**HEAVY TRUCK CRASHES INVOLVING PEDESTRIANS IN COMPARISON TO BICYCLISTS**

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Paper Number 19-0080

## ABSTRACT

Although crashes with vulnerable road users account for a small proportion of all heavy truck accidents they cause particularly severe injuries. In Germany, collisions with bicyclists and pedestrians accounted for only 9% and 4%, respectively, of all injury crashes between a truck over 12,000 kg gross vehicle weight and another road user in 2015. However, vulnerable road users represented 26% of fatalities in these kinds of crashes. While collisions between trucks and bicyclists, particularly in right-turn situations, have recently gained attention in Europe, little research has been dedicated to crashes involving pedestrians. This study describes the circumstances and injury outcomes of severe crashes between heavy trucks and pedestrians in comparison to those involving bicyclists. The German Insurers Accident Database (UDB) provided data on accidents involving heavy trucks, defined as goods vehicles over 11,900 kg GVW: 39 crashes with 43 pedestrians, altogether, and 62 crashes with one bicyclist, each.

The majority of crashes occurred in built-up areas and during daylight, both for pedestrians and bicyclists. While most accidents involving pedestrians took place on a stretch of road (49%) the majority of accidents involving bicyclists occurred at junctions (77%). Females accounted for 58%, each, of the casualties among both groups of VRU's. Pedestrians averaged 57.8 years of age (median: 61 yrs.), and were approximately six years older than bicyclists with an average of 51.6 years (median: 52.5 yrs.). The collision situations for pedestrians and for bicyclist differed considerably. The truck was going straight in the large majority of cases where a pedestrian was struck. Often, the truck was initially stationary and then moved off and collided with the person walking or standing near the vehicle. Crashes between a heavy truck and a bicyclist, on the other hand, were clearly dominated by turning manoeuvres, mostly when the truck made a right-turn at a junction and hit a bicyclist who was travelling alongside on the right of the truck and intending to go straight. 40% of pedestrians were run over, five of them with fatal consequences. Bicyclists were run over in 52% of cases, resulting in nine fatalities. Despite different collision scenarios among pedestrians and bicyclists in crashes with trucks, their injury patterns and severities were very similar. MAIS3+ cases accounted for approximately two thirds among all casualties in both groups. The highest proportion of AIS3+ injuries for pedestrians was found in the thorax region (31%) and for bicyclists in the lower extremities region (40%).

The present work confirms previous studies related to accidents between trucks and vulnerable road users that noted the prevalence of older persons among the VRU's. It adds to the body of research by providing detail data on the different collision scenarios typical of truck accidents with pedestrians and with bicyclists and their injury patterns. Truck driver assistance systems hold a large potential to avoid or mitigate crashes with both VRU groups. While monitoring the right side of the vehicle is necessary to avoid crashes with bicyclists, pedestrian detection needs to focus on the area in front of the truck.

## INTRODUCTION

Vulnerable road users (VRU) have been in the focus of accident research for a long time. However, pedestrians have been addressed primarily regarding collisions with passenger cars and bicyclist have gained increasing attention only during the last couple of years due to the popularity of cycling and the resulting stagnation – and in some countries even the increase – in the number of bicyclist casualties. For instance, the number of killed bicyclists in Germany did not decline in 2017 in relation to 2010 whereas the overall number of killed road users dropped by 13% [1]. While accidents between heavy vehicles and bicyclists are relatively rare, they have been of recent interest both for the public and research because they tend to result in very severe or even fatal outcome for the VRU despite the fact that these accidents typically happen at low speed. Several studies have looked at the causes of these crashes and the role of "blind spots" around trucks and truck-trailer combinations [2, 3]. They found that conflicts between

right-turning trucks and bicyclists riding alongside on their right side and continuing straight present a particularly dangerous situation due to the high risk that the bicyclist gets run over by the truck's wheels [2, 4]. In this context, the potentials of technical measures to enhance the direct and indirect view from the truck cab as well as the introduction of electronic turn-assistance for truck drivers to warn of VRU's in the immediate vicinity of the vehicle have been discussed [4, 5].

Research on crashes between heavy trucks and pedestrians is scarce, though. Recent data available from Belgium and Germany [3, 6], for instance, suggests that these kinds of accidents may be less frequent than those between heavy trucks and bicyclists, but may pose a similar risk for severe or fatal injury to the pedestrian. An analysis of the Rhône Road Trauma Registry in France [7], however, yielded much more pedestrians than bicyclists who collided with a truck.

The present study intends to shed more light on the similarities and differences of accidents between heavy trucks and pedestrians and bicyclists, based on in-depth data obtained from German motor liability insurers. While collisions between heavy trucks and bicyclists and their injuries were the subject of an earlier study [4], this evaluation adds data concerning pedestrians, but maintains the previous methodology. Thus, comparison of the results for the two groups in crashes with heavy vehicles should be facilitated, at least for the situation in Germany.

## METHOD

Crash and injury data came from the German Insurers Accident Database (UDB). This database contains data from samples obtained retrospectively from claim files of German motor liability insurers. Cases recruited for the present study involving heavy trucks were required to have estimated initial claim costs of at least EUR 30,000, covering both personal and property damage, irrespective of the actual payments during claim processing and whether the truck driver or the vulnerable road user was at fault. Since crashes with pedestrians and bicyclists tend to result in higher bodily than material damage, these accidents present rather severe outcomes in terms of injury.

Heavy trucks were defined as goods and service vehicles with a gross vehicle weight (GVW) of 11,900 kg and over and their trailers where present. According to EU definition, goods transport vehicles over 12,000 kg fall into the N3, or N3G category, respectively. They include most tractors for semi-trailers, trucks for long distance transport, either as rigid units or in combination with drawbar trailers, and heavy-duty trucks used in the construction and the waste management industry. Trucks with a GVW of just below 12,000 kg, often registered with a weight of 11,990 kg, are popular particularly for regional distribution services. These trucks belong to the N2 or N2G category, respectively, and were included in the study as well. Buses, farm tractors and special equipment like mobile cranes, etc., were not considered.

Users of bicycles were categorised as "bicyclists" if they had mounted their bicycle at the time of collision. E-bikes and tricycles based on the design of conventional bicycles were taken into account, too, though rarely involved.

Bicyclists walking their bike were categorised as pedestrians as their characteristics resemble rather those of other persons walking when moving in traffic. This is in line with the coding rules for the German police when reporting road traffic accidents. The group of "pedestrians" included also users of devices like kick-boards as well as any person walking or standing on or near the road at the time of the accident. This comprised drivers of motor-vehicles who had just left their vehicle, or were about to enter it. Furthermore, road maintenance workers and the like were counted as pedestrians, although they are defined as a separate group of road users in German national statistics. Two cases of persons intending to commit suicide by running in front of an approaching truck, and being seriously injured, were considered for the analysis as well.

Vulnerable road users who were injured in the course of the accident, but not directly as a result of contact with the heavy truck, were excluded from the analysis. This, for instance, pertained to a car driver who was standing between his vehicle and a van, when a truck rear-ended the van, pushed it forward and wedged the driver between the front of the van and the trunk of his car.

The documentation of crashes usually comprised police reports, witness statements, hospital discharge information and sometimes accident reconstructions and post-mortem reports. Several variables were used to characterise the location of the crash and the actual event as well as the immediate phase preceding the collision.

Injury severity was categorised according to the definition used in the national statistics (killed, seriously injured, slightly injured) and according to AIS 2005, Update 2008 [8], where injury documentation provided enough detail. Furthermore, the Maximum AIS (MAIS) to characterise the overall injury severity, and the highest AIS values were determined for the following body regions: Head/face (including skull and brain), thorax, upper extremities (including shoulder and hands), abdomen, lower extremities (including pelvic bones and feet) and spine (cervical, thoracic and lumbar spine). For clarity, AIS injury severities were grouped into three categories: AIS0-1 for no or only minor injury, AIS2 for moderate injury, and AIS3+ for serious to maximum injury severity.

Run-over may be of particular importance with regard to the injury mechanism in vulnerable road users. For the purpose of this study, run-over is defined as one or more wheels of the vehicle rolling over a portion of the victim's body or at least wedging a body part between a wheel and the ground with resulting injury. Cases where the VRU got under the vehicle and possibly contacted the underbody, but not the wheels, were not counted as run-overs.

The analysis was carried out based on data sets of individuals, i.e., for each injured pedestrian or bicyclist and his or her circumstances of the accident. Thus, in cases of two vulnerable road users being injured in the same event, data pertaining to the infrastructure, the heavy truck and the surrounding conditions are counted twice. Depending on the detail and reliability of data, some of the cases had to be excluded from certain analyses. Therefore, percentage values from the data analysis relate to the number of valid cases.

Differences of values based on continuous variables were tested for significance using the t-test, for dichotomous variables the Chi-square test was applied. Statistical significance was assumed at a p-level of 0.05, otherwise the difference was considered non-significant (n. s.).

## RESULTS

The German Insurers Accident Database (UDB) provided 39 crashes between heavy trucks (GVW of 11,900 kg and over) and pedestrians and 62 crashes between heavy trucks and bicyclists that occurred in Germany between 2007 and 2012, the majority of them (63 cases altogether) in 2012 due to a larger sample of truck accidents drawn for this year. In four accidents involving pedestrians, two persons, each, were injured by the same truck and thus the circumstances of such crashes enter the database twice. Therefore, the material contains 43 pedestrians and 62 bicyclists and the related circumstances of their accidents.

### Road Infrastructure and Environmental Conditions

The large majority of crashes for both groups of VRU's occurred in built-up areas (pedestrians: n = 35; 81%; bicyclists: n = 57; 92%) (n.s.). Of the seven crashes with pedestrians outside of built-up areas, three occurred on a motorway, injuring four persons. While accidents involving pedestrians took place on a stretch of road in nearly half of the cases (n = 21; 49%), most accidents involving bicyclists were located at or in the immediate vicinity of junctions like crossings or T-junctions (n = 48; 77%). This difference in accident site characteristics between pedestrian and bicyclist crashes was statistically significant ($p < 0.01$). With eleven cases (26%), traffic was significantly less frequently controlled by traffic lights at junctions or crosswalks in pedestrian accidents than in bicyclist accidents (n = 33; 53%) ($p < 0.01$).

The large majority of cases were found for weekdays from Monday to Friday. Only three accidents with pedestrians and one with a bicyclist on a weekend were reported. The times of the accidents were almost entirely in the morning hours (6 AM to 12 AM) and the afternoon and early evening hours (12 AM to 6 PM) (pedestrians: n = 39; 91%; bicyclists: n = 58; 94%). Accordingly, the large majority of collisions took place during daylight both for pedestrians (n = 38; 88%) and bicyclists (n = 51; 82%) (n.s.). Road surfaces were rarely wet among both groups, but such conditions were significantly more frequent in crashes with pedestrians (n = 10; 23%) than in bicyclist crashes (n = 5; 8%) ($p < 0.05$).

**Truck Characteristics, Truck Driver and VRU Demography**

The general vehicle type could be determined for all heavy trucks colliding with pedestrians and those colliding with bicyclists. Among crash opponents for pedestrians, 18 (42%) were semi-tractors with trailers, four (9%) were truck-drawbar-trailer combinations and 21 (49%) were single rigid units. Trucks colliding with bicyclists were composed of 25 (40%) semi-trailers, 15 (24%) truck-drawbar-trailer combinations and 22 (35%) rigid trucks. The larger share of rigid trucks in crashes with pedestrians was not significant (n.s.). While only one bicyclist collided with a garbage truck, five trucks of this type were involved in pedestrian accidents, one of them with two pedestrians at the same time, thus appearing twice in the count.

Except for seven trucks, vehicle age at the time of the accident could be determined. It ranged from practically new vehicles to 20 years of age, averaging 5.2 years (median: 4 yrs.) of service for trucks colliding with pedestrians and 5.5 years (median: 5 yrs.) for those colliding with bicyclists.

With one exception, all truck drivers were males, their age ranging between 22 and 65 years (average: 45.4 yrs.; median: 46 yrs.) for those involved in pedestrian crashes and between 21 and 69 years (average: 44.6 yrs.; median: 45.5 yrs.) for those involved in bicyclist crashes (n.s.). Age was unknown for four drivers.

Females accounted for 58%, each, of the casualties among both groups of VRU's: 25 of the 43 pedestrians and 36 of the 62 bicyclists were women (Figure 1). Pedestrians averaged 57.8 years of age (median: 61 yrs.), and were approximately six years older than bicyclists with an average of 51.6 years (median: 52.5 yrs.). Although the VRU's ages appear relatively far from a normal distribution, a t-test was performed, but showed no significant difference between the groups (n.s.).

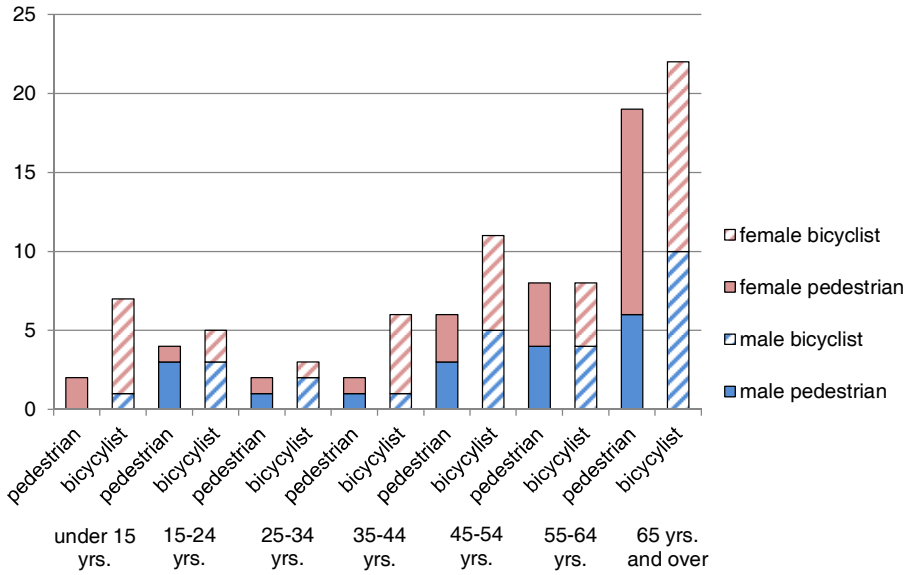


**Figure 1. Pedestrian and bicyclist gender and age distribution**

Females among pedestrians were approximately five years older than their male counterparts (females: average 60.0 yrs., median 67 yrs.; males: average 54.7 yrs., median 56 yrs.), whereas female bicyclists were four years younger than male cyclists (females: average 49.7 yrs., median 50.5 yrs.; males: average 54.2 yrs., median 56 yrs.). For both VRU groups, the difference in age between females and males was not significant (n.s.). Interestingly, five of the pedestrians, aged between 54 and 74 years, were walking their bicycle when they collided with a heavy truck.

Influence of alcohol was reported by the police for none of the truck drivers and only for two pedestrians and two bicyclists.

**Collision Scenarios**

The collision situations for crashes of heavy trucks with pedestrians and with bicyclists differed considerably. With regards to the motion of the truck and the motion or position of the vulnerable road user immediately before of the crash, the scenarios can be broken down into matrices as shown in Table 1 for crashes with pedestrians and in Table 2 for crashes with bicyclists.

The truck was going straight in the large majority of the 43 cases where a pedestrian was struck (Table 1). In most of these situations, the pedestrian was approaching from the right (n = 10; 23%), usually in an attempt to cross the road. In five cases (12%), the pedestrian was moving in the same direction as the truck. Apart from trucks travelling at regular speed, "going straight" includes also situations where a truck was initially stationary, e.g., waiting at a red light, and then moved off and collided with a person walking or standing close to the vehicle. Usually then, the pedestrian was walking slowly or standing right in front of the truck and the driver overlooked him or her when moving off at low speed. The five cases (12%) with a scenario "going in opposite direction" included also persons standing in the path of a continuously moving truck. In a number of cases, the truck side-swept the pedestrian either because the driver made an evasive manoeuvre to avoid the crossing pedestrian or the vehicle passed by a person too closely who was standing by the side of the road or driveway. Accidents with pedestrians were relatively rarely caused by turning trucks. In two cases, a reversing truck hit a pedestrian behind the vehicle.

With 35 cases (56%), crashes between a heavy truck and a bicyclist, on the other hand, were clearly dominated by turning manoeuvres (Table 2), mostly when the truck made a right-turn at a junction or into a driveway and hit a bicyclist who was travelling alongside on the right of the truck, intending to go straight. Situations with the truck going straight were comparably few and included both crashes with a crossing bicyclist and collisions with the truck side-sweeping a bicyclist during an overtaking manoeuvre by the truck driver. In one case, the truck reversed and collided with a bicyclist approaching from behind and in two incidents the truck was parked at nighttime and the bicyclist hit the rear of the trailer.

As a result of the collision, 17 pedestrians (40%) were run over on at least a part of their body by one or more wheels of the truck, in five cases with fatal consequences. Accordingly, 26 pedestrians (60%) were struck by the truck, but not run over in the sense of the above definition, and four of them died. Nevertheless, a number of pedestrians who were knocked down by the truck front face ended up under the vehicle without contact with the wheels. Bicyclists were run over in 33 cases (52%), resulting in nine fatalities. Of the remaining 29 bicyclists without run-over (48%), two were fatally injured. The smaller share of run-over among pedestrians compared to bicyclists was not significant (n.s.).

**Table 1.**
**Absolute and relative frequency of accident scenarios between heavy truck and pedestrian**

| | **Pedestrian motion / interaction with truck** | | | | | | |
|---|---|---|---|---|---|---|---|
| **Heavy truck motion** | going in same direction | going in opposite direction | coming from left | coming from right | swept by left side of truck | swept by right side of truck | moving/ standing behind truck |
| going straight | 5 (12%) | 5 (12%) | 5 (12%) | 10 (23%) | 2 (5%) | 7 (16%) | - |
| turning left | - | 1 (2%) | - | - | - | 2 (5%) | - |
| turning right | 4 (9%) | - | - | - | - | - | - |
| reversing | - | - | - | - | - | - | 2 (5%) |

**Table 2.**
**Absolute und relative frequency of accident scenarios between heavy truck and bicyclist**

| | Bicyclist motion / interaction with truck | | | | | | |
|---|---|---|---|---|---|---|---|
| **Heavy truck motion** | going in same direction | going in opposite direction | coming from left | coming from right | swept by left side of truck | swept by right side of truck | moving/ standing behind truck |
| going straight | 1 (2%) | - | - | 5 (8%) | 2 (3%) | 5 (8%) | - |
| turning left | 2 (3%) | 4 (6%) | 1 (2%) | 1 (2%) | - | - | - |
| turning right | 35 (56%) | - | 1 (2%) | 1 (2%) | - | 1 (2%) | - |
| reversing | 1 (2%) | - | - | - | - | - | - |
| stationary | 2 (3%) | - | - | - | - | - | - |

**VRU Injury Patterns and Severities**

Due to the selection criteria for the cases, all involved vulnerable road users sustained injuries, often being quite severe. Nine of the total of 43 pedestrians were killed (21%) and 34 were seriously injured (79%) according to the definition used in German national statistics. Of the 62 bicyclists, eleven were fatally (18%), 47 were seriously (76%) and four were slightly injured (6%). For five pedestrians and four bicyclists, the complete injury pattern could not be established. Even then, it was possible to derive the injury severity for the most severely affected body region and to determine the MAIS value for most of them. Figures 2–8 provide an overview of the injury patterns and severities.

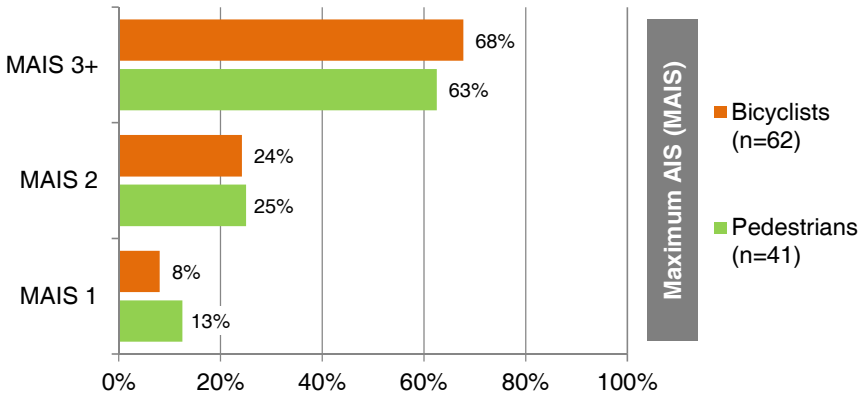


**Figure 2. Distribution of MAIS1, MAIS2 and MAIS3+ for pedestrians and bicyclists**

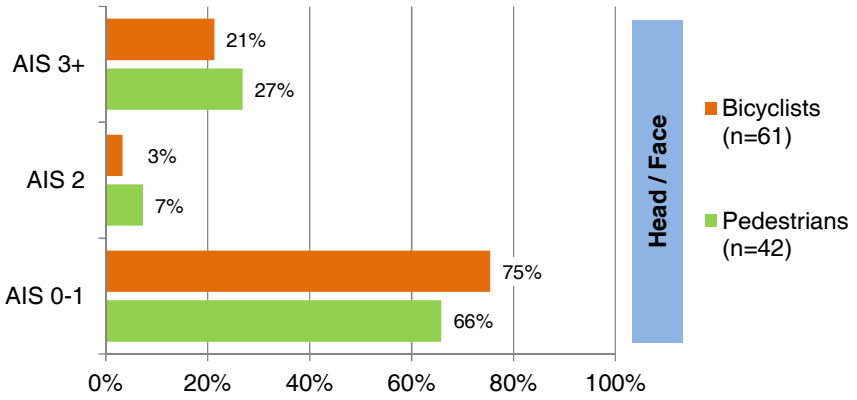


**Figure 3. Distribution of head/face AIS0-1, AIS2 and AIS3+ for pedestrians and bicyclists**

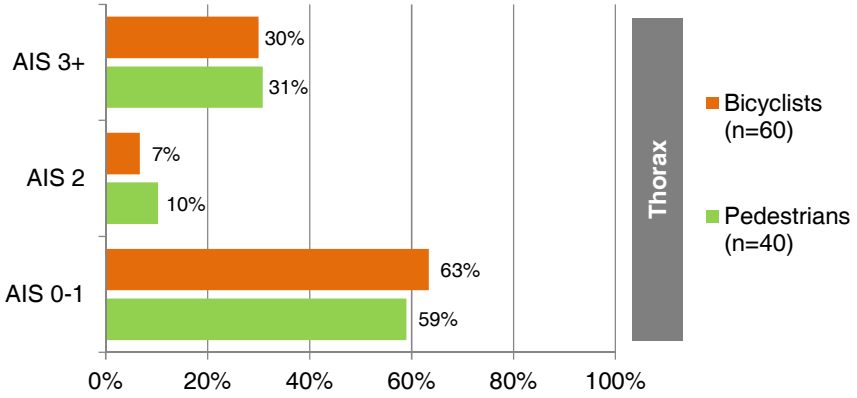


**Figure 4. Distribution of thorax AIS0-1, AIS2 and AIS3+ for pedestrians and bicyclists**

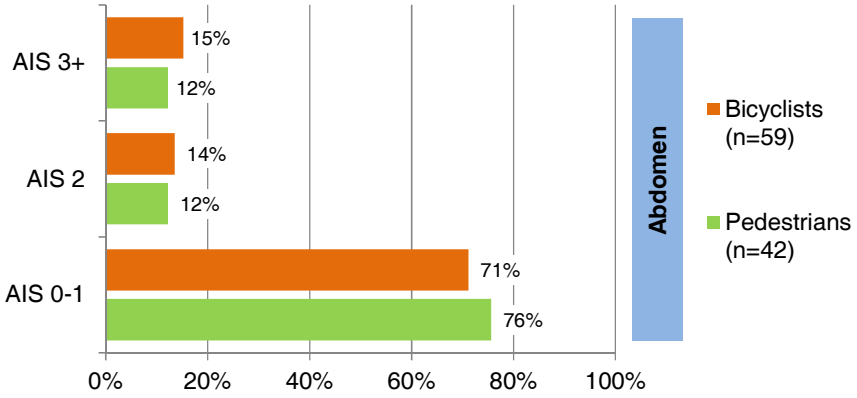


**Figure 5. Distribution of abdomen AIS0-1, AIS2 and AIS3+ for pedestrians and bicyclists**

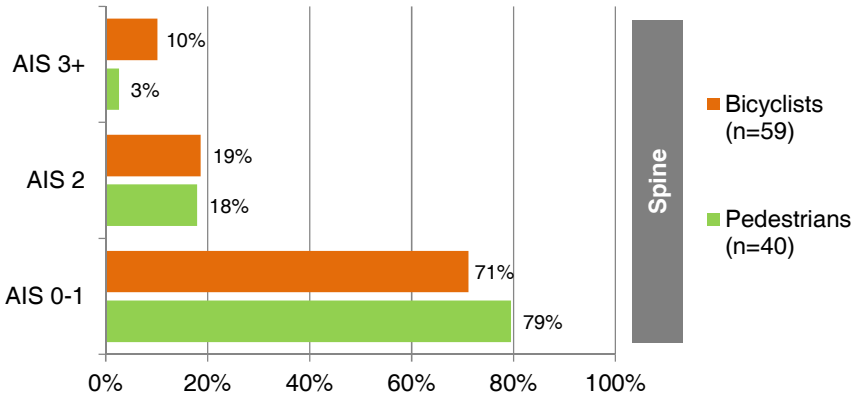


**Figure 6. Distribution of spine AIS0-1, AIS2 and AIS3+ for pedestrians and bicyclists**

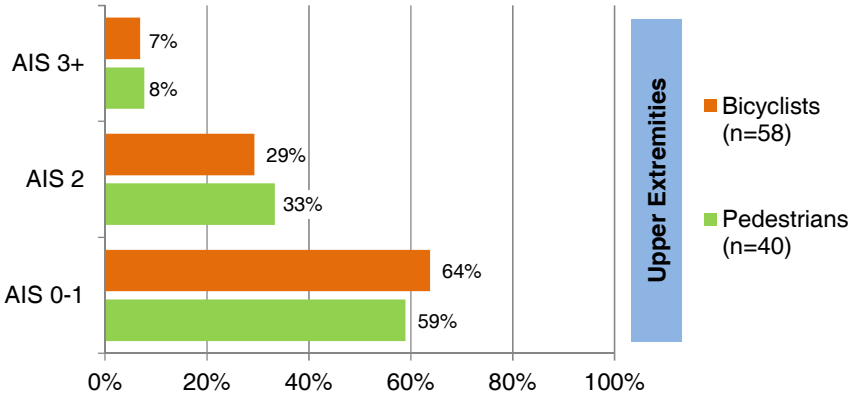


**Figure 7. Distribution of upper extremities AIS0-1, AIS2 and AIS3+ for pedestrians and bicyclists**

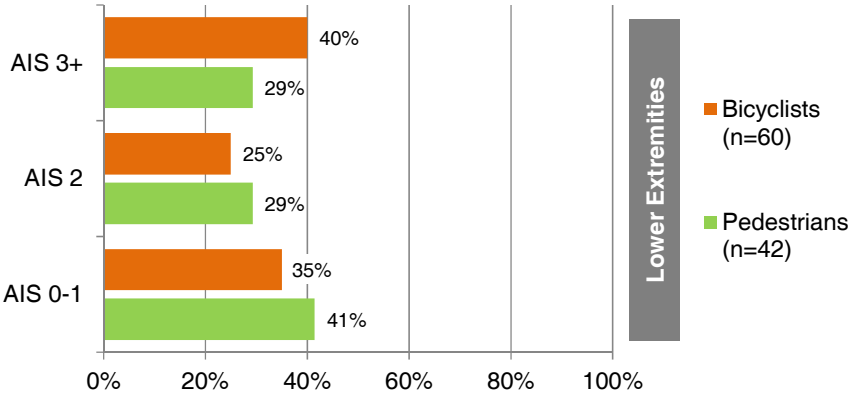


**Figure 8. Distribution of lower extremities AIS0-1, AIS2 and AIS3+ for pedestrians and bicyclists**

MAIS3+ cases accounted for approximately two thirds among all pedestrian and bicyclist casualties (n = 25; 63% and n = 42; 68%, respectively), including fatalities, whereas only five injured, each, (13% and 8%, respectively) were MAIS1. The highest proportion of serious to critical injuries (AIS3+) for pedestrians was found in the thorax region (31% among 40 pedestrians with respective injury data) and for bicyclists in the lower extremities region (40% among 60 bicyclists with respective injury data). Nevertheless, thorax and lower extremity trauma was frequent in both groups. AIS3+ injuries in the latter body region included fractures of the femur and the pelvic bones as well as open fractures of the lower leg. Often, lesions reaching into deep layers of the skin and decollement, both rated as AIS2, were present either as the only injury to the leg or foot or in combination with fractures. These types of injuries can be attributed mostly to a run-over mechanism of the respective body region. AIS3+ thorax injuries consisted primarily of rib series fractures and lung lacerations. AIS3+ abdominal injuries were mostly associated with run-over, too. Serious to critical head/face injuries (AIS3+) occurred in 27% of the pedestrians and 21% of bicyclists with known injury data. While in three bicyclists, AIS6 head injury was found in the form of head crush or brain stem laceration, no such injury mechanism was present in pedestrians. Still, five of them sustained AIS4 and AIS5 intracranial injuries due of severe impact by the truck front face. On the whole, pedestrians and bicyclists presented very similar injury patterns and severities in collisions with heavy trucks.

## DISCUSSION

The present study compares circumstances and consequences of accidents that involved a heavy truck, defined as a goods and service vehicle with a gross vehicle weight of 11,900 kg and over, and either a pedestrian or a bicyclist. The underlying data and methodology have both strengths and limitations.

While past research work often addressed accidents between VRU's and heavy vehicles, in general, the present focus is on trucks of the N3 category. This limits the number of cases available for evaluation, but at the same time makes the results probably more dependable for the class of vehicles under scrutiny. With the chosen relatively high threshold of claim costs as a criterion for case inclusion, the evaluated sample likely reflects accidents with more severe outcome which can be inferred also from the fact that the entire material contained only four cases of VRU's who received merely out-patient care. By including, e.g., road maintenance workers and other persons that may not fit the "classic" image of a pedestrian, our study applied a wider definition of "pedestrians", resulting in a higher rate of injured pedestrians in relation to injured bicyclists (1:1.4 ratio). Nevertheless, the crash and injury mechanisms in collisions with trucks apply also for these casualties. Panwinkler, who did a special analysis of N3 truck accidents in Germany for 2015 [6], reported 318 pedestrian and 739 bicyclist casualties, i.e., a ratio of 1:2.3, but with 49 fatalities, each, in both groups. De Ceunynck et al. [3] quote the Belgian statistics according to which 8% of killed victims were pedestrians and 16% were bicyclists in crashes with heavy goods vehicles in Belgium. The data for the French Rhône region [7] shows the opposite numerical relationship with 73% pedestrians and 27% bicyclists in crashes with trucks. While our sample may reflect the German situation quite well, the ratio of pedestrians to bicyclists in collisions with trucks probably varies considerably in different countries and different regions, possibly owing to the local share of bicycle use.

Regardless of the case numbers for pedestrians and bicyclists, the results from our study underline findings from previous studies that crashes with involvement of heavy trucks are particularly severe. Run-over, at least of one part of the victim's body, was present in 40% of the pedestrians and 52% of the bicyclists. In an analysis of the Renault Trucks VRU database which included only fatal cases, Beillas et al. [7] reported an even higher rate of run-over with 75% among killed pedestrians and 79% among killed bicyclists.

A major factor that appears common to all studies related to accidents between heavy vehicles and vulnerable road users is the prevalence of older persons among the VRU's. With a growing share of seniors in the population in many western countries, the importance of this age group increases among road traffic casualties. 50.7% of all killed pedestrians and 58.6% of all killed bicyclists in Germany in 2017 were persons age 65 and over [1]. Seniors aged 65 years and over represented 44% among pedestrian and 35% among bicyclist casualties in our study. De Ceunynck et al. [3] in their analysis of blind spot accidents involving trucks in the Antwerp area also noted a high percentage of seniors: 80% of pedestrians and 37% of bicyclists were 60 years or older. Beillas et al. [7] reported a 50% share of VRU's over 61 years among fatalities in crashes with trucks. While the increased vulnerability of older victims may

play a role, too, their slower reaction to the unexpected conflict with a truck appears to be a crucial factor. A possible misunderstanding by older bicyclists of the truck's intention when negotiating around street corners was hypothesised by the authors in the previous study on these types of crashes [4]. For several cases of older pedestrians, the data and case descriptions in our material suggest that the seniors were not aware of the risk that the truck driver might not notice them when they passed by the vehicle, often at its front and in close proximity. This is not to say that the pedestrian was automatically at fault when the accident happened, though. In several incidents, the truck driver apparently did not look carefully or did not utilise the available mirrors when moving off from a stop.

## CONCLUSIONS

Previous studies, so far, have come to the conclusion that driver assistance systems, particularly electronic turn-assistance, have a large theoretical potential to avoid or at least mitigate crashes between heavy vehicles and bicyclists [4, 5]. Similarly, pedestrians will likely benefit from driver assistance systems in conflicts with trucks. However, such systems need to be geared to the specific accident scenarios involving pedestrians. Unlike monitoring the right side of the vehicle which is necessary for turn-assistance to avoid accidents with bicyclists, pedestrian protection needs to focus on the area in front of the truck. Since many of these accidents occur when the truck is moving very slowly or is initially being stationary detection of VRU's in the immediate front area should be feasible with state-of-the-art sensory devices. At least one truck manufacturer has not only introduced turn-assistance as an option for its vehicles, but has also upgraded its forward collision alert by including the detection of pedestrians in front of the truck cab at lower speeds [9]. A considerable proportion of the evaluated accidents was apparently caused largely by either a misunderstanding of the present hazard on the part of the vulnerable road user or by negligence on the part of the truck driver. Trainings and campaigns to increase awareness should therefore be tailored to the specific population at risk.

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