

Bicyclist Injury Patterns in Collisions with Motor-Vehicles

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Bicyclist Injury Patterns in Collisions with Motor-Vehicles

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ABSTRACT

Although a large percentage of bicyclist crashes are single-vehicle accidents, i.e., bicyclist falls, collisions with motor-vehicles tend to have more serious outcome for the bicyclist.

292 crashes from the period 2002 to 2010 between bicyclists with injuries and passenger cars and vans from the German Insurers Accident Database (UDB) were evaluated regarding the injury patterns and associated crash circumstances. Injuries were coded according to AIS 2005, Update 2008, and analysed with regards to body region and type of injury.

MAIS 3+ was approximately twice as frequent in bicyclists aged 55 and over as in bicyclists under 55 (39% vs. 17%) ($p < 0.001$; OR = 3.12; 95% CI: 1.81 – 5.39). In particular, serious injury levels (AIS 3+) among bicyclists 55 and over were prominent in the thorax (11%), lower extremity (14%) and head region (16%).

Among the 208 cases with documentation of helmet use, helmet wearing rate was 21% on average, but ranged from 12% among adolescents and seniors to 41% among mid-aged bicyclists. Helmet-users were slightly younger than non-helmet-users (median: 46 vs. 50 years). Helmeted bicyclists sustained fewer minor head injuries (AIS 1; 21% vs. 33%) and serious head injuries (AIS 3+; 2% vs. 18%). Moderate head injuries (AIS 2, 12% vs. 5%) were more frequent among helmet-users (n.s.).

Three types of collision kinematics between bicyclists and motor-vehicles, including being struck by the vehicle front or impact against an open door, demonstrated higher rates (34%) of MAIS 3+ injury than the remaining scenarios ($p < 0.001$; OR = 3.14; 95% CI: 1.68 – 5.85). Crashes involving SUVs or passenger cars showed similar MAIS distributions for the bicyclists (n.s.).

The study results underscore the importance of head trauma and the effectiveness of bicycle helmets, but also the relevance of thoracic and lower extremity injuries in collisions with motor-vehicles, particularly in older bicyclists.

Keywords: bicyclist crash, motor-vehicle, head injury severity, body region, bicycle helmet.

1 INTRODUCTION

Many industrialized countries have seen an increase in bicycle traffic during the last years. For instance, the annual mileage of bicyclists has nearly tripled in Germany since the mid-seventies [1]. Though studies have shown that the number of bicycle single-vehicle crashes is of similar magnitude to that of collisions with motor-vehicles [2], [3], [4] the risk for serious or fatal inju-

ry is considered to be higher when motor-vehicles are involved. For 2012, the German national statistics reported 86 killed bicyclists as the result of a single-vehicle crash and 172 in accidents involving a passenger car [5]. Several studies have exclusively examined accidents between bicyclists and cars or vans [6], [7] with the focus often being on injuries of bicyclists, particularly head injuries, who were struck by the front of a motor-vehicle. Detailed breakdowns by bicyclist age [2] or body regions other than the head [7] have rarely been made available, though. A study on head injuries in bicyclists based on hospital data [4] indicated that serious to severe head injuries (AIS 3+) were more frequent in older bicyclists and that the proportion of motor-vehicle involvement increased with the severity level of head injuries.

In light of this, the present study is intended to provide more insight into the injuries including, but also beyond head trauma sustained by bicyclists of different age groups in accidents with cars and vans. Other types of motor-vehicles as crash opponents are not covered in this study. Accidents between bicyclists and motorcycles or heavy vehicles are not only less frequent [3], but also differ considerably from the typical characteristics of crashes with cars and consequently result in different injury patterns.

Furthermore, potential contributory factors like body-style of the opponent vehicle, collision kinematics and helmet-wearing status of the bicyclist will be addressed and evaluated in this study.

2 MATERIAL AND METHODOLOGY

2.1 Study material

Study material came from the German Insurers Accident Research Database (UDB) which currently comprises approximately 8,000 road traffic accidents in Germany. Documentation is based on a random selection of third party motor loss insurers' claim files under the condition that at least one person was injured and that the total claim cost, consisting of personal injury and property damage, amounted to at least 15,000 Euros. Therefore, the material tends to reflect accidents of more serious outcome than the national statistics on average.

For the present study, 292 crashes from 2002 to 2010 between a motor-vehicle, moving or stationary, and a bicyclist who had been injured were available. Opponent motor-vehicles were restricted to cars and vans up to 3.5 tons gross vehicle mass. Crashes with bicyclists who had dismounted their bike or were walking it at the time of the collision were excluded. Of the total of 292 cases, 249 originated from the accident documentation obtained in the course of regular sampling for the UDB. The remaining 43 cases came from material of a previous study on crashes involving sport utility vehicles (SUV) [8], also being based on documentation from loss insurer claim files. Therefore, crashes between bicyclists and SUVs are overrepresented in the data material.

Case documentation usually included bicyclist demographic data (gender, age) and injury documentation, type of bicycle used and helmet use, information on the crash opponent (vehicle type and model, year of first registration) and a description of the conflict between the road users and the subsequent collision. Depending on the depth of documentation, some cases may lack information on certain variables. Therefore, evaluations of the material relate to the number of valid cases.

2.2 Methodology

The evaluation focused on the description of bicyclist injury patterns and the circumstances associated with them. These were derived from a variety of sources including clinical documentation, police reports, self-reporting by patients and emergency doctor's or coroner's reports in accidents where bicyclists were killed. All available injury information was coded by the study team according to the Abbreviated Injury Scale AIS 2005, Update 2008, [9] and grouped by body regions (head, face, neck including cervical spine, thorax including thoracic spine, abdomen including lumbar spine, upper extremities and lower extremities). Coding was strictly conservative based on the level of available injury detail. Therefore, the actual injuries were possibly more serious in some cases than what could be safely coded based on the available documentation. This may have been the case, for instance, with bicyclists who died at the scene of the accident and where no autopsy was performed. Also, some traumatic brain injuries may possibly have been rated as more severe if additional information, e.g. about the size of a brain contusion or haemorrhage, had been available.

Beside AIS-coding, the MAIS (Maximum Abbreviated Injury Scale) was determined for each bicyclist. MAIS is the highest AIS value found in a patient with multiple injuries and is often used to characterize the overall injury severity of the human body. MAIS could be determined for all injured bicyclists except one where description of the head injury was too unspecific to allow AIS-coding for this region and establish the MAIS value, likewise. Due to the fact that only injured bicyclists were selected for the study, the material contained no cases of MAIS 0.

Bicyclist crashes are known to entail severe head injuries sometimes while other body regions exhibit only minor or moderate injuries [4], [10]. In such cases, the highest AIS value found for the head will likely determine the MAIS value. On the other hand, bicycle helmets can reduce the severity of injury to the head or face region and may thus have considerable effect on the MAIS value. In order to be able to compare overall injury severities regardless of whether a helmet was worn or not, we introduce a modified MAIS score ("MAIS TrEx") which considers only injuries to the trunk (including thorax and thoracic spine, abdomen and lumbar spine) and to the upper extremities (including shoulder, arms and legs) and lower extremities (including pelvis, legs and feet). In other words, body regions whose injury risk may potentially be influenced by a bicycle helmet (head, face, neck with cervical spine) are excluded from consideration when using the MAIS TrEx.

Head injuries were furthermore categorized as to whether they classified as fractures of the skull, extracerebral injury (within the skull, but outside of the brain matter), intracerebral injury (within the brain matter) or concussions.

Helmet use was also documented where this information was available. For 85 bicyclists, however, it was not possible to determine whether a helmet was worn or not.

Documented types of bicycles were categorized as:

- Comfortable bicycle (including so-called city and Holland bikes)
- Sport bicycle (including sport, racing, mountain and trekking bikes)
- Other type of bicycle (including children's, folding and BMX bikes)

The types of opponent motor-vehicles were characterized as:

- Passenger cars (including station wagons, coupes and convertibles with a height of less than 1590 mm and a ground clearance of less than 170 mm)
- SUVs (vehicles for personal transport with a height of at least 1590 mm and a ground clearance of at least 170 mm, including pick-ups derived from these designs)
- Minivans (also termed multi-purpose vehicles MPV, vehicles for personal transport with a height of at least 1590 mm and a ground clearance of less than 170 mm)
- Vans (vehicles primarily for goods transport, or for personal transport derived from these designs, with a maximum gross vehicle mass of 3,500 kg)
- Other or unknown vehicle types (e.g. car-based delivery vehicles with a box-shaped body attached to the driver cabin, with a maximum gross vehicle mass of 3,500 kg)

The criteria used to discriminate between SUVs, minivans and conventional passenger cars were in accordance with the definition used in the EU research project IMPROVER [11].

The locations of first impact of the bicyclist or the bicycle on the opponent vehicle were differentiated between the front, rear, left and right side of the vehicle body.

The bicyclists kinematics during the collision with the motor-vehicle were categorized based on the scenarios proposed by Otte et al. [12] (Fig. 1):



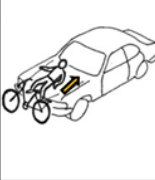




						
Impact and flight over hood or trunk	Sliding contact and bicyclist fall	Impact on front, thrown up on hood	Impact on side with change of trajectory	Impact on side w/o. change of trajectory	Impact and bicyclist remaining on bike	Low-speed impact, bicyclist gets under veh.
Type I	Type II	Type III	Type IV	Type V	Type VI	Type VII

Figure 1. Categorization of bicyclist collision kinematics, modified from Otte [12]

- Type I: Impact on the vehicle, often the side of the vehicle body, with subsequent flight of the bicyclist over the hood or trunk without major contact to it.
- Type II: Narrow-angled impact on the vehicle with sliding contact and subsequent bicyclist fall.
- Type III: Impact on the front of the vehicle and throwing the bicyclist up on the hood.
- Type IV: Impact on the side of the vehicle with change of bicyclist trajectory due to impact of his body on the vehicle.
- Type V: Impact on the side of the vehicle without change of bicyclist trajectory due to being thrown on the hood or trunk of the vehicle or collision with an opened vehicle door.

- Type VI: Impact on the vehicle, often the side of the vehicle body, with the bicyclist remaining on his bike.
- Type VII: Bicyclist fall and subsequently getting in front or under the vehicle. For the purpose of this study, also cases with a low-speed impact followed by the bicyclist falling, getting under the moving vehicle and possibly being dragged, were included here.

Differences in distribution between categories, e.g. between age groups, were tested for independence by a chi-square test. Statistical significance was assumed at p-values smaller than 0.05. Odds ratios (OR) provided are unadjusted, with 95% confidence intervals (CI).

3 RESULTS

3.1 Bicyclist demography

The largest group consisted of bicyclists aged 65 years and over (22%), followed by bicyclists 45 to 54 years old (20%) (Fig. 2). Children under 15 and adolescents from 15 to 24 years constituted only 7% and 8%, respectively, in the material. In all age groups, there were more male than female bicyclists except for those aged 65 and over with 32 men and women, each.

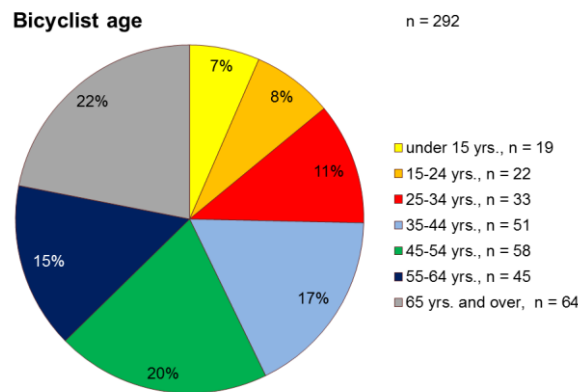


Figure 2. Age distribution among 292 injured bicyclists after collision with a motor-vehicle.

Of the 233 bicyclists with known type of bicycle used, 97 (42%) were riding comfortable bikes, including five with power-assist, and 126 (54%) were riding sport bikes (Fig. 3). Only ten (4%) used other types, among them six on children's bikes. From young adults (25-34 years) to seniors (65 years and over) the proportion of comfortable bicycles increased steadily and the proportion of sport bicycles decreased, respectively. Senior bicyclists rode comfortable bicycles in 75% of the cases, among them four out of the five power-assisted comfortable bicycles. In contrast, 15% among those 25-34 years old used comfortable, but 85% used sport bicycles. A considerable share of other types of bicycles was found only among children (under 15 years) where they accounted for nearly one third.

In 208 cases, the bicycle helmet-wearing status could be established. Helmets were worn by 43 bicyclists, 165 did not use a helmet. The average helmet-wearing rate was 21%. However the rates differed considerably between the age groups (Fig. 3) from approximately 12% (bicyclists aged 25-34 years and bicyclists 65 years and over) to 41% (bicyclists aged 35-44 years).

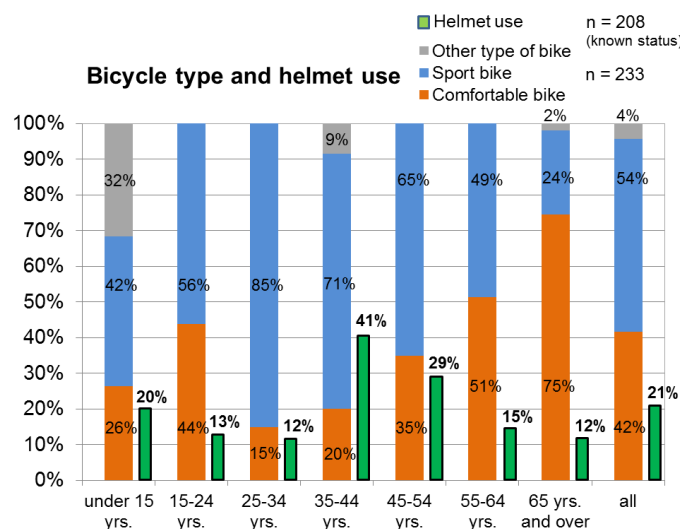


Figure 3. Distribution of bicycle types used and helmet-wearing rates within age groups.

3.2 Bicyclist injuries

Applying the definition of injury outcome according to the German national statistics [5], seven of the 292 bicyclists were killed (deceased within 30 days after the accident), 186 were seriously injured (requiring in-patient treatment in hospital for at least 24 hours) and 99 were slightly injured (all other casualties). Maximum AIS values (MAIS) were available for 291 bicyclists since one lacked sufficient documentation of his head injuries. Twenty percent sustained minor (MAIS 1) and 55% moderate injury severity (MAIS 2) (Fig. 4). One quarter (25%) was at least seriously injured (MAIS 3+). With 39% on average, the proportion of MAIS 3+ was significantly higher in bicyclists 55 years and over (55-64 years: 36%; 65 years and over: 41%) compared to 17% on average in bicyclists under 55 years ($p < 0.001$) (OR = 3.12; 95% CI: 1.81 – 5.39). It was lowest in the groups aged 35-44 and 45-54 years and in children under 15 years (between 12% and 16%). On the other hand, these three groups demonstrated the highest frequency of moderate injury severity (MAIS 2) ranging between 57% and 71%.

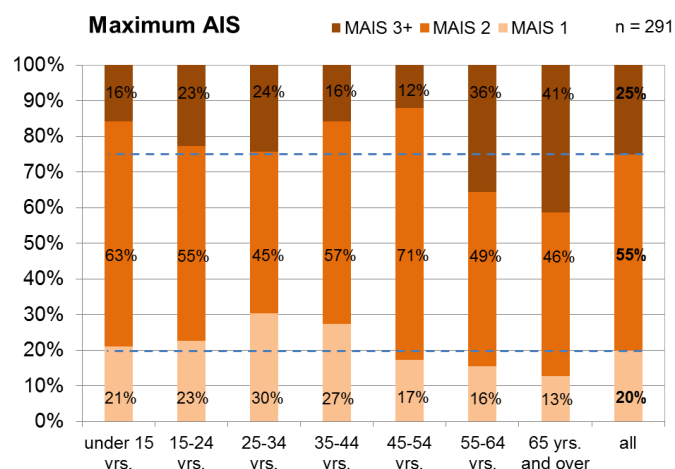


Figure 4. MAIS distribution within age groups (dashed lines indicate average proportion from total data set).

For an analysis of the maximum injury severity score that is restricted to the contribution by trauma of the trunk and the extremities, i.e. ignores the effect of head, face and neck injury on the MAIS, the newly defined MAIS TrEx (see Chapter 2.2) is used. With 28%, the average proportion of MAIS TrEx 3+ in bicyclists 55 years and over (55-64 years: 27%; 65 years and over: 28%) exceeded the average of 8% for those under 55 years (OR = 4.25; 95% CI: 2.16 – 8.35). MAIS TrEx 3+ was least frequent in child (under 15 years) and adolescent bicyclists (15-24 years) as well as in the group aged 45-54 years (Fig. 5).

In this context, a MAIS TrEx value of “0” indicates an injury pattern where injury was located exclusively in the head, face or neck region. Fourteen bicyclists (5%) presented MAIS TrEx 0, eight of which exhibited AIS 3 head injury.

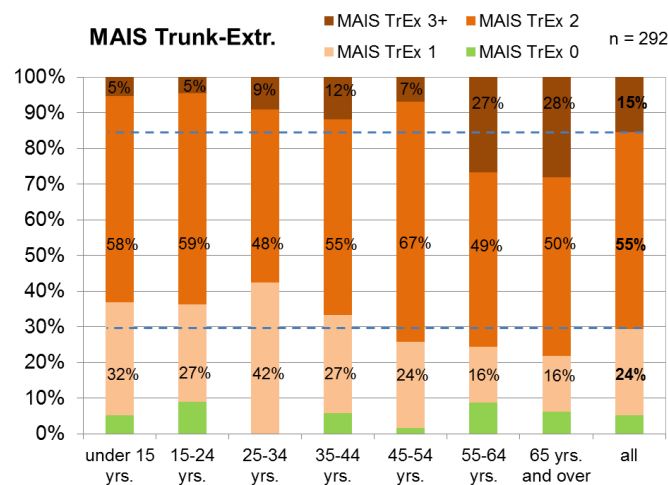


Figure 5. MAIS TrEx (trauma of trunk and extremities only) distribution within age groups.

The following detailed look at the distributions of injury severity in individual body regions reveals additional differences depending on bicyclist age.

3.2.1 Abdominal injuries

Injuries to the abdominal region were rare and did not exceed AIS 2 severity (Fig. 6). The highest frequency of AIS 2 injury severity was found in bicyclists 54 years and over, but also in children under 15 years. Among the AIS 2 injuries, only three organ contusions and haematoma were reported. With 20 bicyclists, the majority of AIS 2 injuries pertained to the lumbar spine, most of them being fractures of vertebral bodies. In twelve of the accidents with AIS 2 abdomen injury, the front of the opponent vehicle was involved, and in nine cases the right side of the vehicle.

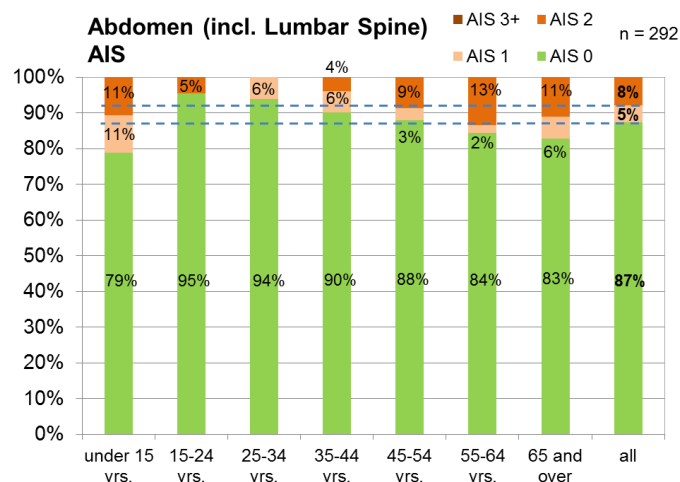


Figure 6. AIS distribution for abdominal injuries (incl. lumbar spine) within age groups.

3.2.2 Thoracic injuries

Thorax trauma comprised injuries to the ribcage and its contents as well as to the thoracic spine (Fig. 7). Twelve spinal injuries were documented. They did not exceed AIS 2 severity and consisted mostly of vertebral body fractures, half of which were accompanied by rib fractures. Rib fractures were documented for 31 bicyclists. Of the 19 cases of AIS 3+ trauma to the thorax, 18 involved serial rib fractures (at least three fractured ribs), ten of them accompanied by pneumo- or haemato-pneumo-thoraces. Except for a 4-year-old bicyclist who was struck by a reversing SUV and got under the vehicle, thoracic injuries AIS 3+ were found only in bicyclists from 35 years on and their proportion apparently increased with age. Serious thorax injuries were significantly more frequent in bicyclists aged 55 years and over (11%) as compared to those younger than 55 years ($p < 0.01$) (OR = 3.65; 95% CI: 1.33 – 10.02). The front of the opponent vehicle was struck in 19 collisions with AIS 2+ thoracic trauma, and the right side of the vehicle in eight accidents. The rear portion was involved in two cases.

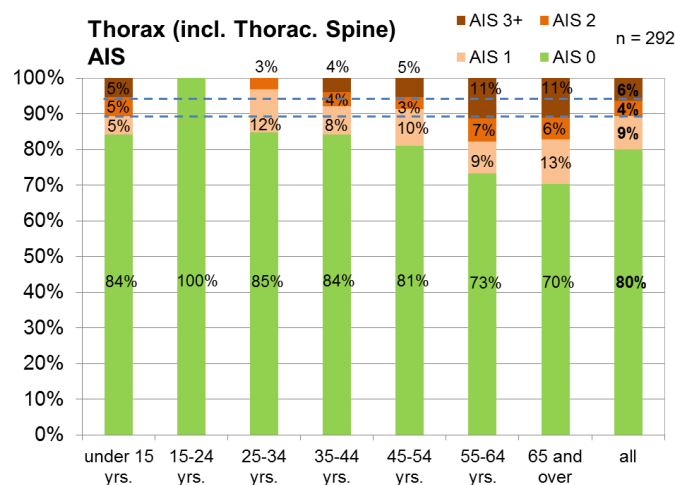


Figure 7. AIS distribution for thoracic injuries (incl. thoracic spine) within age groups.

3.2.3 Lower extremity injuries

Lower extremity trauma included injuries to the pelvis, upper and lower legs and the feet. On average, almost one third of the 292 bicyclists remained uninjured in this body region whereas 107 (37%) sustained AIS 2+ injuries, the majority being fractures (Fig. 8). In more than half of the AIS 2+ cases, a fracture of the lower leg was involved. Fourteen femur fractures, but also some open or complex fractures of the lower leg accounted for the large majority of AIS 3 cases. Eighteen cases of pelvic fractures were documented; with the exception of two, all being stable fractures rated as AIS 2. For 17 bicyclists, knee injuries of AIS 2 severity were reported. In bicyclists 55 years and over, serious lower extremity injuries (AIS 3+) were significantly more frequent than in those aged under 55 years ($p < 0.05$) (OR = 3.49; 95% CI: 1.43 – 8.53). Of the bicyclists with injury severities AIS 2+, 72 were struck by the front of the opponent vehicle, twelve collided with the left and 14 with the right side. In three cases, the rear of the vehicle was involved and in one instance, a bicyclist braked hard, fell in front of an SUV and one wheel overran his foot.

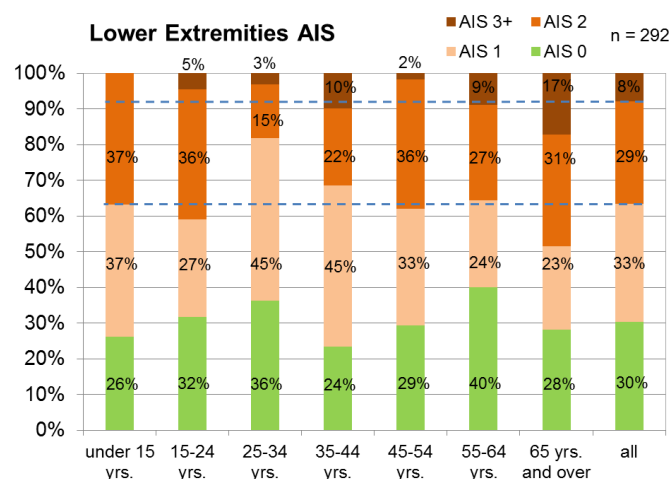


Figure 8. AIS distribution for lower extremity injuries (incl. pelvis) within age groups.

3.2.4 Upper extremity injuries

Upper extremity trauma included injuries to the shoulder girdle, the upper and lower arms and the hands. Altogether, 81 bicyclists presented AIS 2+ injuries (28%), consisting mostly of fractures and dislocated joints (Fig 9). AIS 2 injuries were dominated in number by simple fractures of the ulna or radius (28 bicyclists), followed by fractures of the scapula or clavicle (23 bicyclists). The eight AIS 3 injuries documented were open or complex fractures of the lower arm or the humerus bone. Bicyclists 55 years and over were underrepresented with regards to the proportion of AIS 2 injuries to the upper extremities, but accounted for seven of the eight AIS 3 injuries. With 35% on average, the proportion of AIS 2 injuries of bicyclists between 25 and 44 years was significantly higher than for the remaining age groups ($p < 0.05$) (OR = 1.97; 95% CI: 1.12 – 3.44). Upper extremity injury severities AIS 2+ occurred when colliding with the front of the opponent vehicle in 41 cases, with the left side in 19 cases, and with the right side in 18 cases. The rear of the vehicle was involved twice.

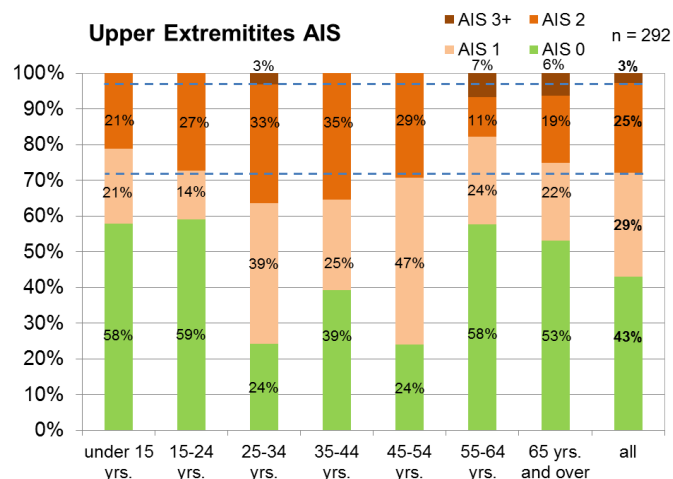


Figure 9. AIS distribution for upper extremity injuries (incl. shoulder) within age groups.

3.2.5 Neck injuries

Neck injuries occurred rarely, and for 263 (90%) of the 292 bicyclists the case documentation did not indicate any neck injuries. For 22 bicyclists (8%), AIS 1 cervical spine distortions were reported and only seven (2%) sustained AIS 2+ injuries. Three of these had died at the accident site and instable neck fractures were suspected in two cases. These bicyclists had also sustained concomitant severe trauma of the head and thorax. Five of the collisions involving AIS 2 neck injuries occurred with the vehicle front, one with the front fender and one with the rear portion of a car that had been struck by a truck and hit the passing-by bicyclist while skidding.

3.2.6 Facial injuries

Injuries to the face, including skeletal fractures in the facial region and lost teeth, were reported for 58 bicyclists (20%). AIS 2 injuries were documented in 12 cases and consisted almost exclusively of facial bone fractures including the lower portion of the orbits. Six of these showed concomitant AIS 3 injuries to the head. The opponent vehicle's front was involved six times, the left and the right side twice, each, when bicyclists sustained AIS 2 facial injuries.

3.2.7 Head injuries

By definition according to the AIS coding rules [9], injuries to the head comprise fractures of the skull (vault and basilar structure) and the soft tissue surrounding it as well as traumatic brain injury, whether intracerebral (within the brain matter) or extracerebral (outside the immediate brain, but inside the skull). For 291 bicyclist, documentation of present – or absent – head injury was sufficient to determine the head injury severity. Altogether, 123 (42%) bicyclists received injuries to the head and of these 34 (12%) demonstrated AIS 3+ injury severity. Fig. 10 shows the distribution of head injury severities among the different age groups. The largest proportion of AIS 2+ severities was present among bicyclists aged 15-24 years (23%) and seniors aged 65 years and over (23%). However, the occurrence of AIS 2+ head injury severity in bicyclists 55 years and over was not statistically different from that of bicyclists under 55 years ($p = 0.153$), nor was the difference for AIS 3+ ($p = 0.098$). With 22%, also children de-

monstrated a considerable share of moderate and serious (AIS 2+) head injuries, though based on a relatively small number of cases.

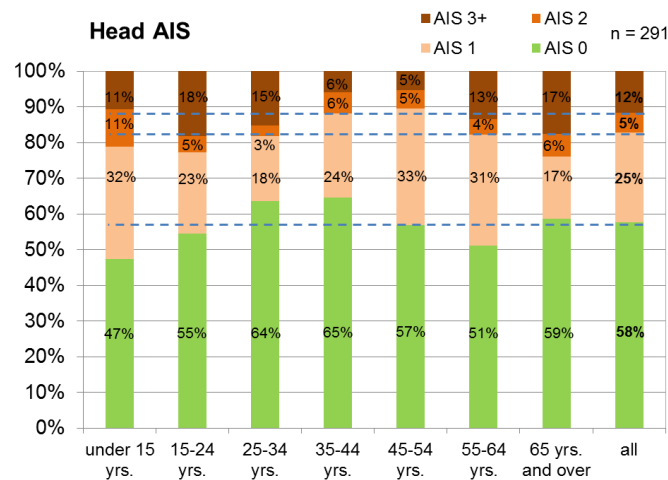


Figure 10. AIS distribution for head injuries (excl. face) within age groups.

Pure concussive injury, i.e. concussion accompanied at most by soft-tissue injury to the head, was found in 36 cases without loss of consciousness (AIS 1) and in eleven cases with brief loss of consciousness (AIS 2). Diffuse axonal injury (DAI) which, according to the AIS coding rules, should only be coded when prolonged unconsciousness cannot be explained by other kinds of traumatic brain injury [9] was mentioned in none of the clinical documentations. Unconsciousness that was naturally associated with serious and severe brain injuries or was due to clinically induced coma during intensive care treatment was not coded separately in the course of this study. Skull fractures were seen in 23 bicyclists, consisting of 20 cases of vault or basilar fracture, four of them combining both kinds, and three cases of unspecified skull fracture. Intracerebral injuries, including contusions and hemorrhages in the brain matter and two documented cases of resulting brain stem compression, were found in 25 bicyclists. Twenty-two bicyclists sustained extracerebral injury with eleven cases, each, of subarachnoid haemorrhage (SAB, AIS 2+) and subdural hematoma (SDH, AIS 3+) and three cases of epidural hematoma (EDH, AIS 3+). Except for two isolated cases of EDH and one of SDH, all extracerebral injuries occurred in presence of other head trauma like skull fractures or intracerebral injury.

Head injury severities AIS 2+ were found in 29 cases of collision with the front of the opponent vehicle, in eight cases with the left, and in seven cases with the right side, and three times with the rear of the vehicle.

3.3 Helmet use and injuries

As mentioned above, documentation about helmet use yielded 43 bicyclists with a helmet and 165 without a helmet. On average, helmet users were 44.4 years old (median: 46 years), non-wearers were 47.7 old (median: 50 years), the difference not being statistically different (Welch's t-test, Student's t-test: n.s.; $p > 0.05$). With 23% versus 42%, the share of women was significantly less among helmet-wearers than among non-helmet-wearers ($p < 0.05$). Also, the proportion of users of sport type bicycles was significantly higher among helmet-wearers (85%) than non-wearers (50%) ($p < 0.01$).

Nine of the helmet-wearers (21%) and 48 of the non-wearers (29%) sustained MAIS 3+ injury severities, the difference not being significant (n.s.; $p = 0.276$). When considering only injuries to the trunk and to the extremities, eight helmet-wearers (19%) presented MAIS TrEx 3+ severities as opposed to 24 non-wearers (15%) (n.s.; $p = 0.522$).

Head injuries sustained by bicyclists with known helmet status could be determined with regards to their severity in 207 cases (43 helmeted, 164 unhelmeted) and with regards to the type of head injury in 206 cases (43 helmeted, 163 unhelmeted). No head injury (AIS 0) was reported for 28 (65%) of the helmet-wearers and for 72 (44%) of the non-wearers ($p < 0.05$) (Fig. 11). The odds to sustain a head injury, regardless of severity, among non-wearers were more than twice those of helmet-wearers ($OR = 2.38$; 95% CI = 1.19 – 4.80). AIS 3+ injury severity of the head was found in only one bicyclist with a helmet (2%), but in 29 unhelmeted bicyclists (18%) ($OR = 9.02$; 95% CI: 1.19 – 68.24). With five (12%) versus nine bicyclists (5%), head AIS 2 injury was more frequent in helmet-wearers than in non-wearers, however not statistically significant (n.s.; $p = 0.154$).

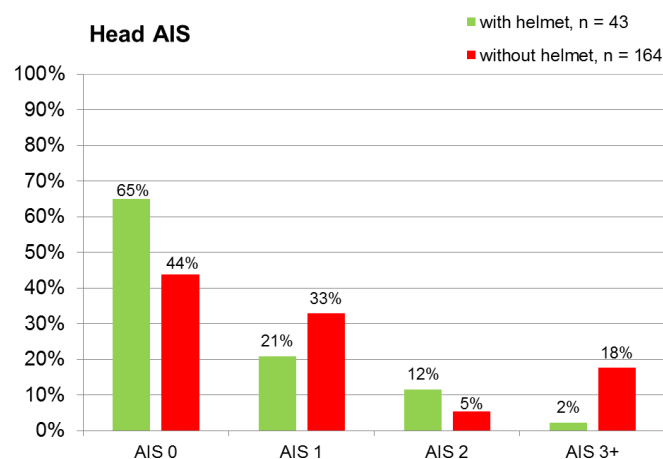


Figure 11. AIS distribution for head injuries (excl. face) by helmet use.

The relative frequency of the different types of head injury, depending on helmet-use is provided in Fig 12. Several bicyclists showed a combination of different head injuries. The data for concussive injury describes the frequency of isolated concussion (at most, accompanied by soft-tissue injury to the scalp) without (AIS 1) and with brief loss of consciousness (AIS 2). The frequency of soft-tissue injuries is given for their occurrence without any concomitant head injury. Helmet-wearers presented only one case, each, of intracerebral and extracerebral injury and skull fracture. Therefore, no test for statistical significance was carried out. In contrast, approximately 12% of bicyclist not wearing a helmet sustained these types of head injury, often in combination. While concussion without loss of consciousness (LOC) accounted for approximately 16% of cases of both helmet-wearers and non-wearers, a higher proportion of helmet-wearers than non-wearers sustained concussion with brief loss of consciousness (7% and 4%, respectively). Due to the small absolute numbers, no statistical testing was performed.

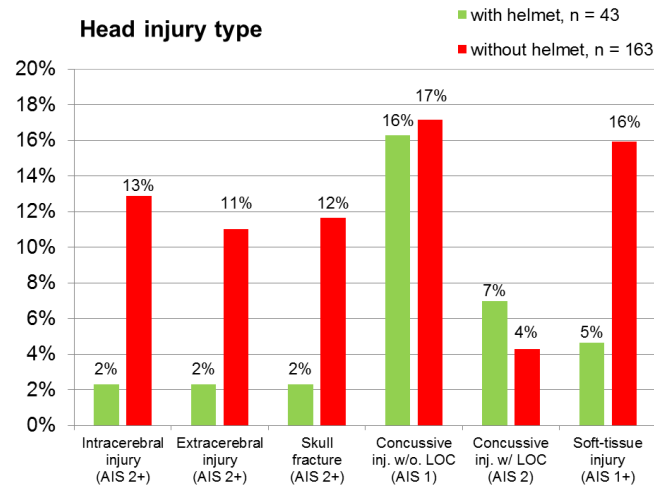


Figure 12. Frequency of head injury types (excl. face) by helmet use.

As explained above, injuries to the face and the neck were relatively infrequent anyway. The 43 helmet-wearers demonstrated similar proportions of AIS 1 facial injury (16%) and AIS 1 neck injury (12%) to those of non-wearers (16% and 7%, respectively). One case of AIS 2 face and AIS 2 neck injury, each, was documented for helmet-wearers as opposed to ten cases of AIS 2 face and six AIS 2 neck injuries among non-wearers.

The opponent vehicle's front was involved in 49% of the collisions with helmet-wearing bicyclists and in 63% of the collisions with bicyclists not wearing a helmet, the difference not being statistically significant (n.s.; $p = 0.091$). The left and the right side of the motor-vehicle were approximately equally involved among both groups of bicyclists.

3.4 Role of opponent vehicle

As explained previously, 249 collisions between motor-vehicles and bicyclists came from the regular samples of the German Insurers Accident Database and 43 cases were sourced specifically from collisions with SUVs. Although crashes involving SUVs are relatively low in number in Germany, their larger share in the study material allowed an investigation into the effects of different motor-vehicle types on injury outcome for bicyclists.

When accidents with SUVs and passenger cars were considered irrespective of the impacted side of the vehicle, SUVs were associated with nearly the same proportion of MAIS 3+ injury among the bicyclists than passenger cars (23%, each) (n.s.; $p = 0.784$) (Fig. 13). The largest share of MAIS 3+ was found for minivans with 30%, but was based on only 23 cases involving this type of vehicle, not being significantly different from other vehicle types (n.s.; $p = 0.537$). Other and unknown vehicle types were associated with an even higher proportion of MAIS 3+ (70%), but included only 10 cases, which defies further interpretation of these results. The majority of these vehicles were commercially used delivery vans, their design based on small passenger cars. All accidents occurred in built-up areas with some of the motor-vehicles going at very low speed or standing.

The proportion of bicyclists with MAIS 3+ injury after colliding with the front of an SUV (17%) was even smaller than among those having been struck by the front of a passenger car (25%), but not significantly different (n.s.; $p = 0.294$). The proportion of bicyclists with MAIS TrEx 3+

from a collision with the front of an SUV (8%) was also smaller than for those struck by the front of a passenger car (17%), albeit based on small numbers.

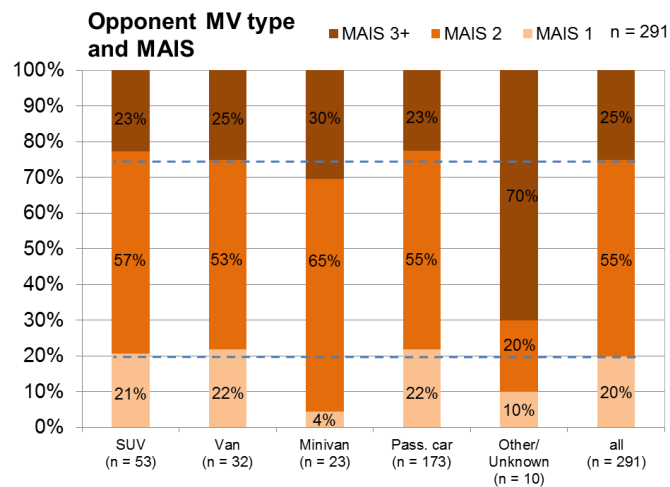


Figure 13. MAIS distribution by opponent motor-vehicle type.

3.5 Bicyclist kinematics during collision

The general motion of the bicyclist during the collision with the opponent vehicle could be determined from accident records and witness testimonies in 255 cases. In one instance, the MAIS value was not available, so that 254 cases remained for analysis. The type IV kinematics category (impact on the side of the vehicle with change of bicyclist trajectory) was by far most frequent, accounting for one third (34%) of the accidents with the respective available information (Fig. 14). Type III (impact on the front of the vehicle and being thrown up on the hood) followed with one quarter (25%). Type V kinematics accounted for 19% and included 21 cases of a bicyclist colliding with an opened vehicle door.

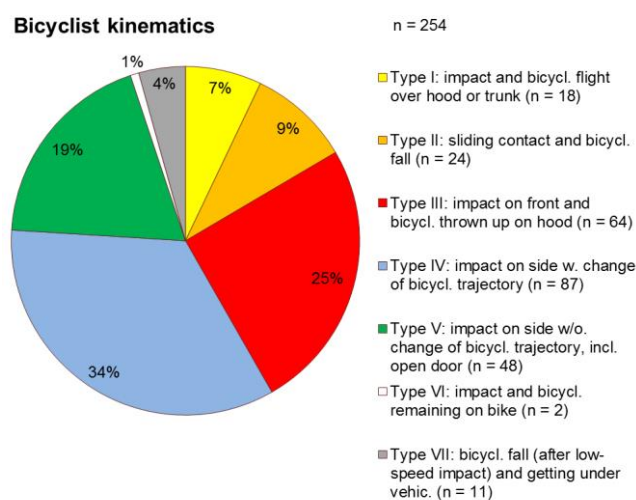


Figure 14. Distribution of collision kinematics among 254 injured bicyclists.

With a MAIS 3+ percentage between 9% and 17%, type I, type IV and type VII were less prone to involve serious injuries as opposed to type II, type III and type V kinematics that demonstrated the largest proportion (approximately 34%, each) of MAIS 3+ injured bicyclists (OR = 3.14; 95% CI: 1.68 – 5.85) (Fig. 15). The differences in MAIS proportions between the types II, III and V and the remaining kinematics types were statistically significant ($p < 0.001$) due to the differences in frequency of MAIS 3+. Only two bicyclists, presenting MAIS 2 injuries, belonged to the type VI category.

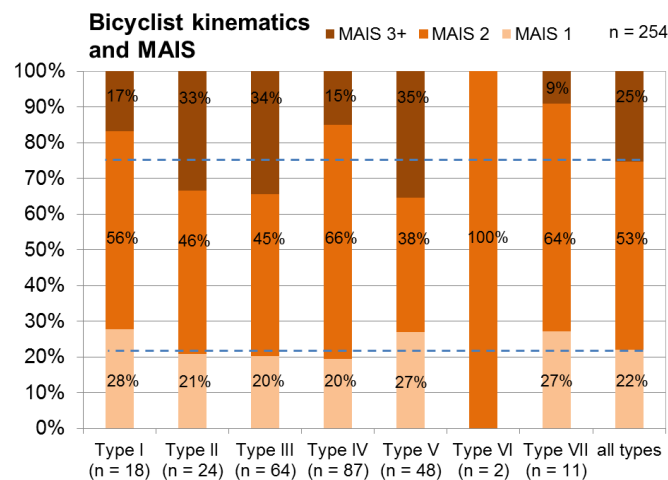


Figure 15. MAIS distribution by bicyclist collision kinematics type.

4 DISCUSSION

Our study aimed at describing injuries sustained by bicyclists in collisions with passenger cars and vans. Older people (55 years and over) represented not only the largest share of injured bicyclists, but also sustained serious injury patterns (MAIS 3+) at a significantly higher rate than other age groups. When we introduced the MAIS TrEx criterion in order to consider only contributions of the trunk and the extremities to the overall injury severity this difference was even more pronounced. This indicates that at ages from approximately 55 years on the odds to sustain serious injuries not only to the head, but also to other body regions increases substantially. This appears to be true particularly for AIS 2+ thoracic injuries in adults, the percentage of which increased steadily with age in our material. Lustenberger et al. [13] studied bicyclist injuries after impact by a motor-vehicle in the U.S. National Trauma Databank and emphasized the increasing risk of death for bicyclists 65 years and over. However, bicyclists under 15 years accounted for one third and bicyclist 56 years and over only for 9% in their patient group which deviates clearly from the age distribution in our study and suggests a completely different population of injured bicyclists in the U.S. and Germany.

The trend towards increasing injury severity with age does not seem to apply across all body regions to the same extent. For instance, bicyclists in the age groups from 25 to 44 years demonstrated the highest proportion of AIS 2+ upper extremity injuries. The ability of a young adult to brace his or her upper body – to a certain degree – in a collision with a car may cause more arm and shoulder injuries in return.

Head trauma and the protective potential of bicycle helmets have been a focal points of bicyclist injury research long since. Almost half of all MAIS 3+ cases in our material were determined – at least in part – by the severity of the head injury. The head presented the most seriously injured body region in six of the seven fatalities, none of which had been wearing a helmet.

Our study confirms the thesis that helmets protect not only against soft tissue injury, but particularly against serious and severe head trauma. While the odds to sustain head injury in general were more than twice as high for non-helmeted as compared to helmeted bicyclists, the data indicated an odds ratio nine times as high for AIS 3+ head injury, though involving a small number of cases among helmet-users. Skull fractures, extracerebral and intracerebral injury occurred in approximately one in five bicyclists not wearing a helmet as opposed to one isolated case, each, found in three of the 43 helmet users. Several non-wearers presented combinations of these types of head injury which increases the risk of unfavourable outcome for the patient, but is not reflected in the AIS value. Concussion with brief loss of consciousness was slightly more frequent among helmet wearers, though not statistically significant. Whether this is due to mitigation of otherwise more serious injury by the helmet or whether there is actually a higher risk of sustaining concussion with a helmet cannot be answered momentarily. There was similar evidence of a slightly higher rate of concussion and AIS 2 brain injury, respectively, in helmet-wearers in two recent studies which comprised not only collisions with motor-vehicles, but also bicyclist single-vehicle crashes [4], [10].

Criticism of helmet wearing, or at least helmet laws, has sometimes been reasoned with the thesis that a helmet would increase the rotational motion of the brain in a bicyclist crash. It might thus increase the risk for neck injury or traumatic brain injury like severe concussion or subdural haematoma [14]. The frequency of neck injuries and facial injuries was comparable between helmet-wearers and non-wearers in our study. With some 20%, the rate of facial injuries was considerably lower than in a study from 2013 that looked particularly at head and face injuries of bicyclists arriving at the emergency rooms of two German hospitals [4]. That material, however, was also different in that single-vehicle crashes accounted for more than half of all injured bicyclist. One possible explanation for the lower rate in our material is that face and neck injuries (usually AIS 1 severity) may not be documented in daily clinical routine when much more serious injuries are present.

When considering the motor-vehicle opponent as a potential variable to affect the occurrence of serious injuries in bicyclists, the comparison of SUV and passenger cars did not reveal any difference in overall injury odds as measured by MAIS. Instead, the category of “minivans” and “other motor-vehicle types” (which included a number of delivery vehicles based on passenger-car designs) were prominently associated with MAIS 3+ injuries. To explore whether there exists an actual disparity due to different front shapes, like one-box designs often seen on minivans, or due to different use habits by their drivers would require a larger case basis.

The kinematics of a bicyclist in a collision with a motor-vehicle appear to play an important role for the incidence of serious injury (MAIS 3+). Besides the bicyclist being struck laterally by the front of a moving vehicle, a scenario that has often been the subject of bicycle accident research [6], [7], two other crash configurations also seem to bear a relatively high potential of serious injury. These are collisions of the bicyclist with the side of the motor-vehicle, either with sliding contact or with frontal impact by the bicyclist, and followed by the bicyclist fall. The latter collision type included also a considerable number of impacts against an open vehicle door. In addition, the material contained a small percentage of accidents where the bicyclist fell, got under the – usually slowly – moving vehicle and was either being dragged or part

of his body being overrun by a wheel. Rather surprisingly, the front of the motor-vehicle was involved more often than the rear, as would be expected in case of reversing accidents. Low-speed collisions with involvement of the vehicle front and resulting in running over a bicyclist are considered rather typical for accidents with heavy vehicles [15], but have rarely been described for passenger cars or vans.

Our study has several limitations. The selected case material consists of collisions with motor-vehicles up to 3,500 kg gross vehicle mass that caused injury to the bicyclist. Collisions that resulted in no or very slight injury and with insurance claim costs remaining under the threshold value for inclusion in the UDB database (see Chapter 2.1) were not considered. As mentioned above, the evaluated material is likely to reflect more serious outcome than the total of all crashes between bicyclists and motor-vehicles. On the other hand, this provides a larger number of severe real-world cases that need to be addressed when countermeasures against serious or fatal injury outcome in bicyclists are discussed. Collision speed is one variable that potentially influences injury outcome in the bicyclist. No reliable data existed for bicyclist speeds and collision speeds of the opponent vehicles were available only in approximately half of the cases. Hence, we did not control for this variable in the analysis of injury data and collision kinematics.

Injuries were coded according to AIS 2005, Update 2008, for our study. The code book provides many more options than previous versions to describe the extent of an injury to an anatomical structure. This may have influence on the assigned AIS severity value, for instance when coding brain injury. With the limited information about complex and often multiple injuries to the head – and sometimes to the thorax – in the case material we could not fully utilize the subtle differentiations for diagnoses in the AIS 2005 code book and therefore had to code conservatively. Because of these uncertainties, it was not possible in some cases to distinguish between injury severity levels beyond the category of AIS 3+.

5 CONCLUSION

A population of injured bicyclists can be very inhomogeneous with regards to variables like age, bicycle type and helmet use as well as to the types of motor-vehicle opponents and collision configurations involved. Therefore, caution should be exercised when comparing studies that employ different methodologies, even more, when data was gathered in different regions or even countries. Advanced age has only recently come into the focus of research in bicyclist crashes, but appears to be an important lever when striving to reduce the number of traffic fatalities in many countries. Improved cycling infrastructure will likely benefit bicyclists of all ages, but other efforts may prove quite effective particularly for the group of elderly. Not only is there a need to promote protection of the head among seniors, but other, simple protective measures should also be conceived to address the elevated risk for serious injury of the thorax and the lower extremities.

Nevertheless, the results of our study underscore previous findings of the importance of traumatic brain injury for the overall injury outcome of bicyclists and the effectiveness of helmets in preventing or mitigating serious and severe head injury. Therefore, a differentiation between head injuries of different severity is necessary when comparing bicyclists with and without helmets in order to avoid misinterpretation of results. The slightly higher percentage of AIS 1 and AIS 2 concussion found in the present study, but also in other recent research work, warrants a closer look into this phenomenon.

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