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# In-depth analysis of scenarios and injuries in crashes between cyclists and commercial vehicles in Germany

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**Abstract:** Large vehicles such as buses and heavy goods vehicles (HGVs) pose a serious threat to cyclists and can cause serious injuries. Therefore, it is important to understand current safety issues related to these vehicles, to identify and to develop safety interventions that could address these issues. The aim of this study is to describe the characteristics of and injuries resulting from crashes between cyclists and buses and HGVs. In this study, the German In-Depth Accident Study (GIDAS) was queried for all cases that involved either a bus or a HGV and where the opponent was a cyclist. In total, 98 crashes with the involvement of both a bus and a cyclist, and 295 cases where both a HGV and a cyclist were involved, were identified for our analysis. The crashes with cyclists typically occur within city limits, during daylight conditions, on dry surfaces and with clear weather. The cyclists involved in these crashes are mainly male and cyclists under 18-years old account for 28% of crashes with buses, and 16% for crashes with HGVs. The most common crash scenarios are crossing scenarios and turning-off-a-road crashes. In bus crashes, the collision speeds are mainly below 35 km/h and injuries to lower extremities and head are dominating, caused by the road surface and the front of the bus. In HGV crashes, collision speeds are most often below 20 km/h and injuries to the head and thorax are most common, mainly caused by being run over.

**Keywords:** bicycle, bus, crash data analysis, GIDAS, heavy goods vehicle

## 1 Introduction

There are many benefits of choosing cycling as a mode of transport. It is good for the environment and the health gains when being physically active are many. Cycling for everyone is promoted through the global agenda by the UN's Sustainable Development Goals and is mentioned in several different targets, for example goal 1, 3 and 11 (UN, 2015). However, traveling as a cyclist on the roads is not without danger. In 2021, 1.19 million people died related to road traffic, and cyclist fatalities and injuries are frequent (WHO, 2023). Cyclists account for around 41 000 road traffic fatalities annually (WHO, 2018). In Europe, there were 2 035 cyclist fatalities in 2019, accounting for 9% of all road fatalities (Slootmans, 2021). Cyclists are the only mode of transport where no decline in fatalities can be seen over the last 10 years (Slootmans, 2021).

Amongst potential crash opponents, commercial vehicles pose a significant threat to cyclists. In 2020, heavy goods vehicles (HGV) with a gross weight above

3.5 t accounted for 13% of cyclist fatalities and buses for 2% on a European level (Adminaité-Fodor & Jost, 2020). While a bicycle is small and fast to maneuver, buses and HGVs are large, slow in accelerating, and they need a large area to turn. While buses have better direct visibility and drive on regular routes with drivers being more familiar with the environment, HGVs can appear everywhere, and HGV drivers are often not familiar with local conditions and suffer from worse direct visibility. Furthermore, bicyclist movements are often hard to predict, and drivers can easily misjudge the intention of the bicyclist (Volvo Trucks, 2022). While buses are one of the safest means of road transport today, at least for the occupants inside buses that are well protected, they can do a lot of harm to the people outside of buses, especially pedestrians and cyclists. Buses have been involved in 1.8% of all crashes in Germany in 2021. Out of these bus-involved crashes, 0.8% had a fatal outcome (Destatis, 2022).

To address this issue, one part of the goals of Transport for London (TfL) in the UK is that no one should be killed in or by a bus in London by 2030. This should be achieved by introducing both active and passive safety interventions on buses (TfL, 2018; Edwards et al., 2018). When it comes to the crash scenarios, an Australian study from Ker et al. (2005) shows that the most common bus-bicycle crashes occur at intersections. Of the non-intersection crashes, crashes involving lateral movement are most common and have the highest probability of fatalities. Another Australian study (Baumann et al., 2012) interviewed bike riders and bus drivers, with the result showing that only 10% of the bike riders felt comfortable when interacting with buses, and only 8% of the bus drivers felt comfortable interacting with bicycles.

Similarly, heavy goods vehicles are perceived dangerous as well. While the latest numbers from Germany (Destatis, 2022) show that on a national level, around 1% of all crashes are fatal, this percentage increases to 3.4% when a HGV is involved. Furthermore, although HGVs are involved in 2.2% of crashes in Germany, their share in fatal crashes increases to almost 8%. This overrepresentation in fatal crashes has also been identified in previous studies (Pokorny et al., 2017; Richter & Sachs, 2017; Prati et al., 2018; Schindler et al., 2022) and is very different to what has previously been presented for buses. Conflicts at intersections were identified as the most common conflict scenario between HGVs and cyclists (similarly to what has been identified for buses), especially situations where the HGV turns right and the cyclists continue going straight (Richter & Sachs, 2017; Schindler et al., 2022; Kircher & Ahlström, 2020; Pokorny & Pitera, 2019).

Conflicts between cyclists and commercial vehicles pose a serious threat to cyclists. While some of these conflicts could be addressed by active safety systems, such as blind spot detection (Schoon et al., 2008; Tomasch & Smit, 2023), more in-depth knowledge about these conflicts is necessary in order to design appropriate systems. Therefore, it is important to understand the current safety issues related to these vehicles, to facilitate identifying and developing safety interventions that could address them. The aim of this study is to describe the characteristics of and injuries resulting from crashes between cyclists and buses and HGVs. The results of this study describe the current situation for both vehicle types, and aim to provide a basis for further in-depth investigations into these scenarios.

## 2 Method and data source

The data used in this study is based on the German In-Depth Accident Study (GIDAS) version released in January 2023, that contains over 44 000 crashes collected in the last 23 years. In the GIDAS database, crashes from Germany in the greater areas of Dresden and Hanover are collected. Since 1999, specialists, that are divided into different teams, collect information about crashes where at least one person is suspected of being injured (Erbsmehl, 2009). The information collected is very comprehensive and contains both high level information about the crash environment as well as detailed information about injuries and what caused them.

The database was queried for all fully reconstructed cases that involved either a bus or a HGV with a gross weight above 3.5 t. Afterwards, these crashes were filtered for those that involved a cyclist as well. In total, 98 crashes with the involvement of both a bus and a cyclist were found. In these crashes, 101 cyclists sustained 309 injuries (each cyclist sustained a median of 2 (range 1 to 10) injuries). For cases where both a HGV and a cyclist were involved, 295 crashes were found with 303 cyclists sustaining 1 397 injuries (each cyclist sustained a median of 3 (range 1 to 63) injuries). For simplicity, only buses and HGVs will be referenced throughout the rest of the paper, but these are still all crashes that involve a cyclist as well. The resulting dataset was the basis for the following analysis and descriptive statistics provided in the next section. We also calculated odds ratios with their confidence intervals and significance, to identify factors that could influence the severity outcome of the crash.

To classify the severity of the injuries for the cyclist, we used the police-based severity coding minor (hospitalization less than 24 hours), serious (hospitalization more than 24 hours) and fatal (died within 30 days of the crash). Additionally, for a more in-depth analysis of the injuries and injury sources, we used the latest version (2015) of the Abbreviated Injury Scale (AIS). The injuries were divided into different body regions and different severity levels, where AIS1 is a minor injury and AIS6 is a non-survivable injury. An injury severity of AIS3+ means at least one serious (or higher) injury to the cyclist.

For each injury that a person sustains, an injury-causing part is coded in GIDAS. Almost 300 different, very specific, parts are coded and therefore, the injury-causing parts have been grouped into more general groups. Most groups are self-explanatory, but some need an explanation: the injury-causing part in the 'Other' group are for example roadside objects (e.g. fences, poles) and the group 'Own action or equipment' could be tongue bite or injuries from the person's own glasses or clothing.

## 3 Results

In crashes with cyclists, the most common HGV types are articulated HGVs, HGVs with a special body and box trucks, each with a share of around 21%. The most common bus types are city buses (43%), followed by articulated buses (39%). The crashes typically occur within city limits, during daylight, on dry surfaces and with clear weather (more detailed graphs are in Appendix A). Table 1 shows the odds ratios calculated for these different influencing factors. Only the odds ratio for crash location in HGV-involved crashes (Figure 1) has reached significance in our dataset—indicating that the odds of a fatal outcome in crashes with HGVs are 6.9 times higher in rural areas than in urban areas.

The cyclists involved in these crashes are mainly male. While people under 18 account for 26% of crashes with buses, their share is only 16% in crashes with HGVs (Figure 2). On the other hand, these percentages are flipped for people above the age of 60 (26% of cases with HGVs, 16% of cases with buses). Observed helmet wearing rates for cyclists are 23% in collisions with HGVs and 36% in collisions with buses.

Figure 3 shows the most common conflict scenarios, i.e. the initial conflict situation that led to a collision between a commercial vehicle and a cyclist, based on the German Insurance Association (GDV) classification (GDV, 1973) used in GIDAS. The most common conflict scenarios for buses are crossing scenarios at intersections, followed by turning-off-a-road crashes (Figure 3, left). For HGVs, these are also the most common conflict scenarios, although their order is inverted (Figure 3, right). When looking at the drivers' actions during the collision sequence (Figure 4), it was coded that there was no action of the driver most of the time. The second most common action for both vehicles is braking, while this is closely followed by accelerating for HGVs.

These different crash patterns and driver actions also result in different speed distributions for both vehicle types. While around 30% of HGV-related crashes have an initial speed of 0 km/h (i.e. start from stand still, for example after stopping at a red traffic light), these account only for around 15% of cases for buses (e.g. when buses leave from a bus stop, Figure 5). This also results in generally higher initial speeds for buses compared to HGVs. These higher initial speeds for buses then also result in higher collision speeds, compared to HGVs. While the 80% mark for buses is around 35 km/h, it is only slightly above 20 km/h for HGVs.

For buses, in 45% of crashes the cyclist impacted the right vehicle side and in 34% the vehicle front (Figure 6). For HGVs, both categories account for 40% of cases. Along the x-axis of the bus, 80% of impacts are within the first 7 m of the bus, while for HGVs they are within the first 4.5 m (Figure 7).

In bus-related crashes, the AIS3+ injured cyclists account for around 7% of cases, while this share is 15% for HGV-related crashes. These AIS3+ injuries are predominantly to the head and lower extremities in bus-related crashes, and head and thorax for HGV-related crashes (see Figure 8 and Appendix A for AIS3+). In bus-related crashes, these injuries are mostly caused by the road surface and front of the bus (in particular the windscreen and wheels), while run overs play an important role in HGV-related crashes (Figure 9).

**Table 1** Odds ratios (OR) for fatal vs. non-fatal crashes for HGV- and bus-involved crashes

| Fatal vs. non-fatal | HGV | | | Bus | | |
|---|---|---|---|---|---|---|
| | OR | 95% CI | p-value | OR | 95% CI | p-value |
| Rural vs. Urban | 6.9 | 1.7–28.5 | 0.008 | 3.8 | 0.2–63.4 | 0.353 |
| Nighttime vs. Daytime | 1.2 | 0.3–5.6 | 0.798 | 2.7 | 0.2–32.3 | 0.431 |
| Wet vs. Dry | 0.5 | 0.1–3.6 | 0.461 | 1.2 | 0.1–24.6 | 0.920 |
| Rain vs. No-rain | 0.5 | 0.0–9.0 | 0.649 | 2.3 | 0.1–52.4 | 0.594 |
| Cycle Path vs. No Cycle Path | 0.9 | 0.3–2.5 | 0.808 | 1.6 | 0.1–17.9 | 0.723 |
| Traffic Light vs. No Traffic Light | 1.7 | 0.6–4.5 | 0.330 | 1.4 | 0.1–16.3 | 0.786 |
| CV Driver Reacting vs. CV Driver Not Reacting | 1.0 | 0.3–3.0 | 0.962 | 0.6 | 0.0–6.7 | 0.658 |
| Female vs. Male | 0.8 | 0.3–2.2 | 0.654 | 1.0 | 0.1–11.3 | 0.988 |

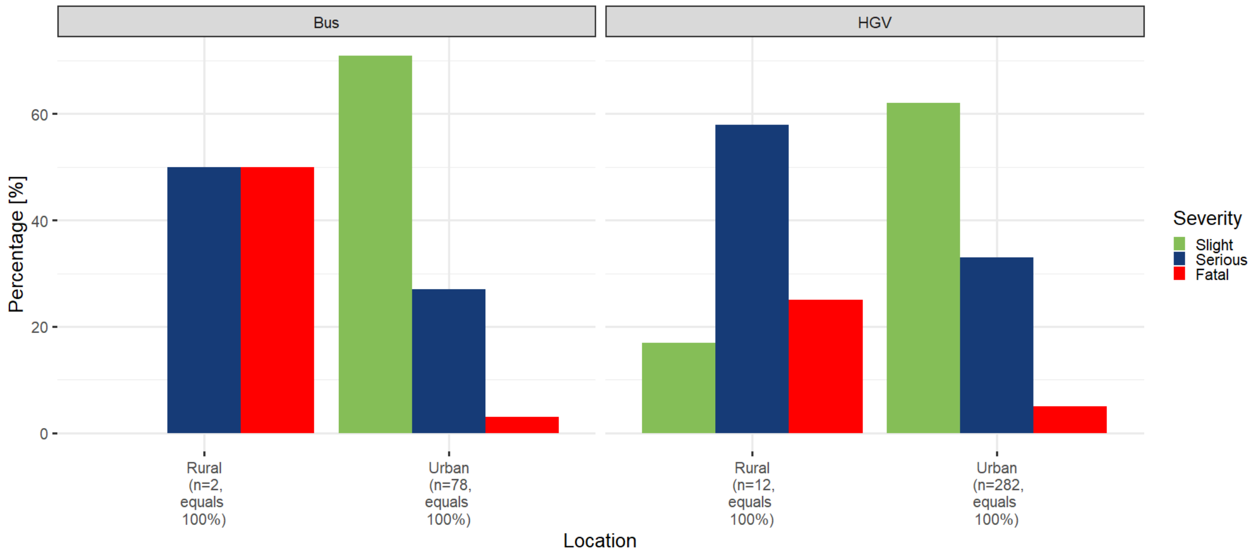


**Figure 1** Crash location distribution by vehicle type and severity

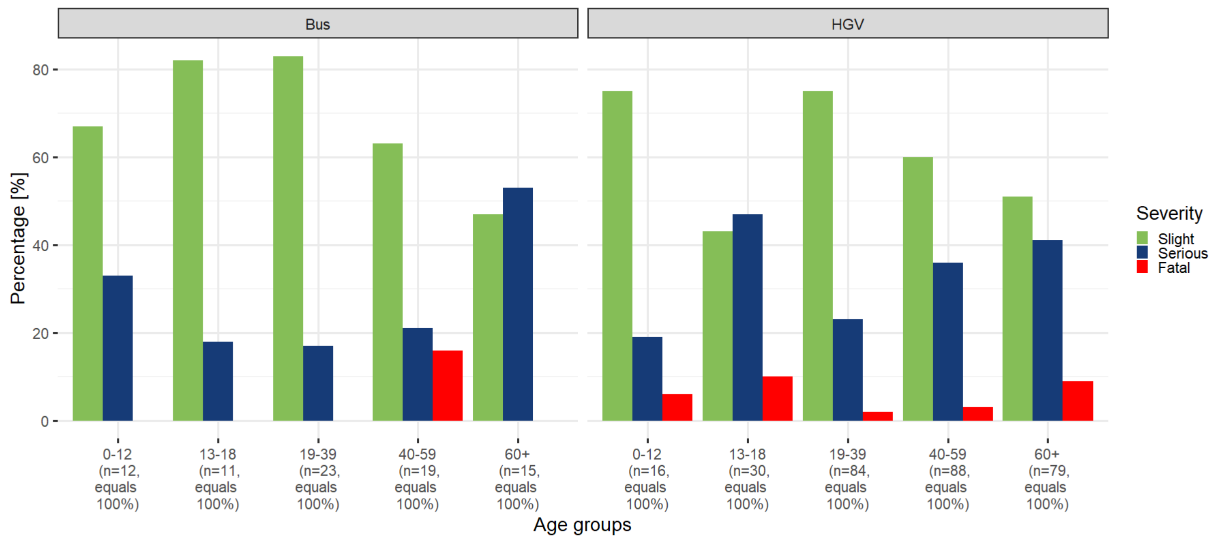


**Figure 2** Cyclist age group distribution by vehicle type and severity

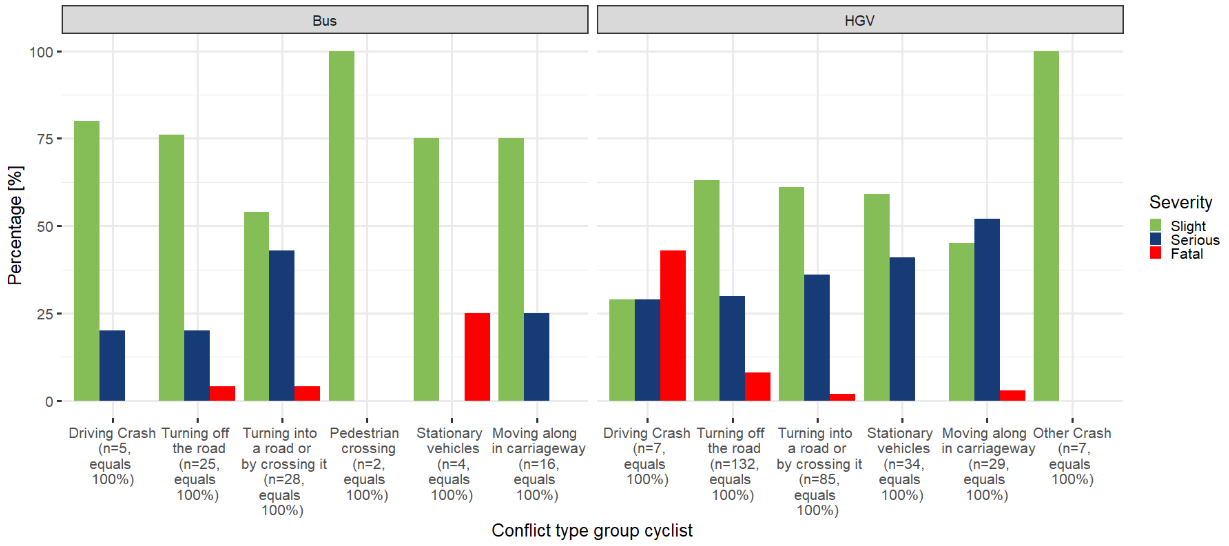


**Figure 3** Distribution of initial conflict by vehicle type and severity

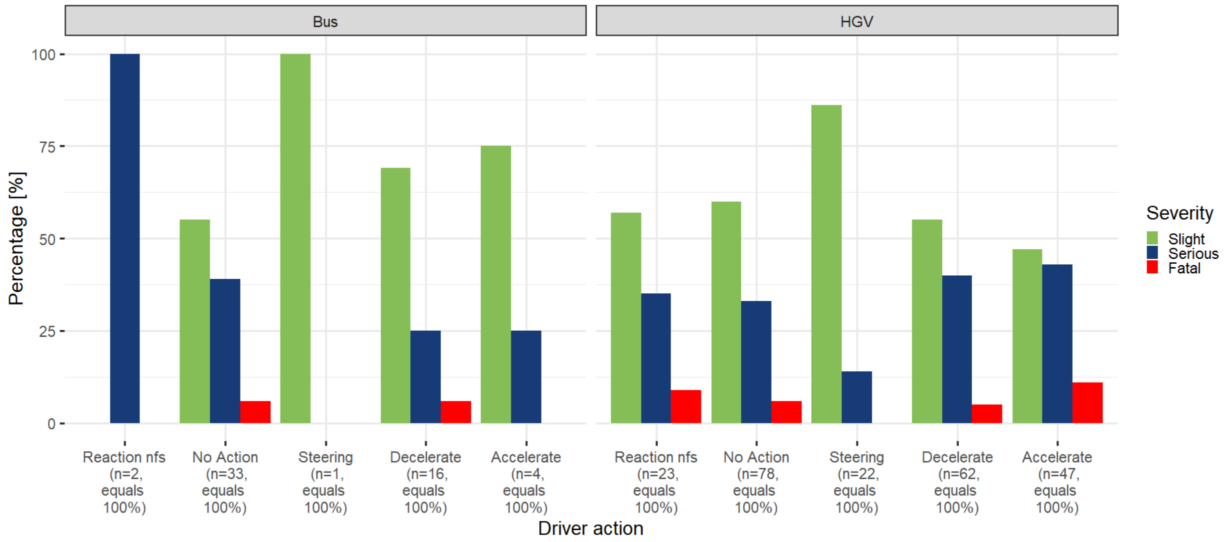


**Figure 4** Driver action distribution by vehicle type and severity

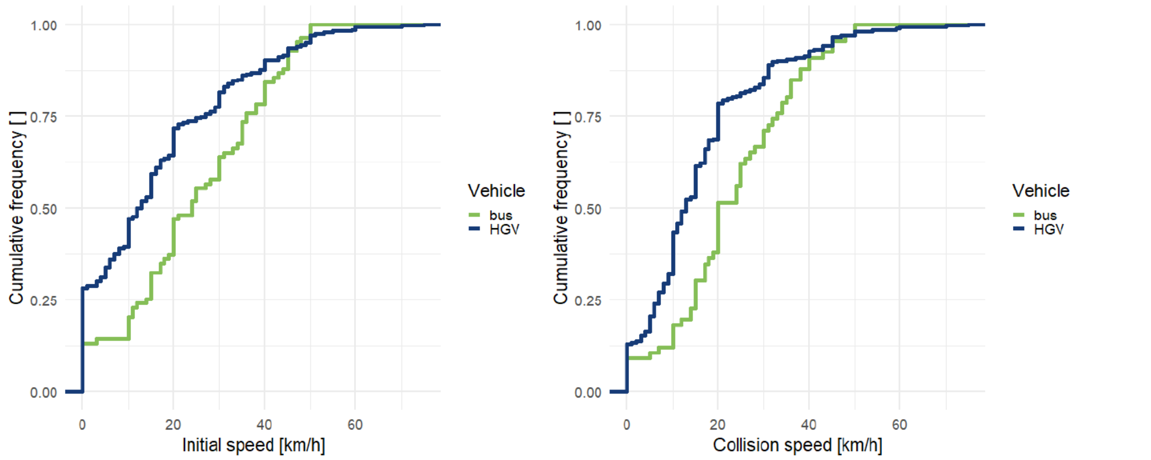


**Figure 5** Cumulative distribution of initial speed (left) and collision speed (right) by vehicle type

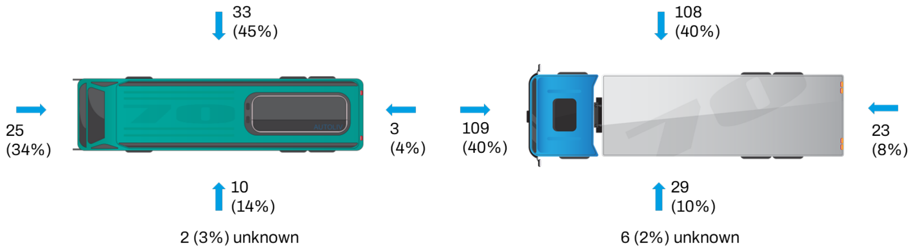


**Figure 6** Direction of impact by vehicle type (left: bus; right: HGV)

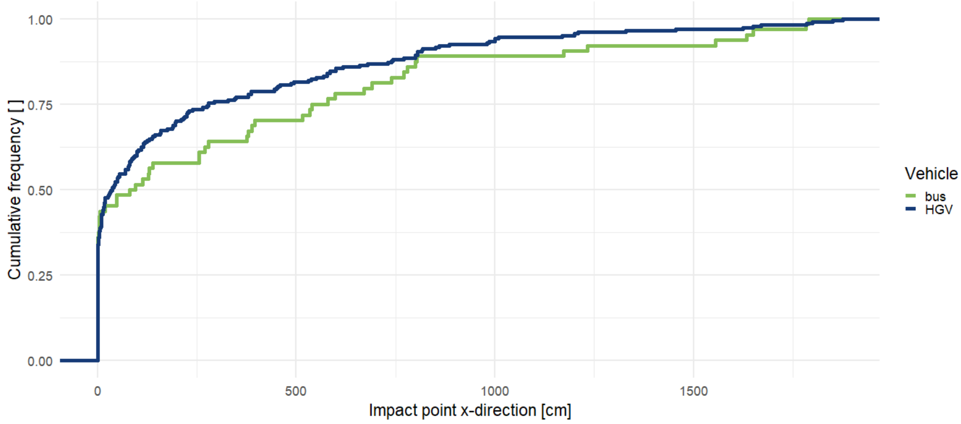


**Figure 7** Cumulative distribution of impact points along longitudinal axis of vehicle, by vehicle type

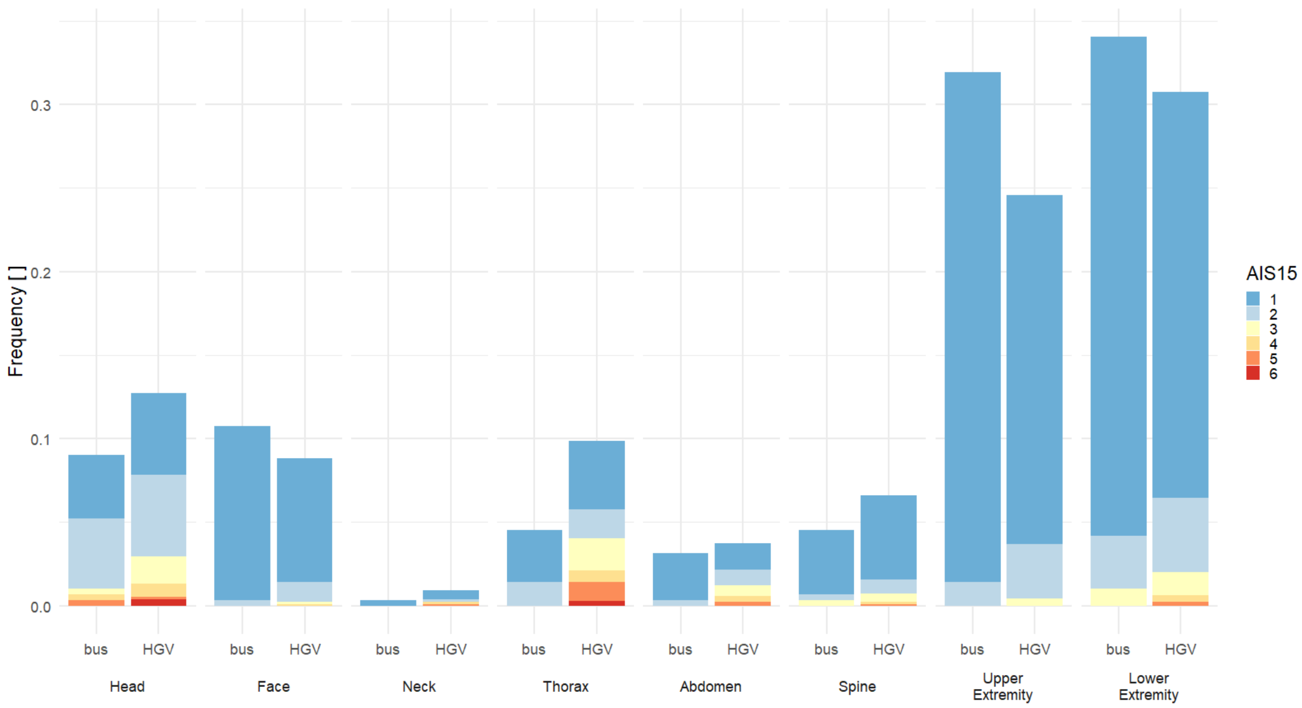


**Figure 8** AIS distribution over body regions by vehicle type and severity

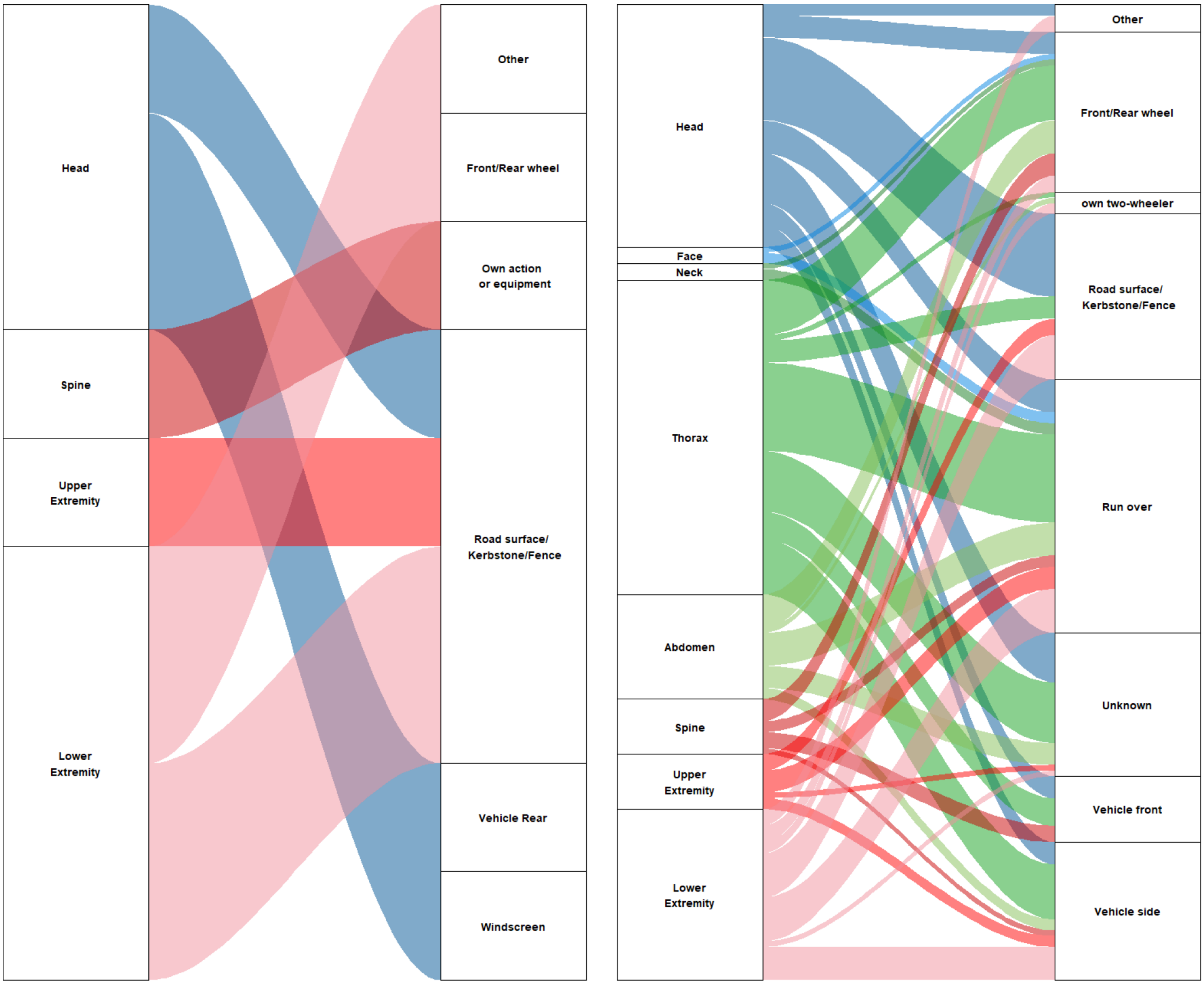


**Figure 9** Distribution of AIS3+ injured body regions and injury sources for buses (left) and HGVs (right)

## 4 Discussion

The results show that most of the crashes happen in urban settings, which was to be expected as cyclists are most commonly traveling in urban areas. As a result, most of the buses are city buses, as these most commonly share the same environment. However, it was quite surprising to see such a high number of articulated HGVs as crash opponents, as these are typically heavy long-haul vehicles that are not designed for urban settings. As these vehicles have particularly large blind spots, it can create dangerous conflict situations especially at intersections. Increased direct vision, automatic braking, blind spot detection, stationary mirrors at crossings or separating bicycles from the rest of the traffic seem effective at avoiding these types of crashes (Schoon et al., 2008; Johannsen et al., 2015).

One notable result was that the third most common action by the HGV drivers during the conflict was accelerating. While this seems counterintuitive at first, it is in line with the crash scenarios identified and a previous study by Ker et al. (2005). Right turn maneuvers are the most common conflict type (Richter & Sachs, 2017; Schindler et al., 2022; Kircher & Ahlström, 2020; Pokorny & Pitera, 2019), and with the low initial speeds it seems to suggest that these conflicts are likely to happen after the HGV has stopped, with cyclists potentially entering the blind spot without the drivers noticing. The HGV drivers then accelerate and perform the turn maneuver, sometimes not even noticing the collision with the cyclist. Nonetheless, even at these low speeds, these crashes result in serious injuries for the cyclists. On the other hand, rural crashes between HGVs and cyclist have almost seven times higher odds to result in a fatal outcome, the only variable that reached significance in our analysis. This could be explained by higher collision speeds associated with crashes in rural areas.

Even though collision speeds in HGV-related crashes are on average only half those of bus-related crashes, the share of serious injuries is two times higher for HGVs. This suggests that injury mechanisms in HGV-related crashes are less speed related, but are also heavily influenced from other sources. Namely, runover crashes have been identified as a major contributing factor, especially for thorax, abdominal and lower extremity injuries. In bus-related cases, the road surface has been identified as the main injury causing part for the cyclists, especially for head, lower and upper extremity injuries. This suggests that the initial impact with the bus is potentially not as severe as the secondary impact to the road surface—which, in addition to the higher collision speeds, then leads to serious injuries. For both buses and HGVs, the impact location is most commonly to the front and right side. This is in line with previous results, e.g. from Volvo Trucks (2022). Wearing a helmet when cycling is a simple and cheap way of mitigating these injuries to the head (Olivier & Creighton, 2017; Pipkorn et al., 2020), and while the general helmet wearing rate in Germany is low at 40.3% (Kathmann & Johannsen, 2023), the even lower rates we identified in crashes with commercial vehicles (23% and 36%) are alarming.

A contributing factor to the large number of run-over crashes could be related to the cyclist's center of gravity in relation to the HGV front. If the wrap transitional point—the point where a person's body wraps around the vehicle—is higher than the center of gravity of the person, it is likely that the person is thrown forward or knocked to the ground (Roudsari et al., 2005). A different front design of the vehicles (e.g. a softer front end) or a frontal airbag that inflates and softens the impact, could prevent people from being knocked to the ground and mitigate injuries caused by the front of the vehicle (Beillas et al., 2011; Pipkorn et al., 2020). Being knocked to the ground also increases the risk of being run over. An over-run protection could mitigate the injuries that are caused when the cyclist is being overrun. An underride protection system that is mounted on the side of the vehicle can prevent the cyclist from ending up under the vehicle and being runover (Lambert & Rechnitzer, 2002; Cottingham, 2022). The road surface was also a common source for injuries to the head and upper extremities. A helmet, protective clothing for the upper body or an airbag vest could potentially mitigate these injuries but would probably be less effective in run-over crashes.

## 5 Conclusions

Large vehicles such as buses and HGVs cause serious injuries to cyclists. In bus crashes, collision speeds are typically below 35 km/h and injuries to lower extremities and head dominate, where the injuries are caused by the road surface and front of the bus. In HGV crashes, collision speeds are typically below 20 km/h and injuries to the head and thorax are most common, mainly caused by being run over. These results provide detailed and actionable insights for manufacturers and agencies that can help to address safety concerns—to make cycling safer.

## CRediT contribution statement

**Ron Schindler:** Conceptualization, Data curation, Formal analysis, Validation, Visualization, Writing—original draft. **Hanna Jeppsson:** Conceptualization, Formal analysis, Validation, Writing—original draft.

## Declaration of competing interests

The authors declare no conflict of interest.

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**Hanna Jeppsson** is a senior traffic safety research engineer at Autoliv Development AB, Sweden. She has a BSc from University of Borås, Sweden. Her main research area is crash analysis for vulnerable road users, such as pedestrians and cyclists, but also including new mobility devices such as e-scooters. Hanna is particularly interested in modelling the relation between impact circumstances and injury outcome for these and other road users.

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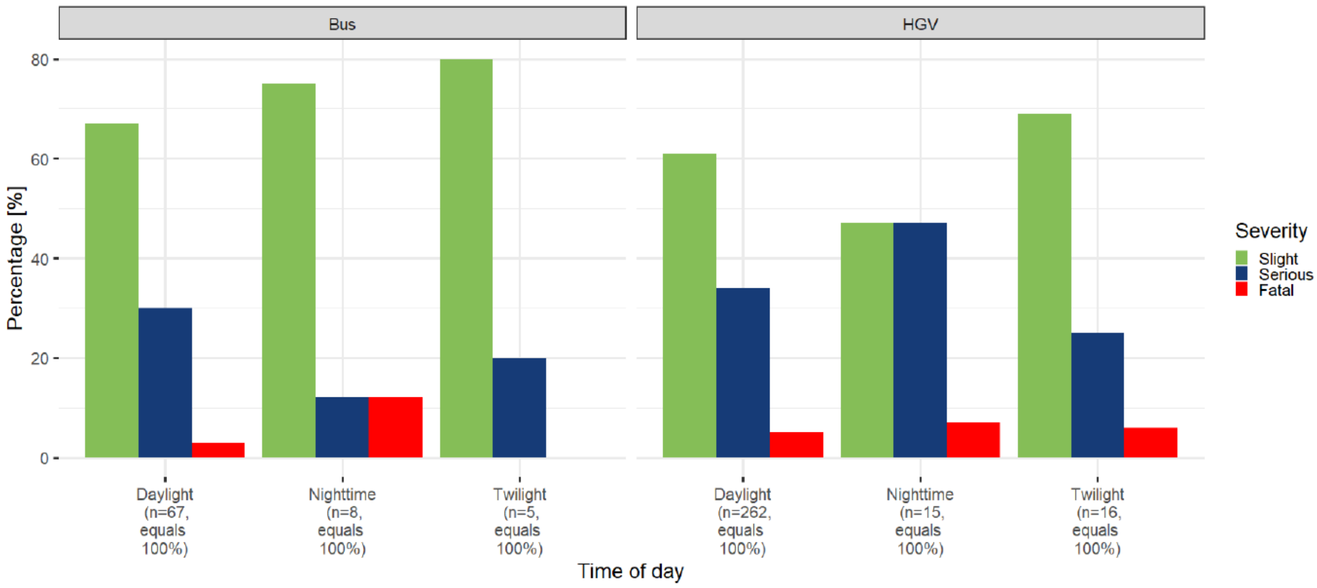
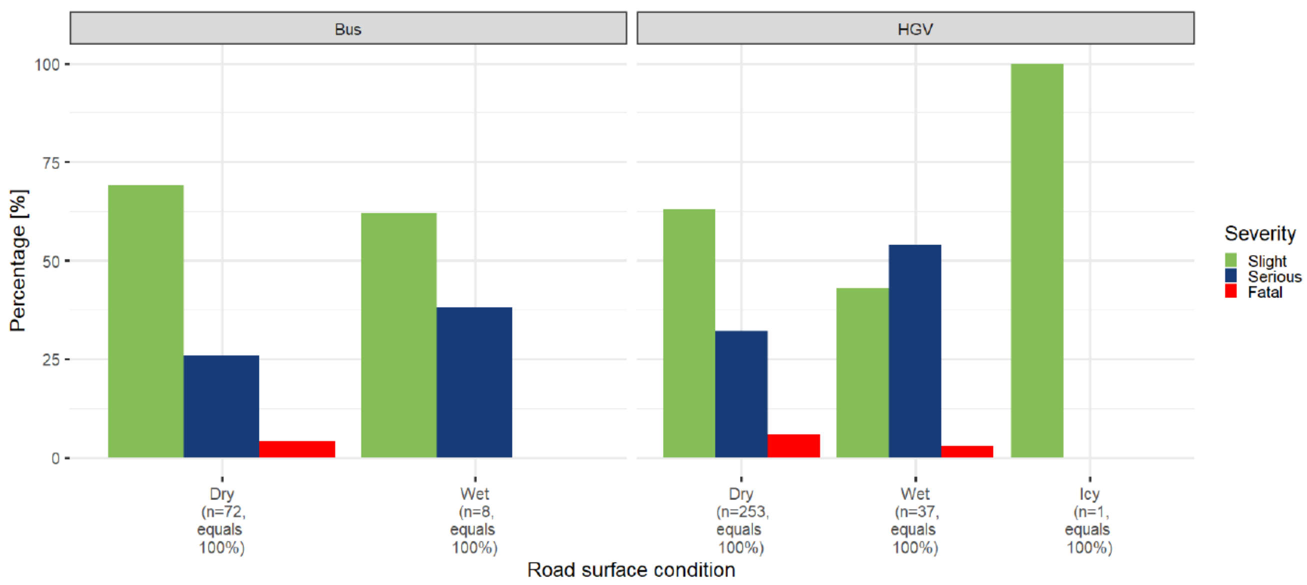
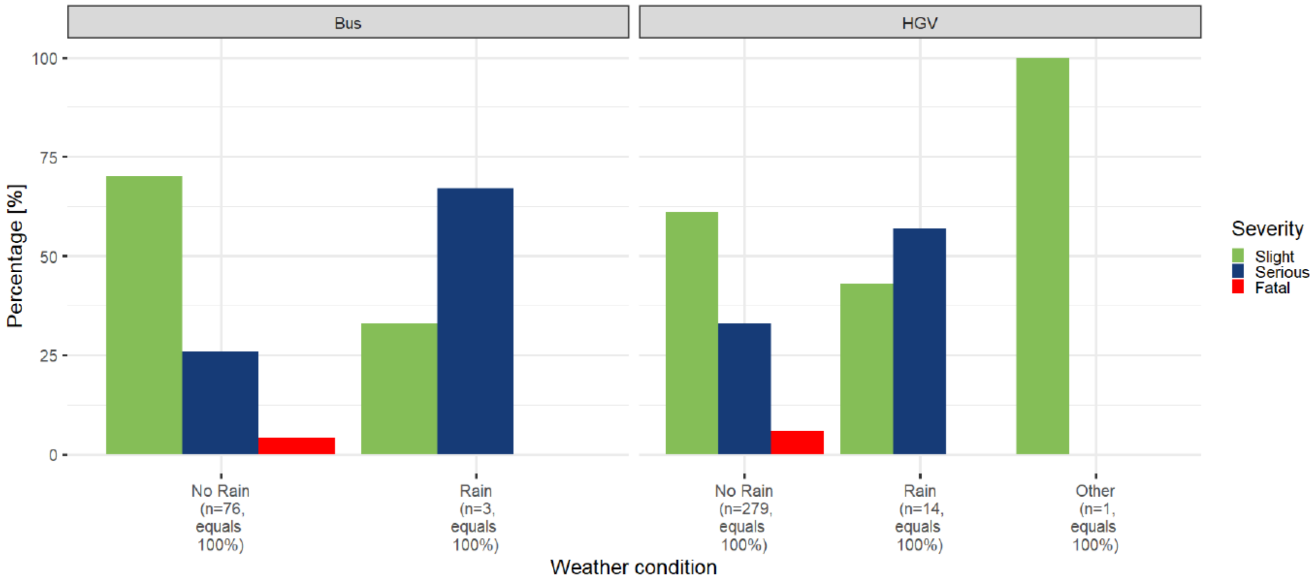
## A Time of day distribution by vehicle type and severity



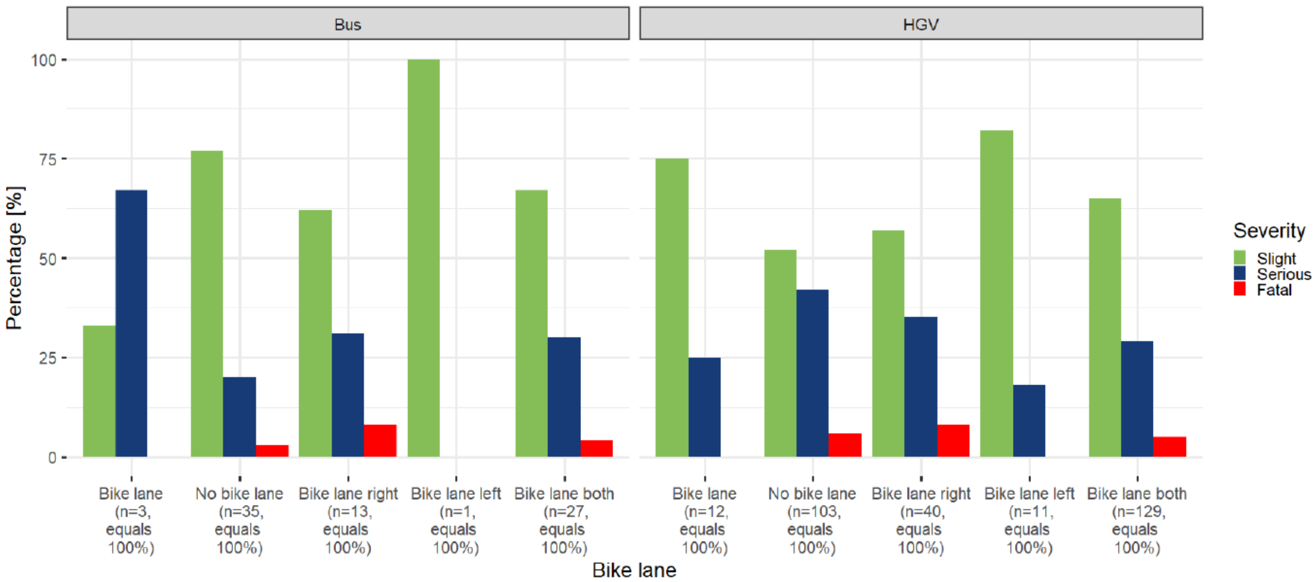

## B Road surface condition distribution by vehicle type and severity



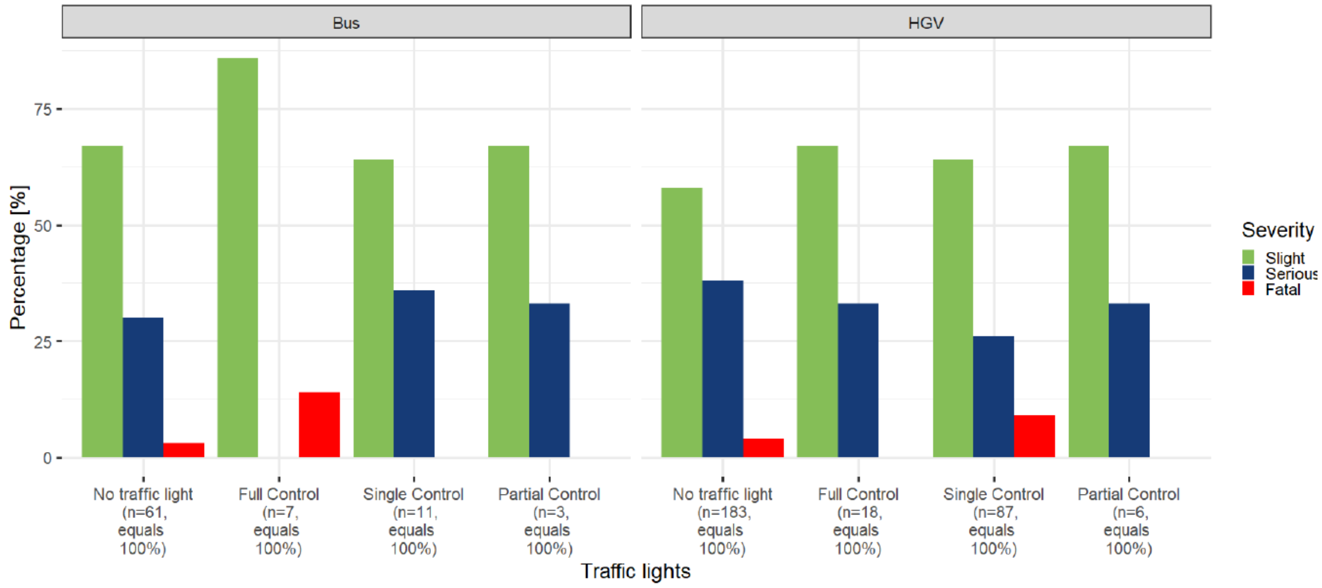
## C Weather condition distribution by vehicle type and severity




## D Bike lane presence by vehicle type and severity



## E Traffic light presence by vehicle type and severity




## F AIS distribution over body regions by vehicle type and severity (only AIS3+ injuries)