years, from 1,338 in 1980, while the total number of injured and killed cyclists (casualties, Figure 2) rose from 54,583 in 1980 to 74,772 in 2012 [1].

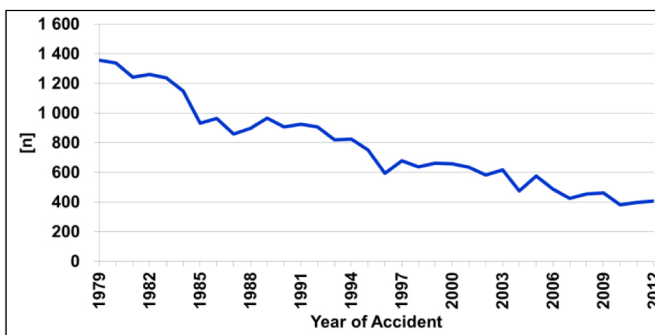


Figure 1. Numbers of bicyclists killed in traffic in Germany from 1979 to 2012 [1].

These figures show the rising amount of accidents due to increase of traffic while the injury severity decreases. This possibly results from a shift of fatal injuries to non-fatal injuries. While it is difficult to analyze the injury situation in Europe due

to different sets of statistical data collected by the EU member states, the decrease of killed bicyclists in Europe can be seen in accordance to Germany [2] during the same period.

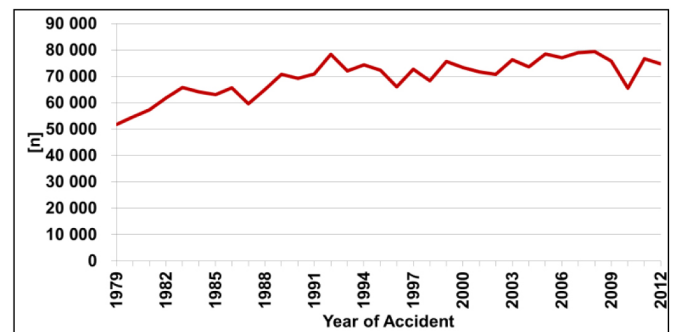


Figure 2. Numbers of injured bicyclists in Germany 1979 to 2012 [1].

The increasing impact of traffic safety measures is perceptible, but the continually high numbers of injured bicyclists show that additional measures still need to be implemented. These may be realized via road planning, vehicle safety through the design of the exterior of the vehicle and active vehicle assistance systems for the prevention of accidents, but also as self-protection measures of the cyclists, for example by wearing suitable protective gear. Injuries of cyclists can be caused by primary or secondary collision with a vehicle or by hitting the road or other obstacles. The heads of riders have been protected by helmets for nearly a century; it all started in

bicycle racing. As early as the beginning of the 20th century, leather crash headgear resembling a crash cap or a crash ring was in use for racing cyclists. It was not until the 1970s that development in the helmet sector continued for cyclists on roads. In the mid-70s, the U.S. company Bell started developing helmets made of EPS (Expanded Polystyrene). Amongst cycling teams it was quickly established that this kind of helmet was able to protect the head much better than previous models. Helmets soon became the standard in bicycle racing and later for all cycling activities.

In 1970 the Snell Foundation published the first U.S. standard on bicycle helmets. Only in the late 80s with the introduction of new helmet materials and an emerging impression of usefulness of head protection on the side of the consumer, bicycle helmets started being used in traffic. With the development of international standards for the design of bicycle helmets, the hard shell helmet emerged, which has changed very little to this day. Changes are limited to some design alterations and demands on convenience, ventilation and protective effect. For the US the ANSI Z90.4 committee helped to get the standard adopted over the objections of manufacturers, later the standard lapsed, and was declared obsolete by ANSI as of February 1995 when the ASTM bicycle helmet standard was adopted as the new ANSI standard [3]. The standard CEN EN 1078 [4] applies to Europe. In addition to the technical design and comfort requirements, which are usually described verbally in the standard, there are also technical requirements, including shock absorption, retention system and chinstrap fastening as well as durability of the helmet material. Shock absorption, the resistance to penetration, effectiveness and strength seem important for the prevention of injuries. In shock absorption tests, the maximum permissible acceleration values for a drop test using a dummy head on a flat anvil and on a curbstone anvil are specified for the predetermined protection areas forehead, back of the head, temples and forehead. These conditions should correspond to the objects of impact in real world accidents. Figure 3 describes the applicable testing zone at the helmet, whose location has been described in the CEN-Standard. It is tested by the test houses in accordance with the so-called "worst case" method, the test points on the helmet are selected by the test houses themselves.

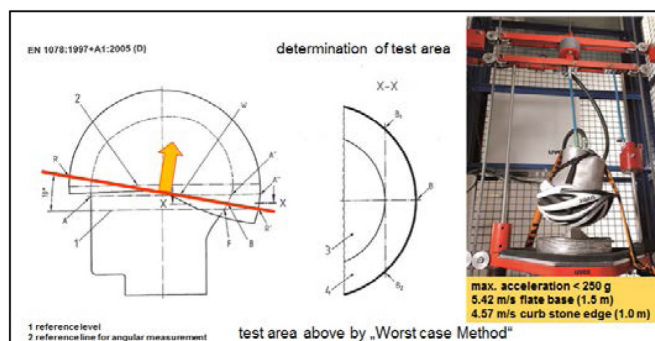


Figure 3. Shock absorption test in accordance with CEN EN 1078 [3].

The effectiveness of bicycle helmets in accidents is described in a variety of ways, but largely positively, in scientific literature. A study by Maimaris et al. [5] in the UK determined that 4% of the wearers of bicycle helmets suffered head injuries in contrast to 11% of those not protected by helmets, whereas an Australian study by McDermott [6] compared the fatality rates of helmet wearers (0.4%) to those not wearing helmets (0.9%). The study highlights the effectiveness of bicycle helmets as injury prevention devices. Studies have also pointed at a reduction of facial injuries due to bicycle helmets. Wesson et al. [7] described a reduction of injuries of the upper facial area, whereas no reduction of injuries to the lower facial area had occurred. This was confirmed by Rivara et al. [8]. However, there are also studies expressing doubts in relation to the effectiveness of bicycle helmets in accidents. In particular, the Australian studies by Voukelatos et al. [9] have to be mentioned in this context. They are based on the annual representation of the ratio of arm and head injuries in conjunction with the date when helmet use became mandatory, and which postulate no indication of the effectiveness of bicycle helmets as potential protection. He assumed that helmet use should lower this ratio as an indicator of the effectiveness of helmets. If this ratio is regarded over time, however, it becomes obvious that in Australia (New South Wales) this ratio decreased continuously from 1985 to 2000, whereas the helmet use for cyclists became mandatory only in 1990, and a total of 3 years passed until 100% of the bicyclists were in fact using a helmet. One explanation is derived from the fact that other measures such as the influence of road safety through planning measures are more effective than wearing a bicycle helmet. In this context UK publications concerning the influence of a mandatory wearing of bicycle helmets are interesting. Walker [10] found that drivers of cars and trucks passed closer to cyclists if they wore a helmet and kept more distance if no helmet was worn. Studies by Adams et al. [11] confirm this influence of the helmet and name risk compensation as the cause of a negative consequence of a practical implementation of a safety measure, which analogous to the introduction of the seat belts and motorcycle helmets, now applies to bicycle helmets, negating a protective effect. Wearing a helmet may affect the behavior of the wearer in traffic and can therefore cause a higher risk of accidents. In contrast, many studies showed that an increase in the frequency of wearing bicycle helmets due to motivating campaigns resulted in a significant decrease in head injuries in cyclists ([12], [13]). The effectiveness of bicycle helmets in literature is often discussed in conjunction with mandatory helmet use, for that reason there are a few studies specifically showing the effectiveness of the helmet in relation to injuries sustained and a scientific assessment of the protective potential of helmets in view of certain injury patterns to the head. In particular in Germany, there are few studies on the effectiveness of bicycle helmets, since as yet helmet wearing rates are very low, which does not permit statistical comparisons of wearers of helmets with those without a helmet and for which usually no control groups were available. Only recently have results concerning the effectiveness of helmets appeared, based on accident analyses for Germany. A study by

the insurance company Allianz published in 2013 [14], advocates the use of bicycle helmets noting that seniors constitute 51% of all fatalities amongst pedestrians and cyclists. One third of all bicycle accidents without involving third parties are falls and that the number of unreported cases here is very high, which means they are not even included in the official accident statistics. A study by the University Hospital Münster published in 2012 [15] also points that way. Kroemer et al. [16] carried out a pilot study for Austria on this subject and estimated their number at 1.6 million for the EU.

For this study the effectiveness of wearing a helmet in the accident landscape in Germany was analyzed and the benefits of bicycle helmets on head injuries were investigated. For this purpose, surveys at the sites of accidents, called on-scene-investigations, in which detailed information on injury patterns, types of injuries and forces that occurred in the course of traffic accidents, were used for this study [17]. The on scene-investigations were conducted by a scientific research team. Subsequently, the movements of the persons involved in the accidents before, during and after the collision were reconstructed, and the velocities of the collision parties were determined. In doing so, impact patterns at the helmets and the impact situations at the head of the cyclists were extracted. The aim of the study is - besides a detailed documentation of the injury situation of cyclists - to analyze incidence and severity of head injuries for cyclists wearing a helmet and for those not wearing a helmet and to perform this analysis on a comparison of these two relatively homogenous collectives of cases concerning the frame conditions of the accidents.

FRAMEWORK OF EVALUATION

Accidents resulting in personal injury, recorded in GIDAS (German In-Depth Accident Study) that had occurred from 2000 through 2012 ($n=25,822$) were evaluated. Solely cases with complete information sets were considered, while incomplete and not reconstructed cases were excluded ($n=2,378$). In the remaining data set 7,027 bicyclists involved in accidents remained, from which those were deducted who had only pushed their bikes or where the bicycle had been parked ($n=12$). A total of 4,245 records relating to cyclists injured in traffic accidents remained and was used for the analysis of comparative case collectives "injured cyclists after traffic accident with and without helmets" (433 persons with helmet versus 3,812 persons without a helmet) in comparable accident conditions.

Figure 4 shows the corresponding evaluation frame of the GIDAS data with the aforementioned exclusions. If any of the evaluation parameters was unknown, the case was excluded from the analysis.

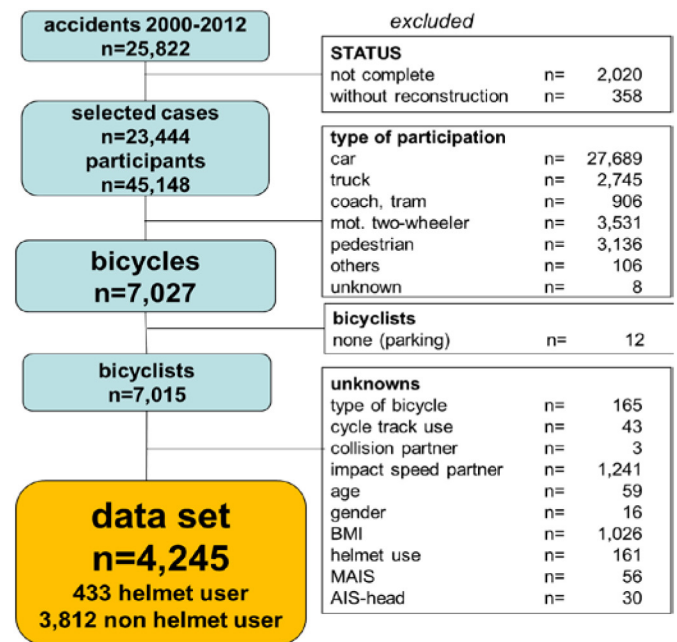


Figure 4. Sample frame of the study.

Then the following set of influencing factors known from experience was selected for a regression analysis concerning head injuries:

- type of bicycle
- use of bike paths
- type of opponent in collision
- collision speed of the opponent
- age of the cyclists
- gender of the cyclists
- BMI
- use of helmet
- MAIS
- AIS head

The Association for the Advancement of Automotive Medicine (AAAM) maintains a widely-accepted, anatomically-based injury severity scale, called the Abbreviated Injury Scale (AIS), which was used in this study to allocate severity for each observed injury on its six-degree ordinal scale [18, AIS90 with update to AIS98]. The injury with the highest severity of the whole body is defined as maximum injury severity (MAIS).

DOCUMENTATION METHOD OF GIDAS

Scientific research teams of technicians and physicians record traffic accidents resulting in personal injury using a statistically random sample for Germany in the regions Hanover and Dresden. GIDAS annually collects detailed data (vehicle deformation, accident traces, injuries and situation at the site of the accident) relating to about 2,000 accidents. Method and validity of the collected data have been described in literature ([17], [19], [20], [21]).



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DESCRIPTIVE OUTCOME PROCESSING

The following statistics extracted from GIDAS data that had been collected at the sites of accidents were weighted to reflect the entire accident landscape in Germany. The accident statistics of Germany of the year 2011 published by the Federal Statistical Office [22] were used as reference data. Weighting factors were the local situation (inside and outside of city limits) and the injury severity (slightly injured, seriously injured, and killed). That way the analysis resulted in a two-dimensional table for six different factors. Using these for the dataset the resulted percentages of the different distributions can be called representative but not extrapolated for Germany. Such weighted results can be seen in the descriptive analysis for each observation excluding the regression analysis. For the regression models the same sample of cases was used, however the results are based on the unweighted data in this sample.

ACCIDENT AND INJURY PATTERNS OF BICYCLISTS

Figure 5 shows the distribution of the collision partners of injured bicyclists. Approximately 69% of all collision partners in road accidents involving bicyclists are cars, both for cyclists with and without helmets.

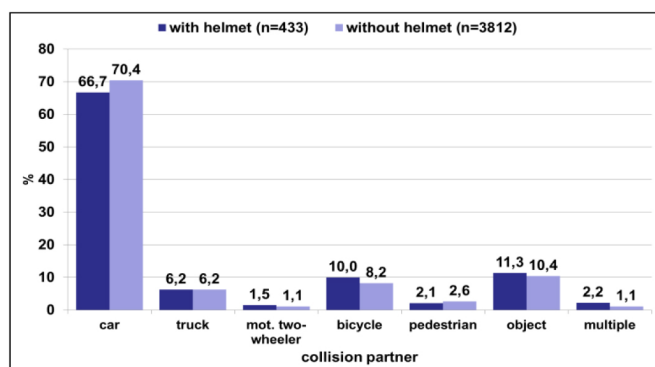


Figure 5. Percentage distribution of the collision partners of injured cyclists with and without helmet.

Approx. 10% of all collisions are single vehicle accidents and occur without the influence of other traffic participants ("object" collisions). The fact that 8% of the collisions involved other cyclists is also noticeable. There is apparently no difference concerning the distribution of collision partners between the groups with and without helmets.

This is also confirmed by Figure 6, which shows the cumulative frequency of the detected collision speeds of the collision partner of the bicyclists with and without helmets. The collision velocities for 80% of vehicles colliding with a bicycle were registered at below 26 km/h, while 10% of the impact velocities exceeded 35 km/h. Thus the comparison of the two groups with and without helmets yields results that are free of distortions and confirms the comparability of the conditions.

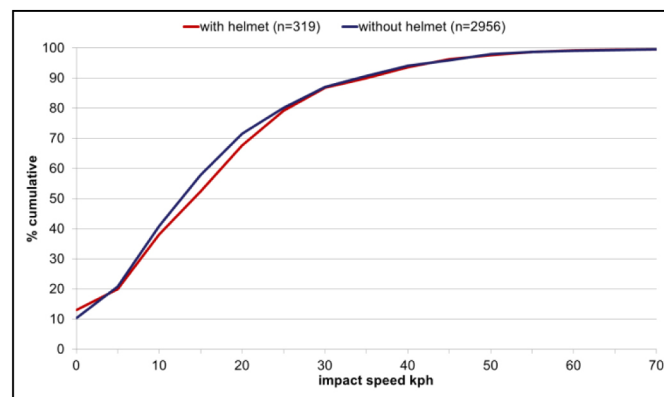


Figure 6. Cumulative frequency of collision speeds of the collision partner of the injured cyclists with and without a bicycle helmet.

Figure 7 shows that approximately 74% of all cyclists suffered injuries of severity MAIS 1, i.e. they were only slightly injured.

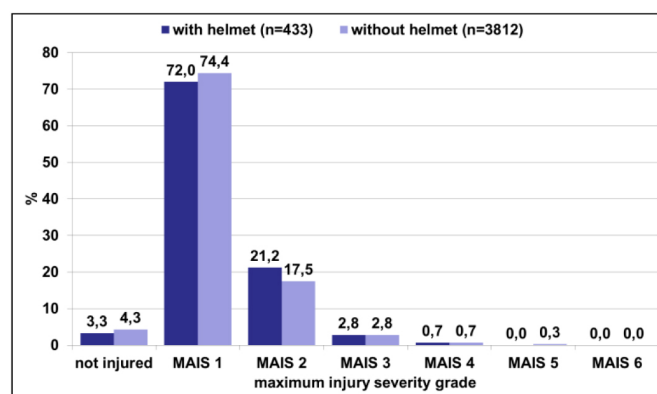


Figure 7. Percentage distribution of the overall severity of the injuries (MAIS) of injured cyclists with and without a helmet.

Differences between wearers of helmets and those without helmet were seen in particular for higher injury severity levels, which occurred only rarely in bicyclists wearing a helmet. Of the 3,812 bicyclists without a helmet, 0.3% suffered critical or fatal injuries (AIS 5,6), while 3.5 % of helmeted and non-helmeted cyclists each sustained injury severities of AIS 3 and 4. It appears remarkable that the proportion of MAIS 2 injuries is higher in the group of helmet users (21.2%) than in the group of cyclists without a helmet (17.5%). This does not match the expectations, but it has to be kept in mind, that the MAIS reflects injuries of all body parts and not only the head injuries, which are influenced by a helmet. One reason could be that helmets are worn more often in rural areas, where bicycle speeds are higher than in urban areas and therefore the probability of suffering MAIS 2 injuries in an accident is higher.

If the overall injury severity MAIS is considered, however, injuries to other body regions may be more common. For that reason, the overall severity of the injuries at the particular body regions with and without helmet is shown in Figure 8.