

COLLISIONS BETWEEN CARS AND UNPROTECTED ROAD USERS - IS THERE MORE TO ADDRESS THAN THE FRONT OF THE CAR?

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Paper Number 17-0359

ABSTRACT

All efforts made until now regarding pedestrian friendly car design focused on the vehicle front. For bicyclists it will be the same. All passive and active measures are designed to handle the impact of a pedestrian or a bicyclist with the vehicle front which may include the wing area also. Accident research proves this approach: It is correct to cover these areas first and with the most effort. But there are certain accident patterns which need attention, too. And furthermore, there are already technical measures available which could address these accident patterns.

For this study, the in-depth database of the German Insurers (UDB) was used. It contains a representative cross section of all third party insurance claims reported between 2002 and 2012. The analyzed datapool contains n=416 bicyclist-car accidents and n=390 pedestrian-car accidents. Data shows the need to address the front impact for bicyclists (59%) and pedestrians (59%) as it is done nowadays. But there are other noticeable problems like the rear impact, for example. 17% (n=63) of the car-pedestrian accidents were rear impacts where the car was reversing slowly. In 63% of these cases the pedestrians were 69 years or older. Almost half of the involved pedestrians suffered MAIS3+ injuries that were all caused by the impact with the ground. It was also interesting that one third of the pedestrians that were hit by the rear end of the car were not moving as the impact occurred. Another example is the side impact for bicyclists. In 37% (n=139) of all bicyclist-car accidents the impact occurred on the side of the car, only 4% (n=15) were rear impacts. Noticeable is that in 18% of the cases the bicyclist got hit by the door of the car during door opening.

The paper will analyse these patterns more in detail and will discuss technical ways to avoid accidents like these. Further on full-scale-tests regarding door opening were conducted to get a better understanding of kinematics and loads. So it could be shown that the door opening angle has an important influence on the kinematics of the bicyclist.

With "Vision Zero" in mind all road safety potentials have to raise especially these where technical "ingredients" are already on the market. Finally it is up to manufacturers, legislation or consumer test organizations to identify safety related shortcomings and come up or ask for suitable countermeasures.

INTRODUCTION

The efforts made thus far to design cars with a pedestrian-friendly shape have been focused, above all, on the front of the vehicle. This will remain the primary goal with regard to cyclist safety. Consequently, the currently available passive and active safety features for cars are designed for collisions of pedestrians or cyclists with the front of the vehicle, including the wings. It has long been clear from the accident research that this is the right approach, and that these areas of the vehicle have the highest priority and require the most work (Kühn, 2004; UDV, 2016). However, the findings from the accident research also show that collisions between cars and unprotected road users include not just frontal collisions but other accident patterns that also need attention, particularly since technical measures can be taken to address these accident patterns (Jänsch et al., 2015).

DATABASE

This study is based on an analysis of the accident data of German insurers. The UDB accident database used for this contains a representative cross-section of all third-party claims reported to the GDV in the years 2002 to 2012. Only personal injury claims of at least 15,000 euros were included. The accident material takes into account all types of road users. For the purposes of this study, all the collisions of cars with cyclists and pedestrians were taken from a total of around 5,000 accidents involving cars. The underlying data pool consists of 416 involving cars and cyclists and 390 involving cars and pedestrians.

COLLISIONS BETWEEN CARS AND PEDESTRIANS

Figure 1 shows the frequencies of different initial contact point locations (impact location) on cars in collisions with pedestrians. It reveals that collisions with the side of a vehicle (side impacts) are the second most frequent type at 23%. Collisions with the left and right side of the vehicle occur with similar frequency, but a significant proportion of collisions (17%) occur at the rear end of the vehicle (rear impacts).

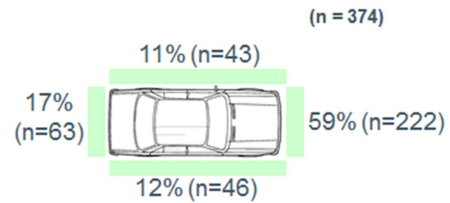


Figure 1: Distribution of impact locations on the car (initial impact at the car) in collisions between cars and pedestrians

Collisions between pedestrians and rear ends of vehicles

With regard to the severity of the injuries sustained in collisions between pedestrians and vehicles, annex 1 shows that 43% of injured pedestrians suffered a MAIS 3+ injury in frontal collisions. These accounted for 66% of all pedestrians with MAIS 3+ injuries in the accident material. If we look at collisions with the rear end of vehicles, we see that 35% of the injured pedestrians sustained MAIS 3+ injuries. These accounted for 16% of all pedestrians with MAIS 3+ injuries. Collisions with the sides of vehicles came just behind. 15% of all pedestrians with MAIS 3+ injuries sustained them in this type of impact.

If we look more closely at the injuries of pedestrians in collisions with the rear end of cars annex 2, we see that 50% of AIS3+ injuries were upper leg injuries. Head injuries were also frequent, accounting for 27%.

The analyses described above show that it is worth analyzing rear impacts in further detail. In contrast to frontal impacts, for example, 89% of rear impacts occurred during daylight hours. Further analysis shows that the overwhelming majority of the collisions involved low-speed maneuvering with virtually no reaction from the driver. In 95% of cases, the vehicle was not moving faster than 10 km/h. The driver reacted by braking in only 7% of these collisions.

If we look at the accident victims in these collisions, we see that 63% of the pedestrians involved were at least 69 years old. Children under 12 years of age accounted for only 6% of the pedestrians involved in these collisions. The analyses of the accident material show that the age of the driver is not significant. Analyses of the gender of the accident victims show that women

accounted for 70% of the pedestrians but only 32% of the drivers involved.

If you compare only the seriously injured pedestrians (MAIS 3+) in frontal and rear impacts with each other (figure 2), the percentage for rear impacts (35%) is not much lower than that for frontal impacts (44%). However, it is noteworthy that 86% of the seriously injured pedestrians in rear impacts were at least 70 years of age, compared with 28% for frontal collisions. Although the collision speeds in rear impacts were significantly lower than in frontal impacts, the advanced age and thus greater vulnerability of the injured pedestrians may offer a plausible explanation for this. Further detailed analyses show that two-thirds of the relevant injuries suffered were caused by a secondary impact with the ground. In frontal impacts only 10% of injuries were caused in this way.

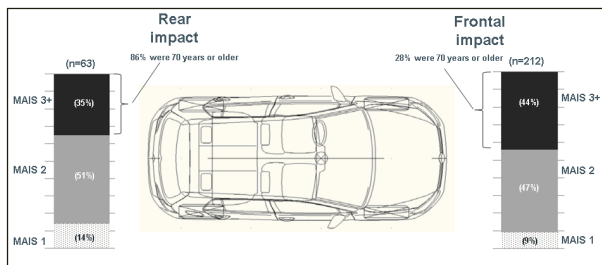


Figure 2: Comparison of the severity of pedestrian injuries in rear and frontal impacts

63% of the vehicles involved in the accidents were no more than five years old at the time of the accident. Based on the accident dates, the vehicles involved in the accidents were therefore manufactured in the period from 1997 to 2007. It is worth noting that 90% of these vehicles are likely to have been without parking sensors or reverse assistance cameras.

To obtain a better understanding of rear impacts with pedestrians, it is necessary to study the accident locations and driving maneuvers more closely. This reveals that this accident pattern can be subdivided into two main categories (figure 3):

- Three-quarters of the cases involved typical parking manoeuvres.
- A quarter of the rear-end collisions did not involve one of these parking manoeuvres. In these cases, the driver reversed against the traffic flow for other reasons, for example in order to give other road users priority (e.g.

ambulances) or to change direction (having missed an entrance, for example).

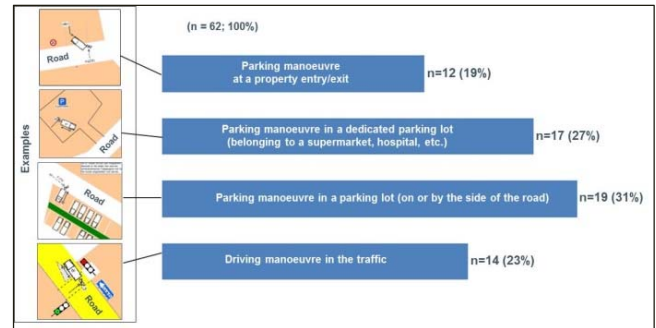


Figure 3: Accident scenarios in collisions between cars and pedestrians involving a rear impact of the car

The most common scenario in the first category (typical parking manoeuvres) was parking on or by the side of the road. This accounted for 31% of the cases. Closer analysis of this scenario revealed the following:

- 12% of the pedestrians involved were not moving at the time of the accident.
- 71% of the pedestrians and 31% of the drivers were women.
- 84% of the pedestrians and 12% of the drivers were older than 65.
- 32% of the pedestrians and none of the drivers were older than 75.
- 75% of the pedestrians suffered their most serious injuries as a result of a secondary impact. 31% of the pedestrians sustained MAIS 3+ injuries.

The second most common scenario in the first category was parking in a dedicated parking lot (belonging to a supermarket or hospital, for example). The patterns involved in this scenario were very similar to those outlined above:

- 24% of the pedestrians involved were not moving at the time of the accident.
- 64% of the pedestrians and 44% of the drivers were women.
- 69% of the pedestrians and 15% of the drivers were older than 65.
- 56% of the pedestrians and none of the of the drivers were older than 75.

- 75% of the pedestrians suffered their most serious injuries as a result of a secondary impact. 38% of the pedestrians sustained MAIS 3+ injuries.

The driving maneuvers in the second category (driving maneuver in the traffic flow) can be described as follows:

- All the pedestrians involved were moving at the time of the accident.
- 10 pedestrians (71%) and 4 drivers were women.
- 9 pedestrians (64%) and 1 driver were older than 65.
- Half of the pedestrians involved suffered their most serious injury as a result of a secondary impact.

Collisions between pedestrians and the sides of cars

As figure 1 shows, collisions between a pedestrian and the left- or right-hand side of a vehicle accounted for 23% of the accidents. There is no significant difference in the number of cases involving the left and right sides of vehicles. Children aged 12 or younger were involved in twice as many collisions with the right-hand side (in 11 cases, accounting for 24% of all accidents) as with the left-hand side (5 cases, amounting to 12% of the total). In 25 of the 89 cases (28%), the pedestrian had contact with one of the vehicle's wing mirrors. In over half of these cases (15 out of 25), the pedestrian was hit only by the wing mirror (17% of all side-impact collisions).

The fact that collisions between pedestrians and wing mirrors occur repeatedly merits further analysis of these accidents. If you look at the smooth contours of modern vehicles, it becomes clear that the wing mirrors are now the only protruding part of the car interrupting these contours. They thus have the potential to cause injury in collisions with more vulnerable road users generally. If we take a closer look at these accident (15 cases) situations, the following becomes clear:

- The average speed of the vehicles involved in these accidents was 40 km/h.

- The pedestrians were generally injured by the secondary impact with the road surface (in 8 out of 11 cases).
- The wing mirrors on the left and right of the car were involved in a roughly equal number of cases.
- The average age of the pedestrians was 62. In 3 out of the 8 cases, the pedestrians sustained MAIS 3+ injuries, all caused by the secondary impact.

An analysis of the accidents revealed that some of them would not have happened if the cars had been equipped with camera monitor systems instead of wing mirrors (see examples in figure 4). Camera monitor systems will thus help to make the contours of vehicles more pedestrian friendly.

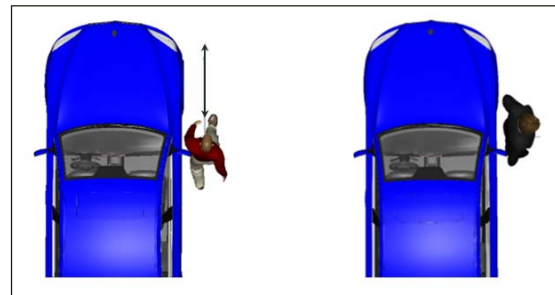


Figure 4: Examples of collisions between a pedestrian and a car's wing mirror (on the left, the pedestrian is walking in the same direction as the car is moving; on the right, the pedestrian is standing with his back to the vehicle as it moves past)

COLLISIONS BETWEEN CARS AND CYCLISTS

Figure 5 shows the frequencies with which different impact locations on cars are involved in collisions with cyclists. 37% (n=139) of all accidents between cars and cyclists were side-impact collisions (side impacts), whereas rear-end collisions (rear impacts) accounted for only 4% (n=15). It is noteworthy that in 18% of the side impacts (n=25), the cyclist collided with a door that was being opened. These accounted for around 7% of all collisions between cyclists and cars in which the impact location on the car is known (n=377). 24 of these cases occurred on the left-hand side of the car. In 23 of these 24 cases it was the driver's door that was hit. However, as

with pedestrians, collisions with the front of the vehicle clearly dominated.

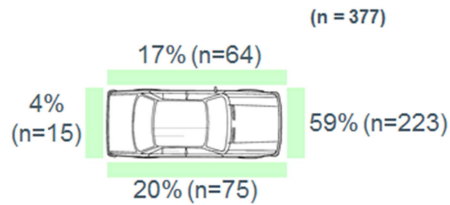


Figure 5: Distribution of impact locations on the car (initial impact at the car) in collisions between cars and cyclists

When we look at injury severity by impact location on the car, we see that, as with pedestrians, the front of the vehicle dominates (annex 3). In frontal impacts 31% of the injured cyclists sustained MAIS 3+ injuries. These accounted for 69% of all cyclists with MAIS 3+ injuries in the accident material. Collisions with the sides of vehicles came next. In collisions with the left-hand side of the car, 24% of cyclists sustained serious injuries (MAIS 3+), and in collisions with the right-hand side, it was 19%. In rear impacts, 13% of the cyclists were seriously injured.

When we look more closely at collisions with the left-hand side of the vehicle, we see that 44% of the serious injuries were head injuries. Around 39% of the serious injuries were to the lower extremities. Annex 4 provides an overview of the injuries sustained by impact location on the vehicle.

Collisions of a cyclist with a car door that was being opened were found to have happened almost exclusively on the left-hand side of the vehicle, indicating a need for further analysis of this accident constellation. Annex 5 shows the injuries of the cyclists in these situations by region of the body.

If we compare the severity of the injuries sustained by the cyclists in collisions with the front of a vehicle with that of cyclists who collided with a door, we find a different distribution within the two groups (figure 6). On the one hand it is noticeable that 21% of all injuries sustained in collisions with a car door are MIA 3+ injuries. However, in comparison to that, frontal impacts are more severe as they result in 50% more MAIS 3+ injuries.

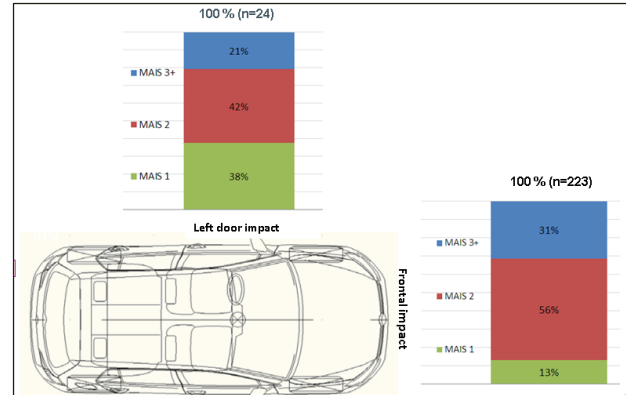


Figure 6: Severity of the injuries sustained by cyclists in collisions with the driver's door compared with collisions with the front of a vehicle

When we look more closely at these 24 cases in which the cyclist collided with the driver's door, it is noteworthy that in 19 cases (79% of the total) the cyclist was riding on the road and attempting to pass the parked vehicle. In most cases in the material studied, there were no separate cycling facilities at the accident location (see examples in figure 7).



Figure 7: Two accident locations in the case material with typical infrastructure

Crash tests describing a collision between a cyclist and an open car door

In order to reconstruct the kinematics involved in these collisions, crash tests were carried out in a project of the Department of Motor Vehicles at TU Berlin. A dummy sitting on a bicycle was pulled towards an open car door at a speed of around 14 km/h. The bicycle traveled along a rail until shortly before the collision. The dummy was also released from its guide rail shortly before the collision. The bicycle and dummy were thus able to move freely. The angle at which the car door was opened was varied. The dummy was fitted with measuring equipment. The sequences of images shown in figures 8 to 10 clearly show the effect of the angle at which the car door is open on the kinematics of the cyclist and the final position of the bicycle. The points of impact of the cyclist with the car door essentially explain the injuries to the head

and extremities derived from the accident data and shown in annex 5.

The larger the angle at which the door was open, the shorter the distance the cyclist was thrown, and in this case the final positions of both the cyclist and the bicycle were near the door.

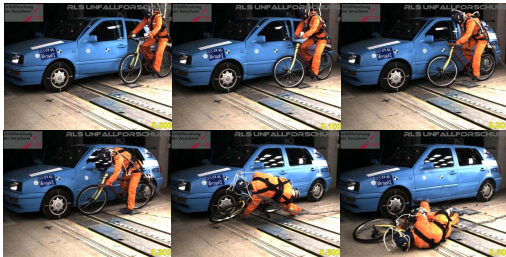


Figure 8: Collision with a driver's door open at an angle of 26.5 degrees and with a small overlap in the handle area of the handlebar

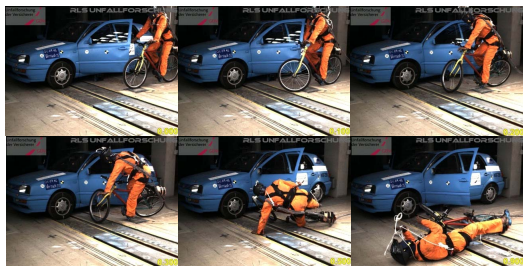


Figure 9: Collision with a driver's door open at an angle of 45 degrees and with a small overlap in the handle area of the handlebar



Figure 10: Collision with a driver's door open at an angle of 90 degrees and with an overlap half the length of the handlebar

Figure 11 shows an example of the critical times and distances involved as a cyclist approaches a car. Assuming a reaction time of 1 second to recognize the danger (the driver's door opening in this case) and decelerating with 3 m/s², a cyclist traveling at 20 km/h would have to be at least 11 meters from the door in order to avoid an accident. On the other hand, at a distance of 6 meters (i.e. about 3 to 4 meters

from the vehicle's rear end), the cyclist would have no chance of reducing speed and would therefore hit the door virtually without braking.

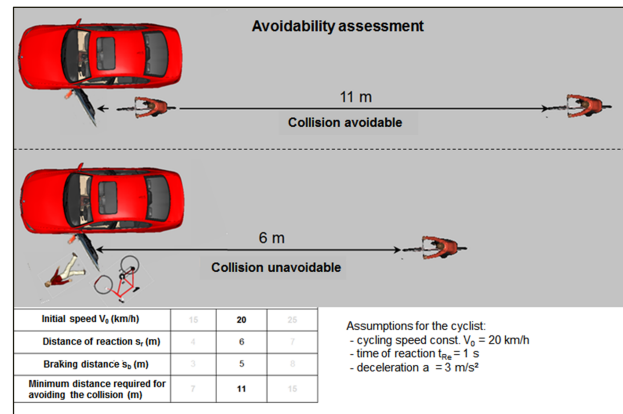


Figure 11: Simplified avoidability assessment for different distances between a cyclist and a car door, assuming the cyclist sees the open door, immediately initiates an emergency braking and comes to a halt (without crashing)

SAFETY MEASURES FOR VEHICLES

Two measures are discussed below for the reversing and door-opening scenarios identified as being relevant in the case of these accidents.

A previous study conducted by the UDV indicated the safety potential of generic systems in accidents involving cars and pedestrians caused by reversing (UDV, 2010). It was found that a driver assistance system with functionality based on systems already available on the market, which detected the presence of people around the rear end of the car and automatically initiated targeted braking in the event of the threat of a collision or prevented the car from starting up, would have significant potential to prevent accidents involving cars and pedestrians (around 13% of the total).

There are already technical solutions available on the market for the door-opening scenario. These warn the driver when vehicles or cyclists are approaching (Audi AG, 2016). Much more promising, however, are systems that prevent the door from being opened in the event of danger. The time period required to allow a cyclist is relatively short, so there is no reason to expect it would be difficult for vehicle occupants to accept this (see figure 12). For example, a cyclist at a

distance of 6 meters from the door traveling at 20 km/h would have passed the car in about 1 second. Even for a slow cyclist (15 km/h), the door would only have to remain blocked for a maximum of 1.4 seconds. It can be assumed that drivers' acceptance of the system would increase once they had experienced its benefits directly.

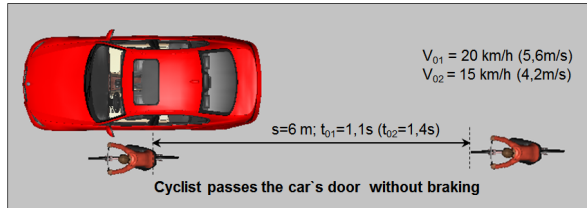


Figure 12: Theoretical assessment of the time required for a cyclist to pass at the point when the driver intends to open the door

In order to achieve the aims of the Vision Zero project, increased efforts are needed to exploit all potential avenues for improving safety. This applies, in particular, to the potential of technology that is already available on the market. All that has to be done here is adapt existing systems to suit relevant accident scenarios. Ultimately, it is up to manufacturers, legislators and consumer test organizations to identify accident scenarios with relevance for safety and find or promote suitable measures that will improve safety.

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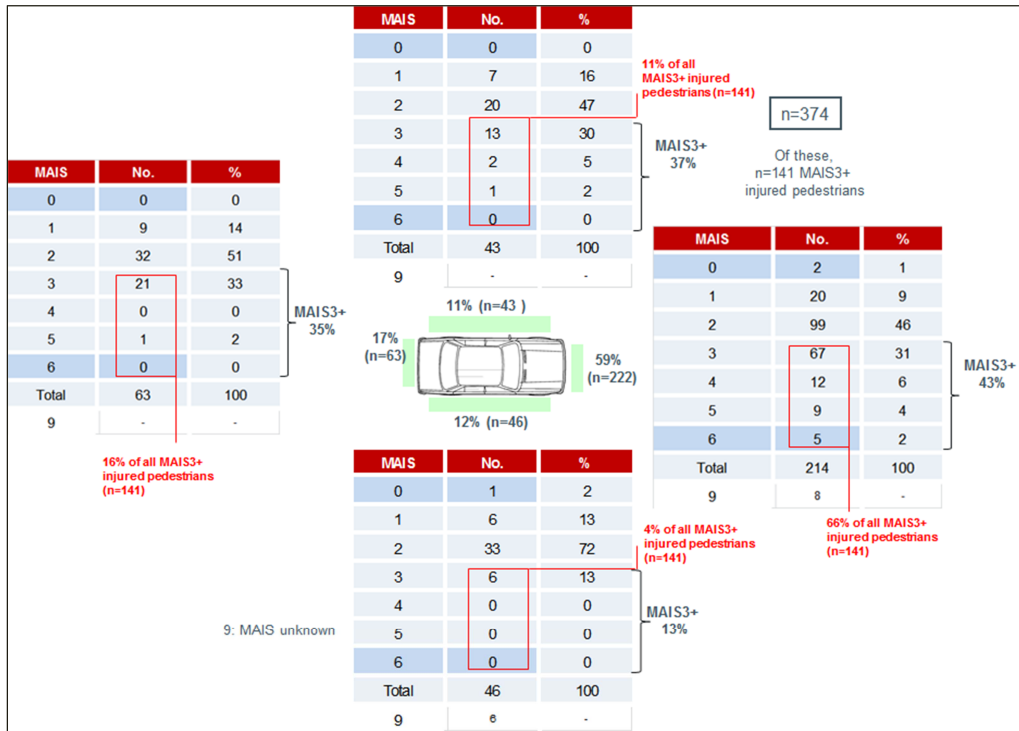
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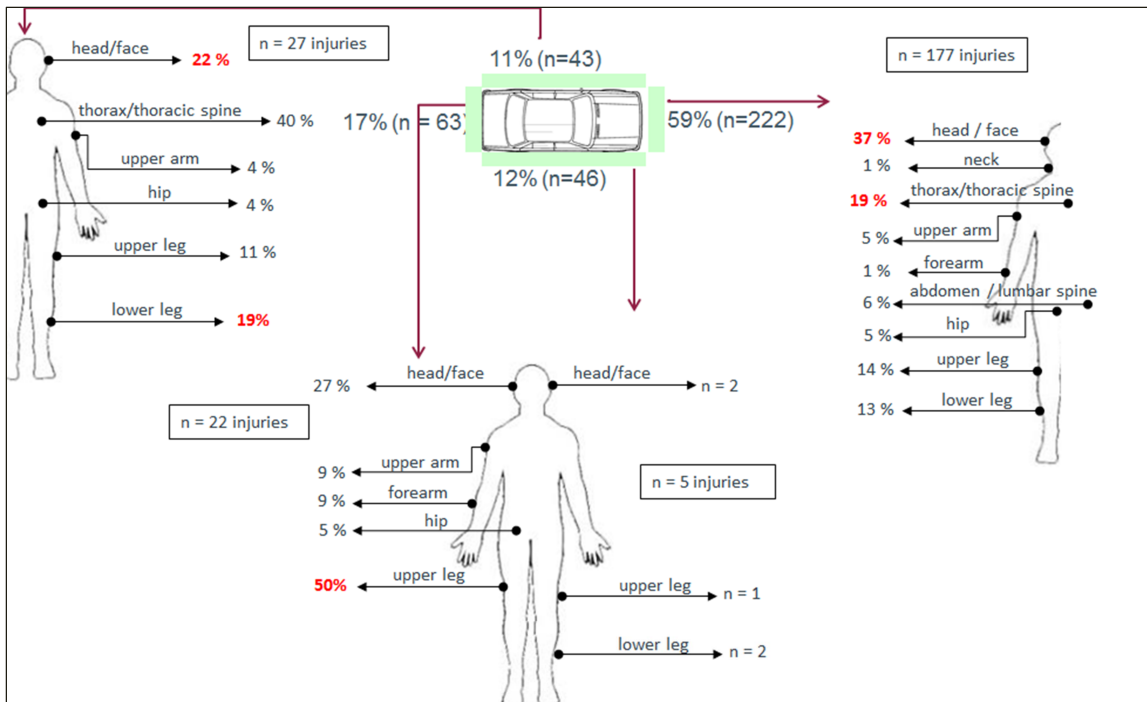
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Annexes

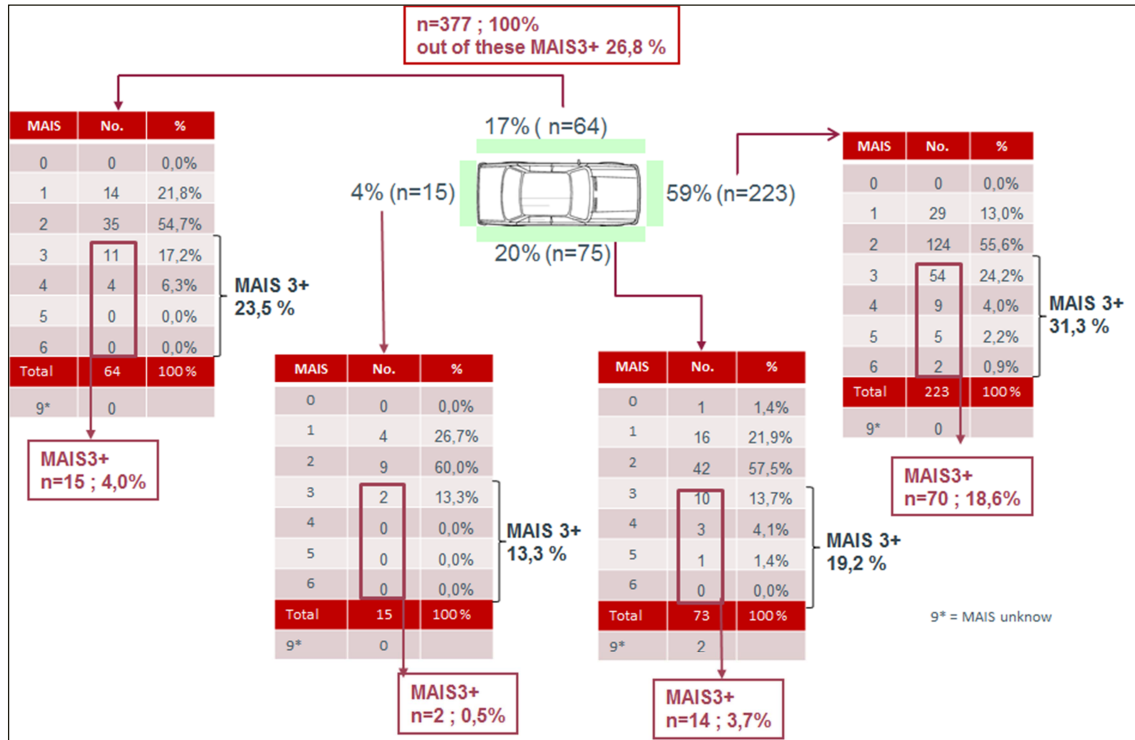
Annex 1 : Injury severity by impact location on the car in collisions with pedestrians



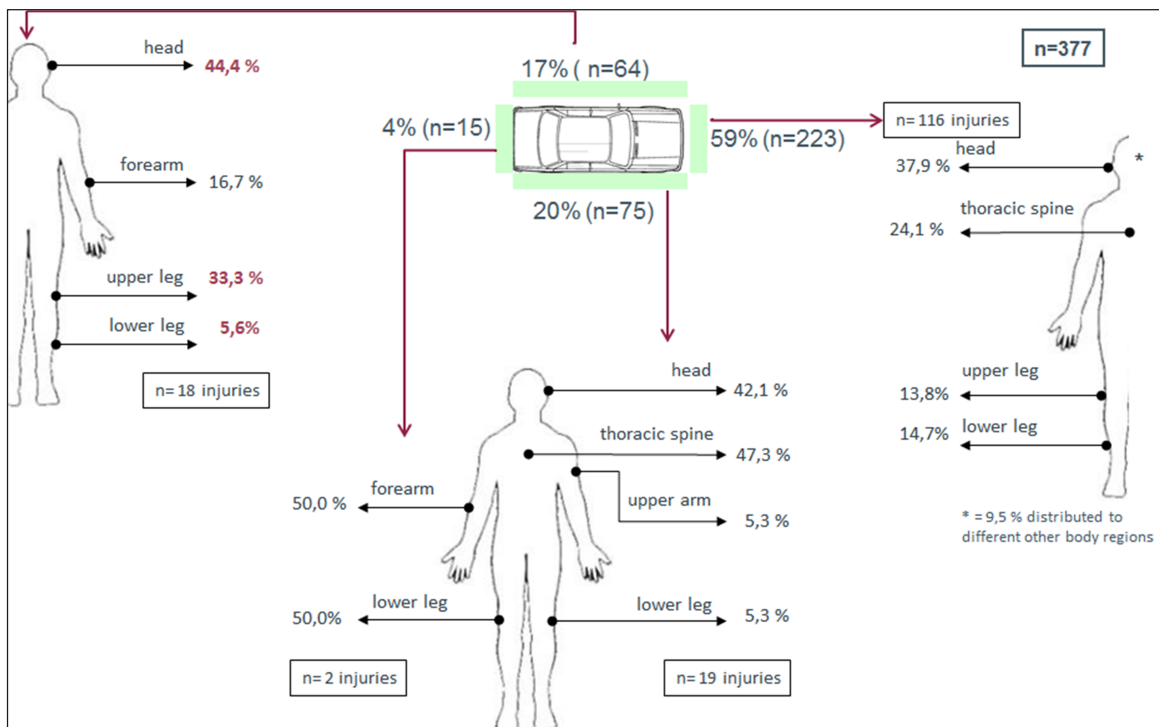
Annex 2 : AIS 3+ pedestrian injuries by regions of the body and impact location on the car



Annex 3 : Severity of cyclists' injuries by impact location on the vehicle by regions of the body and impact location on the car



Annex 4 : AIS3+ injuries of the cyclists by impact location on the vehicle



Annex 5 : Severity of the injuries sustained by the cyclists to different regions of the body in collisions with the driver's door

