Powered Two-Wheeler Accidents in Germany with Severe Injury Outcome - Accident Scenarios, Injury Sources and Potential Countermeasures

Rikard Fredriksson, Bo Sui

Abstract Powered two-wheeler riders is a group for who fatalities are not decreasing at the same rate as for other road users. It is also a group that is likely to increase in the future due to traffic congestion. To develop countermeasures to protect powered two-wheeler drivers it is necessary to understand accident events in detail, the injuries and their sources.

The German database GIDAS was queried for powered two-wheeler crashes where the driver was severely injured (AIS3+), resulting in 332 cases, where the injuries, pre-crash scenarios and injury sources were studied in detail.

The most common pre-crash scenarios were found to be powered two-wheelers losing control, or that another vehicle did not notice the powered two-wheeler. The most common injury source for the powered two-wheeler driver was the surrounding, with cars second. The road surface was the dominating surrounding injury source. An interesting finding was that leg injuries were over-represented in car impacts, and thorax injuries similarly for the surrounding as injury source.

Countermeasures with highest potential to mitigate or prevent severe (AIS3+) injury, include leg and chest protection for the rider, vehicle-mounted warning or automatic emergency braking systems and vehicle-to-powered two-wheeler (V2X) communication.

Keywords AIS3+, injury, injury source, powered two-wheelers (PTW), pre-crash scenario

I. INTRODUCTION

Worldwide, half of the 1.25 million traffic fatalities yearly are vulnerable road-users. The largest group of these are motorized 2-3wheeler riders: every year 285,000 M2-3W riders are killed in traffic accidents, which makes up 23% of all traffic deaths [2]. In Europe motorized or powered two-wheelers (PTW) make up 18% of fatalities in road traffic, and although there has been a reduction in PTW fatalities in Europe, it has been a slower decline than for overall traffic fatalities and therefore its share is increasing [3].

In a report, presented in 2008, 921 PTW accidents in five countries in Europe were studied [4]. A large majority of the injured PTW riders were male, and the head was the most commonly injured body part. A frequent accident partner and injury source were passenger cars, but for fatal accidents a larger share were single accidents. In the PTW-to-car crashes, the most common part impacted was the side of the car, and a majority of the car accidents occurred at intersections. In the 1980s, an extensive study on US motorcycle accidents was performed [5]. This study also showed the frequent scenario of motorcycle-to-car crashes at intersections, where the car violated the motorcycle's right-of-way. Further, the study pointed out the problem of conspicuity, i.e. the problem that other road-users failed to detect the powered two-wheeler. In a German study of all injury levels, it was highlighted that PTW accidents often occur in junctions in conflict with a car where the PTW had priority , or as a single accident with the PTW losing control [6].

Various countermeasures could be considered to address this. Helmets are effective countermeasures to reduce head injury [5,7,8]. Anti-lock brakes (ABS) are already introduced widely on motorcycles and have proven to be effective in reducing accidents and injuries [9,10]. Also there are indications that PTWs with ABS, even when crashes occur, are more likely to keep the rider in an upright position before crash [11]. Other countermeasures introduced recently, although not yet proven efficient, include motorcycle airbags [12], inflatable jackets [13] and stability control [14]. Rizzi has studied the potential of different countermeasures and concluded that ABS on the PTW and safe intersections on rural roads to be most promising countermeasures [15,16]. Autonomous

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Emergency Braking (AEB), now common on passenger cars, has also been proposed and the indication is that it is promising also for PTWs [17-20]

The authors performed in 2015 a study on fatal PTW accidents using the German In-Depth Accident Study (GIDAS) database [21]. The aim of that study was to use the most extensive on-scene, in-depth fatal accident data available to understand injuries, pre-crash accident scenarios and in-crash injury sources, to finally conclude countermeasures with high potential to prevent or mitigate fatal PTW crashes. That study concluded that head followed by thorax were the main body regions for fatal injury. Further, PTW losing control and that the PTW was not noticed by another vehicle were the most common accident scenarios leading to a fatal PTW crash. The most common injury sources were passenger cars, especially the lower parts of the cars, followed by surrounding objects, mainly guard-rails and trees. The study concluded that countermeasures with high potential included innovative helmet or jacket designs, improved PTW visibility, guard-rail redesign, PTW ABS and stability control, vehicle-mounted warning and auto-brake systems, improved car frontal energy absorption and under-run protection for heavy vehicles.

It would be interesting to compare the previous fatal study [21] with less severe crashes to see how this influences the results. While the fatal crashes were often high speed, loss of control accidents with motorcycles (>125 cc) in rural settings, it would be interesting to see if this sample had a larger share of urban crashes with smaller PTWs. The aim of the current study was therefore to use identical sampling criteria and data sources as in the previous fatal study [21], but include all severely injured (AIS3+) to be able to compare directly to the fatal study, but also to draw conclusions about this severely injured group regarding injuries, scenarios and injury sources to conclude most effective countermeasures for severely injured PTW riders, including driver protection as well as PTW- and car-mounted countermeasures.

II. METHODS

Database and inclusion criteria

The GIDAS database was used to extract crash data for this study. GIDAS accident investigation teams operate in Dresden and Hannover and their surroundings. The sample area contains both rural and urban traffic and is chosen to represent, as closely as possible, a *mini Germany*. Work shifts are equally distributed between night and day, with investigators attending accident sites using *blue-light* vehicles, along with police and ambulance personnel, when personal injuries are suspected. To investigate both vehicular and human factors in maximum detail, the GIDAS teams consist of both technical and medical personnel. At least one confirmed personal injury is required for inclusion in the database.

The GIDAS database was queried for accidents with injured riders of PTWs. The parameter ZWART (type of two-wheeled vehicle) was used to define PTWs, where the following were included in the study: motorized bicycle, pedal moped, moped, moped with less than 50 cc, motorcycle with less than 125 cc, motorcycle, scooter up to 80 cc, scooter over 80 cc. Not included from the ZWART category were bicycle, motorcycle with sidecar, trike, quad, motorized scooter trikes, other and unknown. Cases with passengers were excluded, due to the complexity of understanding injury patterns. Only cases with complete reconstructions were included.

The following inclusion criteria were applied:

- cases collected 1999–2014;
- powered (motorized) two-wheeler;
- driver-only cases (cases with passenger excluded);
- all PTW driver ages;
- at least one AIS3+ injury.

This query resulted in 3361 injured PTW drivers, with at least one AIS1+ injury (AIS 2005). Of these, 332 PTW drivers sustained at least one AIS3+ injury.

Injury sources

In this study, sources of the AIS3+ injuries of the PTW driver were analyzed. Injury sources were grouped into *Surrounding, Car, Heavy vehicle, Other PTW, Own body motion, Fire, Own PTW* and *others/unknown*. Objects from the road, infrastructure and off-road objects were then defined as *Surrounding. Surrounding* was then further divided into the sub-groups *Guard-rail, Other fixed objects, Road surface, Off-road. Off-road* objects were defined as any object that was not part of the road or built-up infrastructure, so these then included trees, stones, water passages or ditches. Rails along the road designed to keep a vehicle from leaving the road were defined *Guard-rail*. *Other fixed objects* included street poles, lamp-posts, masts, curb stones, buildings or parked cars. When a passenger car or van was concluded as the injury source, this was defined as *Car*. When the injury source on the car was concluded to be located below the waist line of the car, this was defined as a low impact. High impacts were then to the glass parts, or the A-, B- and C-pillars. In the *Heavy vehicle* category, vehicles such as trucks, buses or tractors were included. When the injury source was found to be from the parts of the PTW, including PTW front/side fairing, handle bar, fuel tank, engine/gearbox tank or frame, then it was defined as *Own PTW*". Injury source of *Own body motion* was found when e.g. biting a tongue. When it was concluded that the PTW driver sustained the injury from being driven over of the car of heavy vehicle, this was defined as *Run over*.

III. RESULTS

As mentioned in the Methods section, cases with passengers were not included in the study. The average driver was a male (97%) and 36 years old. Ninety % of the drivers wore a helmet. 212 (64%) of the drivers rode a motorcycle (>125 cc), 14% a moped (>50 cc), 9% a light motorcycle (<=125 cc), 7% a scooter (<=80 cc), 4% a scooter (>80 cc), 2% a moped (<=50 cc) and 1 % a pedal moped. The mean travelling speed was 66 km/h before the event started, and reached an average speed of 53 km/h at the time of impact. Crashes occurred at impact speeds from 4 km/h up to 185 km/h, and 58% of the accidents happened in an urban setting (TABLE I). Lower extremity injuries were the most common cause of AIS3+ injuries (sustained by 59% of the drivers), followed by chest AIS3+ injury (42%), combining thorax, cervical spine and abdomen, and 25% sustained head and face injury (Fig 1). (In this figure thorax, abdomen and cervical spine was both presented separately and combined into a group called "chest". In the combined "chest" group a driver was only counted once if he e.g. sustained AIS3+ injuries to both thorax and abdomen. Therefore the combined group has a smaller percentage than simply adding up the three sub-groups.)

TABLE I
CRASH DETAILS (N=332)

	Mean	*Min.*	*Max.*
Age (years)	36	13	94
Travelling speed (km/h)	66	4	185
Impact speed (km/h)	53	4	185
Registration year	1995	1967	2011
Male	97%		
Helmet	90%		
Urban/rural	58%/42%		

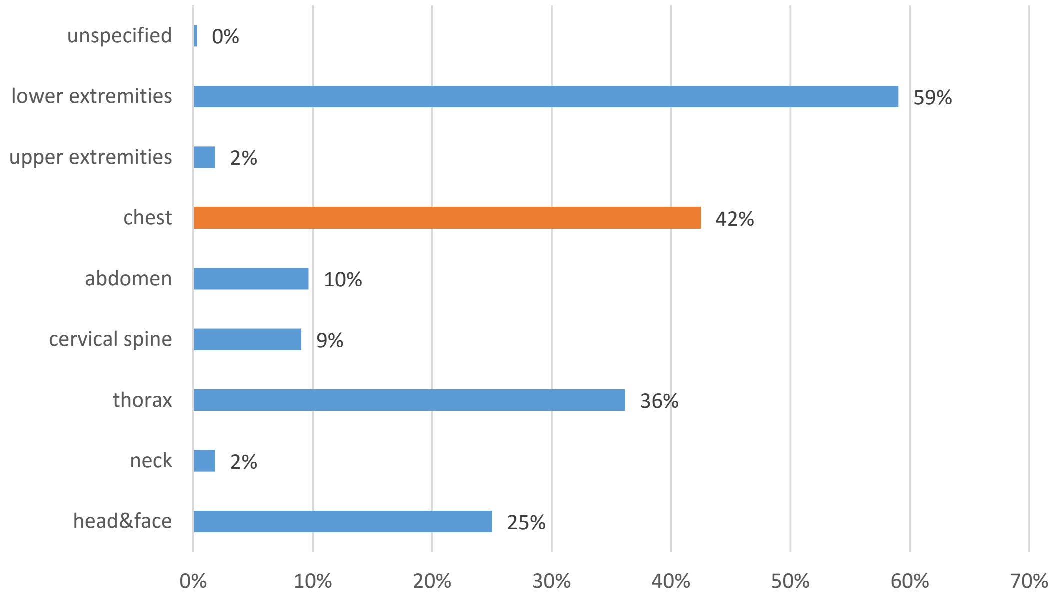

Fig 1. Frequency of drivers sustaining AIS3+ injury to respective body regions (N=332), (chest is a combined region of injury to abdomen, thorax or cervical spine)

Scenario analysis – pre-crash event

Next, the pre-crash motion of the involved vehicles were studied to conclude the detailed scenario leading to the crash. The most common event was found to be loss of control of the PTW, leading to a crash, while the second most common was that another vehicle drives out (crosses) in front of the PTW. In addition, an oncoming vehicle turning or overtaking in front of the PTW was also common (see Fig 2).

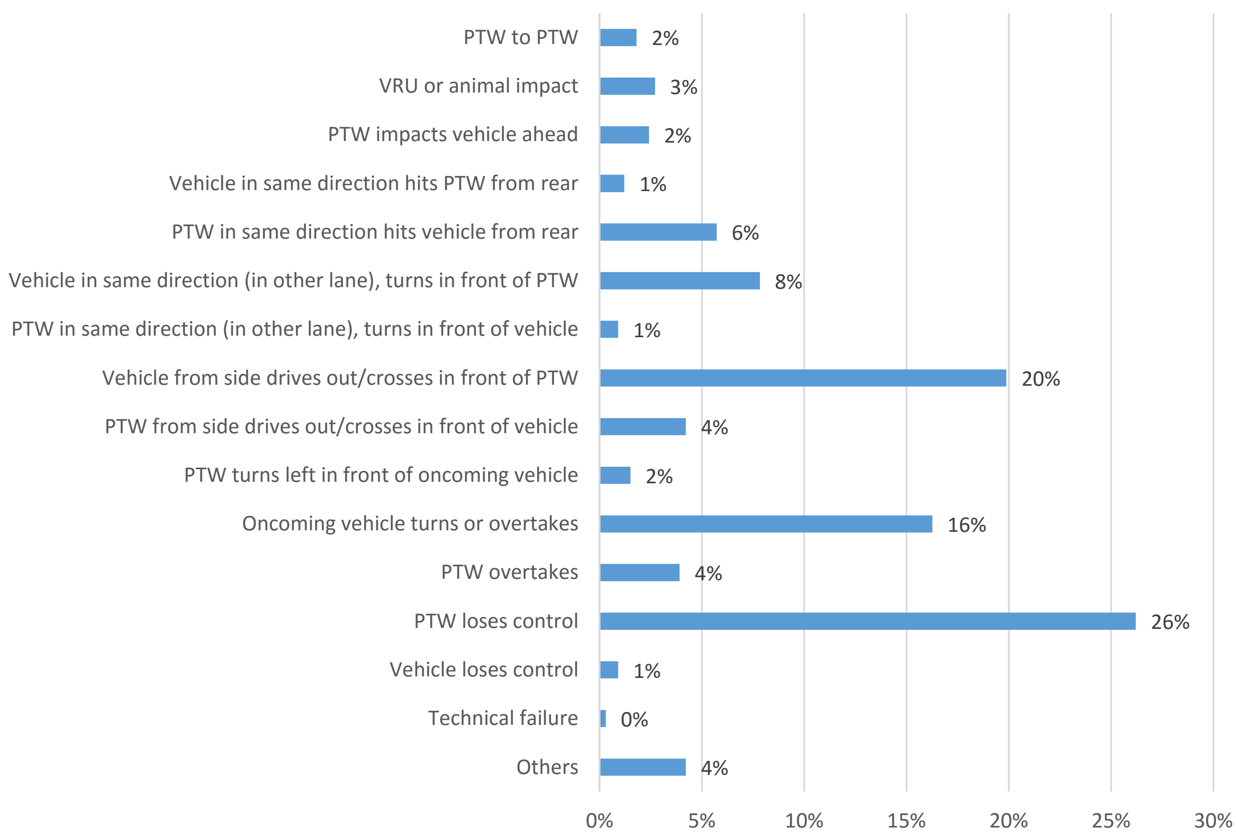

Fig 2. Accident scenario distribution (N=332)

The most frequent scenarios were studied in further detail in order to gain more understanding about the details of the events and the sources of injury. When the *PTW loses control* occurred (n=87), the driver most commonly impacted an object (n=38) (see Fig 3). The object was, in most cases, a tree or a curb. In some of the cases the PTW driver fell to the ground, and then impacted with object (n=18).

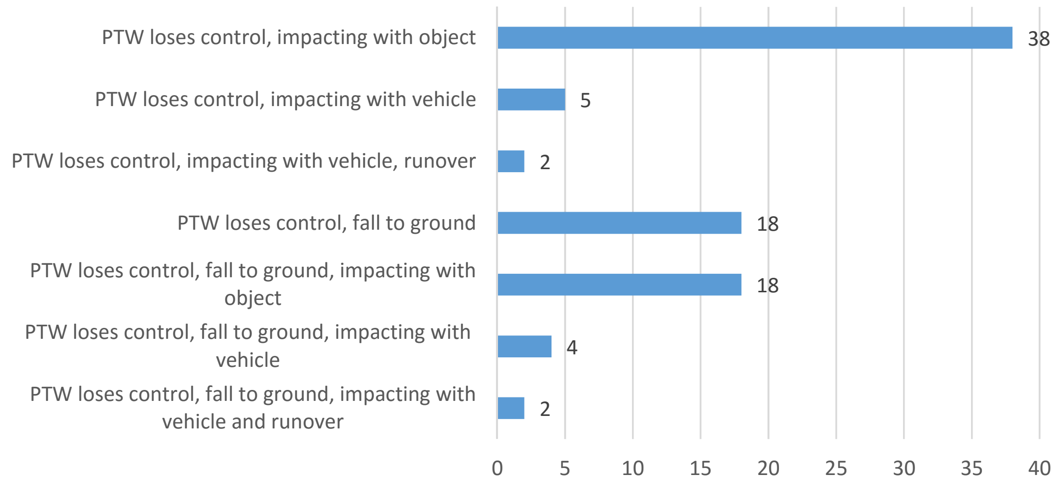

Fig 3. Detailed scenario distribution of scenario *PTW loses control* (n=87)

The second most common event was that another vehicle from the side drives out (crosses) in front of a straight-driving PTW (n=66). For this event type it was not possible to divide into more detailed scenarios. The third most common event (n=54) leading to a AIS3+ injury crash was an oncoming vehicle turning or overtaking in front of the straight-driving PTW. In the large majority of these events, the PTW driver impacted the front or side of the oncoming vehicle (n=51). In two cases the oncoming vehicle overtook the PTW and in one case the PTW was ran over by the oncoming vehicle (see Fig 4).

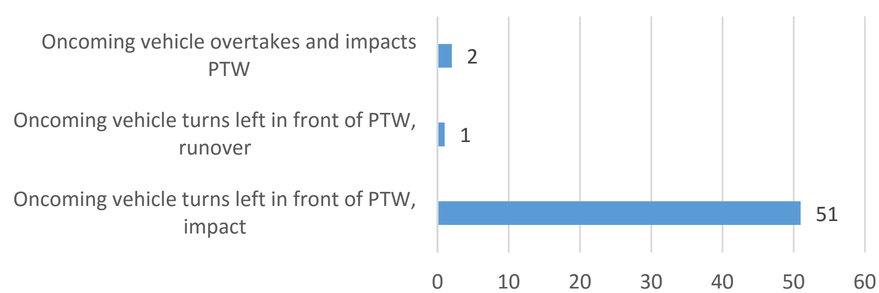

Fig 4. Detailed scenario distribution of scenario *Oncoming vehicle turns or overtakes* (n=54)

Injury sources: in-crash analysis

In the next step the most likely sources of AIS3+ injury were concluded (see Fig 5). Surrounding was estimated as AIS3+ injury source in 58% of the cases. For 46% of the 332 PTW drivers a car was estimated to cause the AIS3+ injury. For 17% of the drivers a heavy vehicle impact was estimated as AIS3+ injury source. Since one person can have more than one body region AIS3+ injured, more than one AIS3+ injury source could be found for the same person. Therefore as seen in Fig 5 the sum of injury source distribution is >100%.

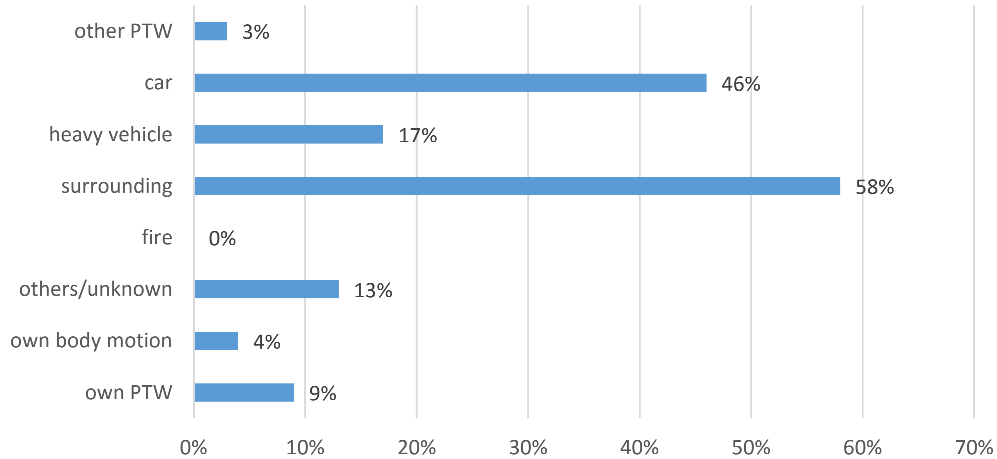

Fig 5. Injury sources grouped, all cases (N=332)

As shown above, in the overview of injury sources (Fig 5), in 58% (n=192) of the 332 PTW drivers the surrounding was considered a cause of AIS3+ injury. The cases with surrounding injury sources were studied in further detail. The most common injury cause in the surrounding was road surface (see Fig 6). For the other fixed objects poles were predominant (n=34), but curbs (n=8) and wall (n=7) were also injury sources in a few cases. Of the off road objects, trees were most common (n=38), ditch (n=5) and water passage (n=1) were also found. See examples from cases in Fig 7.

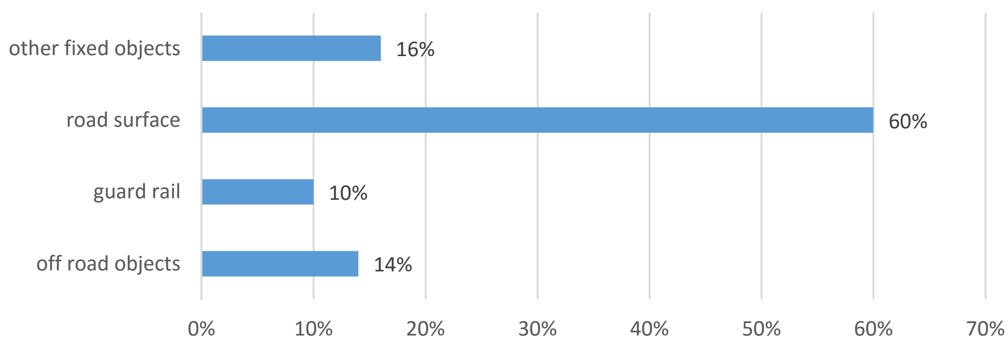

Fig 6. Detailed distribution of *Surrounding* injury sources (*left*) (n=192)

Fig 7. Case examples of *Surrounding* injury sources: *other-fixed (post & curbs)*, *off-road (tree)*, *guard-rail* (from left to right)

Passenger cars was the second most common AIS3+ injury source for the PTW drivers in the study (Fig 5), with 46% of the PTW drivers sustaining AIS3+ injury caused by impact to a passenger car. Car injury sources were dominated by car front impacts (57%) and car side impacts (32%) (Fig 8). A large majority of the car injury sources were located low on the car, such as the bumper area in the front, or the lower parts of the door or fenders on the side – see examples in Fig 9. The car running over the PTW driver was estimated to cause the AIS3+ injury in 6% of the car impacts, and in 1% it was not possible to determine whether it was a low car impact or a runover that caused the AIS3+ injury.

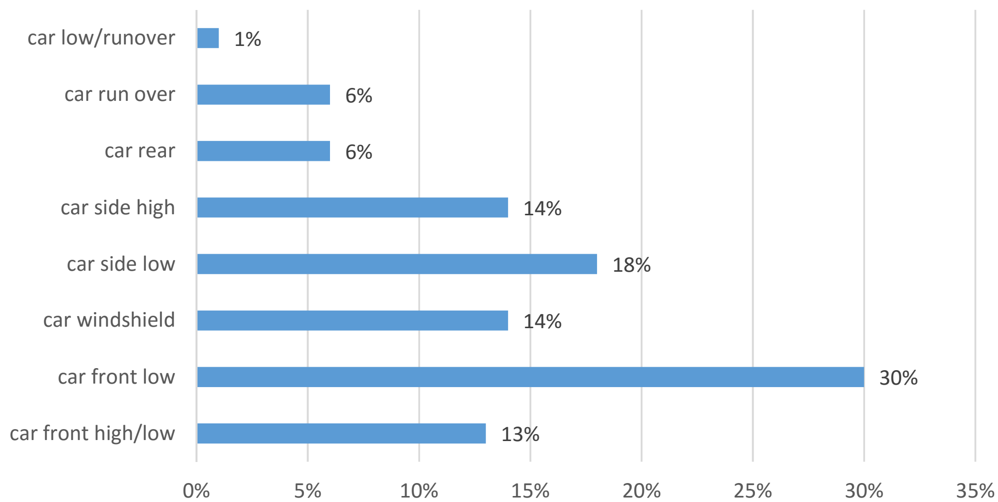

Fig 8. Detailed distribution of *Car* injury sources (n=154)

Fig 9. Case examples of car injury sources: *Car side low, Car front low, Car windshield* (from left to right)

Heavy vehicles were estimated to cause AIS3+ injury for 17% of the injured PTW drivers in the study, as shown earlier in the overview of injury sources (Fig 5). A larger share, compared to car impacts, was estimated to be caused by runover for heavy vehicles (Fig 10).

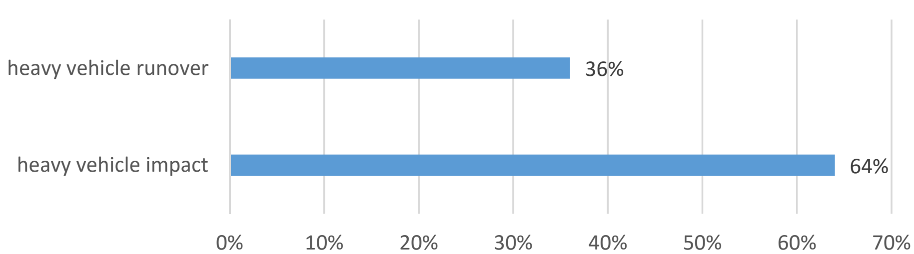

Fig 10. Detailed distribution of *Heavy vehicle* injury sources (n=58)

Injuries and their sources

The distribution of AIS3+ injured body regions was compared between different counterparts causing the AIS3+ injury of the PTW driver. For surrounding as injury source, the thorax was most frequently injured, while cars substantially more frequently injured the lower extremities of the PTW drivers, compared to the surrounding as injury source (see Fig 11).

For vehicle injury sources, when dividing vehicle impact and runover it is difficult to draw a conclusion if there is a different injury distribution (Fig 12), due to the low number of cases in one of the sub-groups (runover only consisted of 12 cases).

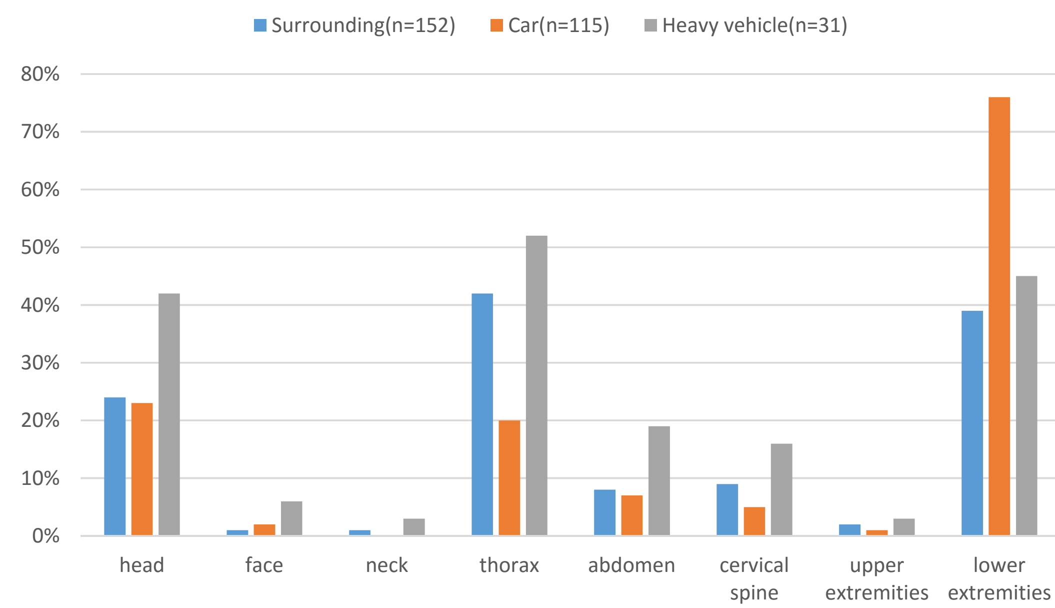

Fig 11. Frequency of drivers sustaining AIS3+ injury to respective body regions for different injury sources

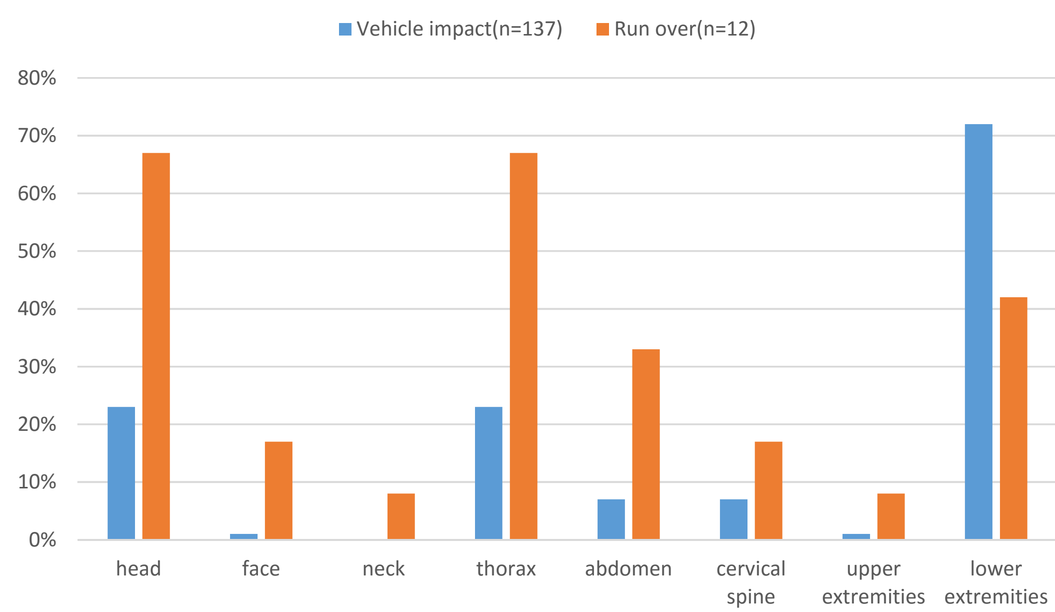

Fig 12. Frequency of drivers sustaining AIS3+ injury to respective body regions for different types of vehicle injury sources

Potential countermeasures

To conclude potentially effective countermeasures, designed from infrastructure, car and PTW perspectives, an analysis combining accident scenarios and injury sources was performed (Fig 13). For the infrastructure, better designed guard-rails would potentially address 4% of the AIS3+ injured accidents (all cases when guard-rail was injury source). The PTW was losing control and falling in 13% of the accidents, indicating that ABS or stability control could be a potential countermeasure in these cases (all scenarios called *PTW loses control* and PTW falls to ground.). In 45% of the AIS 3+ injured PTW cases the scenarios indicated that the PTW was not noticed by the car or heavy vehicle driver before impact, and therefore better PTW conspicuity or vehicle-based warning or AEB systems able to detect PTWs could be effective in these cases (all scenarios where the opponent vehicle was turning in front of the PTW or driving out in front of a straight-driving PTW or impacting straight-driving PTW from rear in Fig 2). For all the above mentioned scenarios that were considered relevant for vehicle-based warning, but excluding *Vehicle hitting PTW from rear*, vehicle-to-PTW communication systems (V2X) was considered as a potential countermeasure. V2X then had a potential in 44% of the cases. If a PTW-based warning or AEB system could be developed, this could potentially have an effect in 19% of the cases where it seemed that the PTW driver did not notice the other road user which it later impacted (all scenarios where PTW impacts to another PTW, or VRUs, animals or another vehicle ahead or from behind, and PTW turns or overtakes in front of another vehicle, plus PTW driving out in front of a straight-driving vehicle in Fig 2). If the cars could be designed with better energy absorption all around the car body, this could address up to 33% of the AIS3+ injured cases in this study (all accidents where a car was the injury source and runover was not involved: see Fig 8). Finally, if cars or heavy vehicles could be designed with protection to prevent running over the PTW driver, this would address 4% of the severe accidents.

Since some of these severe cases are potentially addressed by more than one countermeasure, it is not possible to simply add them up. Therefore, this was checked case-by-case. When combining all countermeasures it was found that in 100% of the cases the accident was addressed by at least one countermeasure. That means that a combination of all countermeasures would address all severely injured PTW drivers.

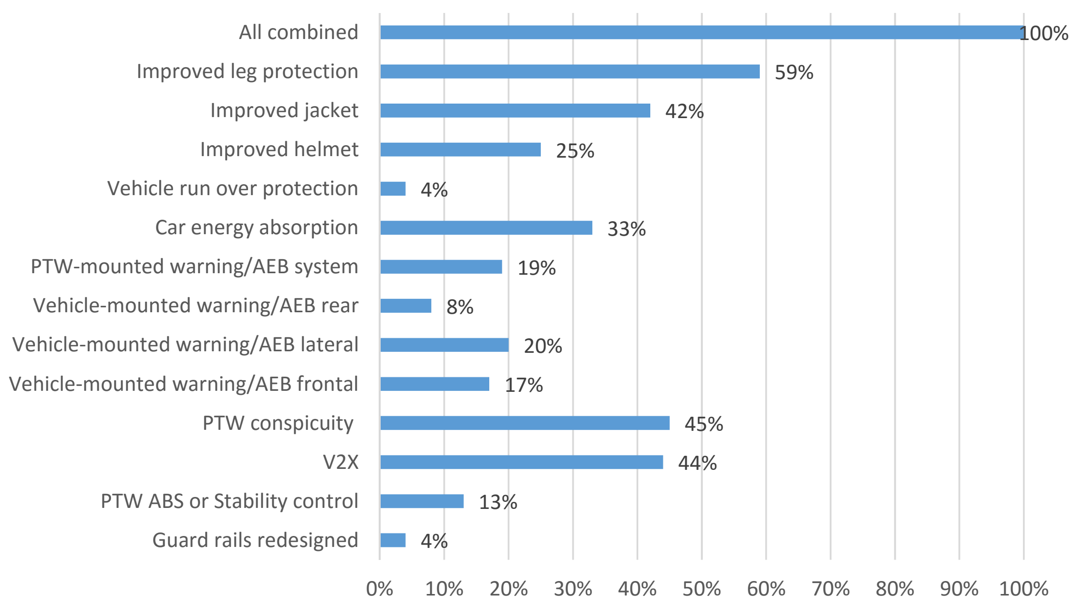

Fig 13. Share of fatal accidents potentially addressed by various countermeasures (N=332).

IV. DISCUSSION

In this study we analyzed crashes in Germany where PTW drivers sustained severe (AIS3+) injury. In the analysis we included both the pre-crash and in-crash event to try to conclude the most common scenarios and injury sources, and then finally possible protection countermeasures.

Lower extremities and the chest were the most common body regions to sustain severe injury, according to this study of AIS3+ injured PTW drivers, while head injury placed third. Compared to an earlier study on fatal crashes but otherwise with identical setup, data source and selection criteria, the fatal study was dominated by head injuries [21]. The difference is probably due to the high use of helmets in this population, combined with the lower energy in these crashes. Both travelling and impact speed was considerably lower in these serious crashes. This was also reflected by the higher share of urban crashes in the group sustaining serious injury compared to the group with fatal outcome. A majority of the serious crashes occurred in urban areas, while the fatal crashes most commonly occurred in rural settings. Mean age of the drivers were very similar between the two groups. Improved leg protection as well as an improved jacket seems to have high potential for seriously injured PTW drivers, since these body regions were the most commonly injured. There have been studies showing that boxer engines reduce leg injury [22], so there is a possibility to look into improved designs, or even in-crash activated protection for the lower extremity. For the chest there are also rider jacket design ideas with inflatable structures that may be worth looking into.

The most common scenario was the PTW losing control, but in contrast to the earlier fatality study, in a large number of these cases the PTW driver did not fall to the ground. The two other common scenarios was a vehicle driving out (crossing) in front of the PTW and violating the PTW’s right-of-way, and an oncoming vehicle turning or overtaking in front of the PTW. In both these later scenarios the PTW was driving straight and was apparently not noticed by the vehicle. Combined these three scenarios were the dominating scenarios covering more than 60% of all crashes. Compared to fatal crashes, the PTW losing control and falling is less common, while a vehicle driving out (crossing) in front of a PTW is more common in the serious crashes. ABS and stability control as well as vehicle-mounted warning or AEB systems could be potential countermeasures to address the most common scenarios for seriously injured PTW drivers. ABS is now common on new motorcycles and has proven to be effective [9,10] and stability control has also been introduced [14]. Vehicle-to-PTW communication systems (V2X) could also be worth looking into, and it may be sufficient that the PTW is sending, not receiving, since in a majority of cases the other vehicle did not notice the PTW and violating its right-of-way.

The most common injury source was the surrounding, closely followed by cars. In the earlier fatality study the order was vice versa, with cars causing most injury. The road surface was the dominating part of the surrounding causing serious injury, which was very different to the fatality study where guard-rails and off-road objects were the dominating injury sources in the surrounding. So, for the seriously injured PTW drivers from the surrounding, it seems to be most efficient to focus on ABS/stability control of the PTW as well as enhanced self-protection of the PTW driver. For the car injury sources, the lower car front was dominating, similar to the earlier fatal study. It is possible that the improved car front energy absorption of later car model years, due to recent enhanced pedestrian protection requirements may have an effect in the near future. In a crash database there is always a lag since the majority of cars are not new, it will take some time to see such an effect. In the same way also the rapid increase of ABS equipped PTWs could change the impact pattern with higher and more upright impacts, due to the change in kinematics with less cases of sliding before the crash [11]. The case PTWs in this study were checked manually and it was found that very few of them were equipped with ABS. Heavy vehicles are not as common as injury sources, but for the cases we have runover is common. It is therefore important to develop better runover prevention measures. When we looked into more detail of injury mechanisms, i.e. injury sources of different body regions, the results indicated that leg injuries were predominantly caused by car impacts, while thorax injuries are more common when the surrounding was the injury source.

This study was performed with the aim to conclude possible countermeasures to address drivers of PTWs. Both pre-crash and in-crash (active and passive) countermeasures were considered. In the pre-crash phase, it was found that vehicle mounted warning systems or AEB systems would have high potential since in most cases, when a PTW and vehicle collides it is the vehicle which made a maneuver or crossing which indicates it did not notice the approaching PTW. Vehicle-to-PTW (V2X) communication could potentially also address this, and in this case it would be effective that the PTW only sends out a signal (receiving not as important). Another solution to address this is of course to equip the PTW driver with more visible clothing, but this has been addressed for a long time and it seems difficult to make improvements there. ABS is likely an effective countermeasure, since many accidents were caused by the PTW losing control and falling. ABS is already common on later model years, so hopefully we will see the result from this soon in reduced frequency of this accident type. New systems have also been shown for stability control, and if they are introduced successfully they may also be important to reduce this common accident type. For passive (in-crash) protection this study indicates that leg protection for car impacts, and thorax protection for road surface impact would have high potential. Possibly a deployable leg protection device and inflatable jackets could address this. With more ABS-equipped PTWs we will have a larger share of upright impacts, which implies that PTW airbags could have a higher protection potential. Although more or less all drivers in this study were equipped with helmets, head injury was still frequent, indicating that development should continue on helmet design. Finally, the study showed that if we combined a number of these countermeasures we could address a substantial part of these severe accidents involving PTW riders.

V. CONCLUSIONS

This is a follow-up study to an earlier fatality PTW accident study using otherwise same data source and inclusion criteria [21]. We found both similarities and differences to the fatal study. The severe crashes (in this study) occurred naturally at lower speeds, but also more frequently in urban settings. The majority of severe crashes were in urban areas, and the contrary for fatal crashes. The typical PTW driver was, just like in the fatal crashes, young, male and wearing a helmet. While head injuries dominated in fatal crashes, leg and chest injuries dominated in the severe crashes.

The pre-crash scenarios that most commonly led to these accidents was the PTW losing control, or that another vehicle did not notice the PTW so therefore crossing in front of a straight-driving PTW or overtaking or turning in front of an oncoming PTW leading to a crash. The vehicle crossing scenario was the most obvious difference with higher frequency than fatal crashes, most likely due to the more urban setting in severe crashes.

The most common injury source for the PTW driver was the surrounding, with cars second. This was contrary to the fatal crashes which had reverse order of these injury sources. The road surface was the dominating surrounding injury source in the severe crashes, while on- and off-road objects dominated in the fatal crashes. For the car injury sources the car lower front dominated for both groups. An interesting finding was that leg injuries were over-represented in car impacts, and thorax injuries similarly for the surrounding as injury source.

To conclude, this study and the earlier fatal study, showed that both preventive (active) and protective (passive) devices could have high potential to protect PTW drivers. The protective measures have highest potential on the PTW (not other vehicles) for leg and chest protection. Possible devices are deployable structures for leg protection on the PTW and inflatable jackets for the chest. Despite the high helmet use, the severely injured still sustained a fair amount of head injuries, and for fatally injured it was the main cause. This shows that innovative improvement in helmet design would have high potential. The rapid increase of ABS equipped PTWs is likely to have a large effect on keeping the driver more upright changing the impact kinematics with other vehicles with possibly higher and more controlled impacts, as well as less loss-of-control accidents. This leads to larger protection potential of equipping PTWs with airbags. Preventive (active) measures would have most effect if placed on the cars and trucks, since accident causes are dominated by these other vehicles not noticing the PTW, not vice versa. The most common scenarios are junction or overtaking scenarios, so they need to have omni-directional capability. V2X communication systems could also have high potential, and here only a sending signal (not receiving) from the PTW would have high effect.

VI. ACKNOWLEDGEMENT

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VII. REFERENCES

[1] Rizzi, M., Strandroth, J., Holst, J., and Tingvall, C. Does the improved stability offered by Motorcycle Antilock Brakes (ABS) make sliding crashes less common? In-depth analysis of fatal crashes involving motorcycles fitted with ABS.

[2] World Health Organization. Global status report on road safety 2015. 2015, World Health Organization: Geneva, Switzerland.

[3] European Road Safety Orbservatory (ERSO). "CARE database - Traffic safety basic facts 2015 - Motorcycles & Mopeds" Internet http://ec.europa.eu/transport/road_safety/pdf/statistics/dacota/bfs2015_motomoped.pdf. 2016-03-31].

[4] MAIDS. In-depth investigations of accidents involving powered two wheelers. 2008, ACEM: Brussels, Belgium.

[5] Hurt Jr., H.H., Ouellet, J.V., and Thom, D.R. Motorcycle accident cause factors and identification of countermeasures,

Volume 1: Technical report, N.H.T.S.A. US Department of Transportation, Editor. 1981, Traffic Safety Center, University of Southern California: Los Angeles, USA.

[6] Liers, H. Analysis of the accident scenario of powered two-wheelers on the basis of real-world accidents. *Proceedings of Expert Symposium on Accident Research*, 2013. Hannover, Germany

[7] Mallory, A., Duffy, S., and Rhule, H. Head Injuries to Helmeted and Unhelmeted Motorcyclists in US Trauma Data. *Proceedings of IRCOBI (International Research Council On the Biomechanics of Impact) Conference - short communication*, 2013. Göteborg, Sweden

[8] USDoT. Traffic Safety Facts, 2008. Data – Motorcycles. 2008, Department of Transportation: Washington DC, USA.

[9] Teoh, E.R. Effectiveness of Antilock Braking Systems in Reducing Fatal Motorcycle Crashes. 2010, Insurance Institute for Highway Safety: USA.

[10] Rizzi, M., Strandroth, J., and Tingvall, C. The effectiveness of Antilock Brake Systems (ABS) on Motorcycles in Reducing real-life Crashes and Injuries. *Traffic Inj Prev*, 2009. 10: p. 479-487

[11] Rizzi, M., Strandroth, J., Holst, J., and Tingvall, C. Does the improved stability offered by Motorcycle Antilock Brakes (ABS) make sliding crashes less common? In-depth analysis of fatal crashes involving motorcycles fitted with ABS. *Traffic Inj Prev*, 2016: p. 0

[12] Kuroe, T., Namiki, H., and Iijima, S. Exploratory study of an airbag concept for a large touring motorcycle: further research second report. *Proceedings of 19th International Technical Conference on the Enhanced Safety of Vehicles (ESV)*, 2005. Washington DC, USA

[13] BikeBone. "Hit-Air Motorcycle Airbag Vests and Jackets" Internet http://www.bikebone.com/page/BBSC/CTGY/AT. 2015-03-28].

[14] Sgambati, F. and Lich, T. The safety benefits of motorcycle stability control. *Proceedings of SAE Government & Industry meeting*, 2015. Washington DC, USA

[15] Rizzi, M., Strandroth, J., Johansson, R., and Lie, A. The potential of different countermeasures in reducing motorcycle fatal crashes: what in-depth studies tell us in *22nd International Technical Conference on the Enhanced Safety of Vehicles (ESV)*. 2011: Washington DC, USA.

[16] Rizzi, M., Kullgren, A., and Tingvall, C. The combined benefits of motorcycle antilock braking systems (ABS) in preventing crashes and reducing crash severity. *Traffic Injury Prevention*, 2016. 17(3): p. 297-303

[17] Savino, G., Giovannini, F., Baldanzini, N., Pierini, M., and Rizzi, M. Assessing the potential benefits of the motorcycle autonomous emergency braking using detailed crash reconstructions. *Traffic Inj Prev*, 2013. 14 Suppl: p. S40-9

[18] Savino, G., Pierini, M., Rizzi, M., and Frampton, R. Evaluation of an autonomous braking system in real-world PTW crashes. *Traffic Inj Prev*, 2013. 14(5): p. 532-43

[19] Savino, G., Pierini, M., Thompson, J., Fitzharris, M., and Lenne, M.G. Exploratory Field Trial Of Motorcycle Autonomous Emergency Braking (MAEB): Considerations On The Acceptability Of Unexpected Automatic Decelerations. *Traffic Inj Prev*, 2016: p. 0

[20] Savino, G., Rizzi, M., et al. Further development of Motorcycle Autonomous Emergency Braking (MAEB), what can in-depth studies tell us? A multinational study. *Traffic Inj Prev*, 2014. 15 Suppl 1: p. S165-72

[21] Fredriksson, R. and Sui, B. Fatal Powered Two-Wheeler (PTW) crashes in Germany – an in-depth study of the events, injuries and injury sources, in *IRCOBI (International Research Council On the Biomechanics of Impact) Conference*. 2015: Lyon, France. p. 22-33.

[22] Rizzi, M. Can a Boxer Engine Reduce Leg Injuries Among Motorcyclists? Analysis of Injury Distributions in Crashes Involving Different Motorcycles Fitted with Antilock Brakes (ABS). *Traffic Inj Prev*, 2015. 16(7): p. 739-46