Injury Patterns of Older Car Occupants, Older Pedestrians or Cyclists in Road Traffic Crashes with Passenger Cars in Europe – Results from SENIORS

M. Wisch, M. Lerner, E. Vukovic, D. Hynd, A. Fiorentino, A. Fornells

Abstract Europe has benefited from a decreasing number of road traffic fatalities. However, the proportion of older road users increases steadily. In an ageing society, the SENIORS project aims to improve the safe mobility of older road users by determining appropriate requirements towards passive vehicle safety systems.

Therefore, the characteristics of road traffic crashes involving the elderly people need to be understood. This paper focuses on car occupants and pedestrians or cyclists in crashes with modern passenger cars. Ten crash databases and four hospital statistics from Europe have been analysed to answer the questions on which body regions are most frequently and severely injured in the elderly, and specific injuries sustained by always comparing older (65 years and above) with mid-aged road users (25-64 years).

It was found that the body region thorax is of particularly high importance for the older car occupant with injury severities of AIS2 or AIS3+, whereas the lower extremities, head and the thorax need to be considered for older pedestrians and cyclists. Further, injury risk functions were provided. The hospital data analysis showed less difference between the age groups. The linkage between crash and hospital data could only be made on a general level as their inclusion criteria were quite different.

Keywords crash data, hospital data, older car occupants, older cyclists, older pedestrians.

I. INTRODUCTION

The Safety ENhanced Innovations for Older Road userS (SENIORS) project (funded by the European Commission) aims to improve the safe mobility of the elderly covering the main modes of transport as well as specific requirements of this vulnerable road user group. This paper provides selected results from the crash and hospital data analyses. More details can be found in [1].

The Data Collection, Transfer and Analysis (DaCoTA) project found that the risk of being killed in a crash was higher for the elderly than for the mid-aged in most of the EU24 countries based on crash data from 2010 [2]. Almost two-thirds of the elderly fatalities were men, but women made up a higher proportion of fatalities among the elderly (36%) than within the whole population (24%). Thirty-eight percent of elderly fatalities were pedestrians. Among the larger countries, the percentage of elderly pedestrian fatalities was greatest in Romania (62%) and least in the Netherlands (14%). Conversely, the proportion of elderly fatalities who were car drivers ranged between 6% in Romania and 50% in Ireland. Compared to mid-aged fatalities, there were less elderly fatalities on motorways and on rural roads, but more on urban roads. The national distributions varied greatly between the member states.

The Coordination of Vehicle and Road Safety Initiatives (COVER) project [3] found that older occupants more often received thoracic injuries than younger ones. About 50% of the 17-25 year olds had no torso injury compared with 33% of the 46-65 year olds. From 66 years and above, the percentage of occupants with no injury to the wider thorax remained at about 31%, but the proportion of MAIS2 and MAIS3+ torso injuries increased. Also, young occupants tended to receive skeletal injuries less frequently than older occupants. Older persons showed more skeletal injuries associated with internal injuries rather than younger persons who often have internal injuries without rib fractures. Further, younger occupants tended to receive either an abdomen injury alone or a lung injury alone. The crash data analyses also showed that younger occupants did not receive any rib injury in isolation and younger ones sustained AIS3+ lung injuries without a series of rib fractures.

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Collisions involving elderly drivers were found to more often occur in daylight, on weekdays and on roads that are not affected by snow or ice compared to other drivers [4]. The most common collision type among older drivers was found to be at intersections, a situation where fast processing of information and quick reactions is needed. The typical intersection collision is an older driver making a left turn, crossing an on-coming vehicle in the opposite direction [5]. In fatal crashes at intersections where the crash severity was within survivable limits, senior occupants were found to be overrepresented [6]. Many of the collisions occurred on dry roads in good visibility conditions. Older drivers were also less likely to be involved in rear impact incidents, but seemed to be involved in accidents in which traffic signs had to be read and followed.

Reference [7] analysed frontal impact crashes and found that for front seat passengers most serious injuries were to the chest and these were mainly sustained by older women in low severity crashes. Older occupants (over 52 years of age) were 3.7 times more likely to receive an AIS2+, and 2.8 times more likely to receive an AIS3+ torso injury than younger occupants (12-52 years). The three most common chest injuries of the elderly victims were rib fractures (24%), flail chest (10%), and sternum fractures (6%) [8]. Reference [9] found that seniors tend to die from chest injuries while young people tend to die from head injuries. According to another study [10], seniors admitted to a hospital after a crash may die from only a few rib fractures. The rib and sternum fractures in older occupants in frontal crashes were found often to be caused by safety belts [11]. Reference [12] compared injury rates for elderly (50 years and older) versus young (17-30 years) car drivers wearing a seatbelt (German In-Depth Accident Study (GIDAS), years 1999-2009). They concluded for example that the elderly were not injured more frequently in crashes; and did not suffer statistically from a higher injury severity. Also, they suffered less often from head injuries; but had more trauma injuries of the thorax and legs, especially in cases of above a delta-v of 50 km/h. Their legs showed a seven times higher risk of AIS 2+ injury; but their risk of cervical spine injuries was low; and they suffered more often from rib fractures. The age, vehicle mass, delta-v and deformations influenced significantly the injury severity; and the victim’s body height and Body-Mass-Index did not show any influence.

SENIORS complemented existing knowledge with hospital data analyses to obtain a more complete sample of injuries. This allowed checking that the smaller sample in collision databases is representative at the injury level. This paper focuses on selected key results. Further findings can be found in [1].

II. METHODS

Datasets

Crash databases from various European countries and hospital statistics in the last few years were analysed in three major steps to obtain an overview on the crash occurrence and identify injury patterns of older road users as car occupants and pedestrians or cyclists in crashes with modern passenger cars (manufactured after 2005). Table AI (see appendix) provides an overview of the analysed collated European, national and in-depth crash datasets as well as hospital statistics. Detailed descriptions of each database can be found in [1].

First, the international and national crash datasets were used to provide an overview on the injury distributions for different age groups and for car occupants, pedestrians and cyclists. Secondly, the aim of the in-depth crash data analysis was to identify crash scenarios, their characteristics including injury probability functions and most important injury levels per body region and road user type. Thirdly, hospital statistics have been analysed to complement the information gained by additional cases and listing most frequent single injuries. Injuries were described using the common injury severity classifications *slightly*, *seriously* and *fatally* injured (according to country-specific definitions). It has to be noted that the definition of "injury" varies considerably among the various EU countries affecting thus the reliability of cross country comparisons, see also Section Discussion. Further, injuries have been analysed using the detailed AIS coding. Hereby, *MAIS* describes the maximum AIS coded per person and *mAIS* the maximum AIS coded per body region.

As the focus of the study was on *older road users (65 years and older)*, a reference group was defined as *mid-aged adults (25-64 years)*. Younger road users were also included in the analysis; however, this group was not considered for direct comparisons due to their specific behavioural patterns in road traffic and biomechanical properties.

Data queries

Regarding *car occupants* the filter criteria for the first analysis step were:

1) All types of crash opponents, and
2) Cars manufactured in 2005 or later, and
3) Belted occupants only, and
4) Known injury severity, sex and age of occupants.

Regarding *pedestrians* and *cyclists* the filter criteria for the first analysis step were:

1) Crash opponent had to be one passenger car manufactured in 2006 or later (Year 2006 was chosen as it was required then for all new types of passenger cars to fulfil the pedestrian protection demands set by the type approval EC directive 2003/102.), and
2) Known injury severity, sex and age of casualties.

The second analysis step used in-depth crash data to describe differences in injury severity levels and specific injury patterns. The third step used hospital data and complemented the information gained by lists of most frequent injuries. It has to be noted that the above-mentioned filters could not be applied to all databases and hence, findings might deviate across the datasets due to that.

Injury probability functions

The Probit regression (or probit model) was applied to specify the probability of sustaining a certain injury severity (expressed as AIS level) using R [13] and the MASS package (function *polr*, *Hess matrix = TRUE*). This model uses the inverse standard normal distribution of the probability as a linear combination of the predictors. Model corresponding coefficients, intercepts and the Akaike Information Criterion are provided.

III. GENERAL RESULTS

The analysis of the collated European and high level national crash datasets confirmed largely findings from the literature. For example, the data consistently demonstrated a higher risk of serious and fatal injury for older car occupants and external road users. Cyclist injuries were heavily biased towards males, while injuries to older pedestrians were strongly biased towards females.

Only a few databases offer collated crash information on a European level. In SENIORS, the European centralised database on road accidents (CARE) and International Road Traffic and Accident Database (IRTAD) were analysed as these were assumed to be representative for Europe. Fig. 1 shows the injury distributions for different age groups and road user types in all kinds of road traffic crashes. Overall, it could be seen that the injury severity increased with age. Highest absolute numbers for seriously injured casualties and fatalities were found for car occupants. For cyclists, a higher share (nearly factor 2) of male casualties was found. In contrast, an increasing share of female casualties and their injury severity by age were found for pedestrians.

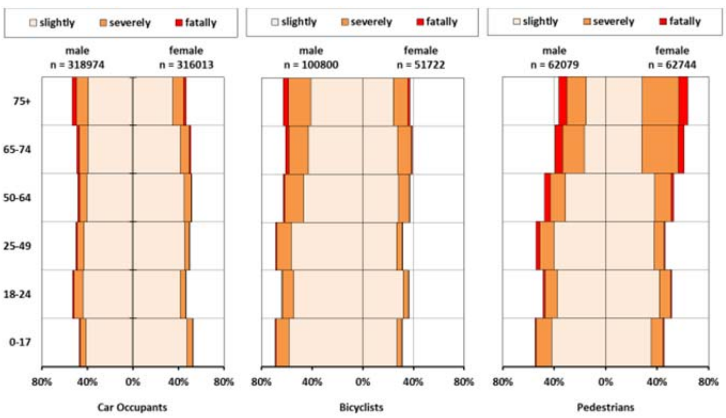


Fig. 1. Injury severity distributions in the EU28 countries by age group and road user type, Source: IRTAD and CARE, year 2014, including latest available data from Bulgaria (2009), Greece (2013), Ireland (2013), Malta 2010, Poland 2013, Slovakia (2010), Slovenia 2013) and Sweden (2014).

Road accidents on the public highway in Great Britain, reported to the police and which involve human injury or death, are recorded by police officers onto a STATS19 report form. Spanish national crash data from the Direción General de Transito (DGT) was also analysed. Fig. 2 and Fig. 3 show the distributions of the recorded injury severities for car occupants, pedestrians and cyclists, respectively.

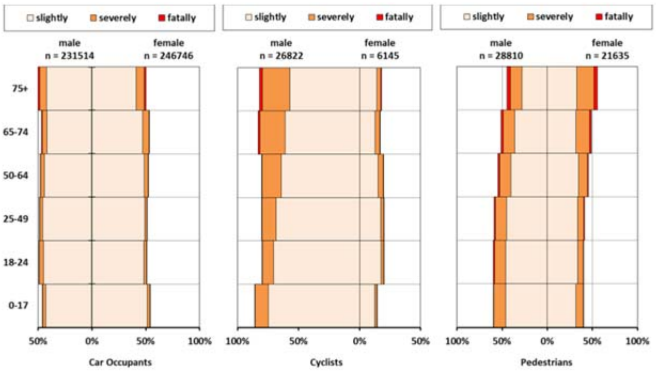


Fig. 2. Injury severity distributions in the UK by age group and road user type, STATS19, 2004-2014.

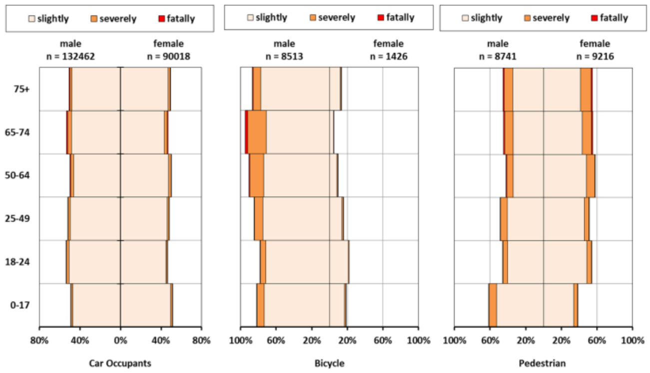


Fig. 3. Injury severity distributions in Spain by age group and road user type, DGT, 2011-2013.

Key conclusions for both national datasets were summarised in Table I.

TABLE I

KEY CONCLUSIONS FROM NATIONAL CRASH STATISTICS – UNITED KINGDOM AND SPAIN

Road user	STATS19 (UK)	DGT (Spain)
Car Occupants	Far more reported car occupant casualties than pedestrians or cyclists. Slightly more female car occupant casualties than male, but more serious male and almost double fatal male (0-64 years old). 65+ female more likely to be seriously injured than male.	Shares of serious and fatal injuries increased slightly with age (except for young men between 18 and 24 years). 65-74 years showed the highest ratio of severe and fatally injured casualties. Older females suffered slightly more frequently from a serious or fatal injury outcome than males of this age group.
Cyclists	Injury frequency very biased towards males, at all injury levels. Bias increased with injury severity.	Injury severity increased with age. Cyclists 75+ years showed less often severe injury outcomes.
Pedestrians	Pedestrian injury biased towards male at 0-64 years, equal at 65-74 and biased towards female at 75+. Similar pattern at all injury levels.	Injury severity increased slightly with age. Whereas male children suffered more frequently from a higher injury severity than females, women 50+ years showed serious or fatal injuries more often than men.

IV. DETAILED FINDINGS ON CAR OCCUPANTS

Car occupants accounted for the largest group in the selected datasets of each database. In general the injury level of car occupants is lower than the injury level of pedestrians or cyclists. The largest number of injuries for car occupants was at AIS1.

Body regions

The thorax was identified as the most critical body region for car occupants. The thorax showed the highest share of AIS3+ injuries of all body regions; see exemplarily results from the Swedish TRaffic Accident Data Acquisition (STRADA) and the Road Accident In-Depth Studies (RAIDS) from the United Kingdom in Fig. 4 and Fig. 5, respectively. Although on a low level, GIDAS showed the highest numbers for AIS2 and AIS3+ injuries of older car occupants in the thorax compared to other body regions. An especially high share of AIS1, AIS2 and AIS3+ thorax injuries was found in the dataset of the Initiative for the Global Harmonization of Accident Data (IGLAD) compared to other body regions. Overall, this was the case for the mid-aged (25-64) and for the elderly group (65+).

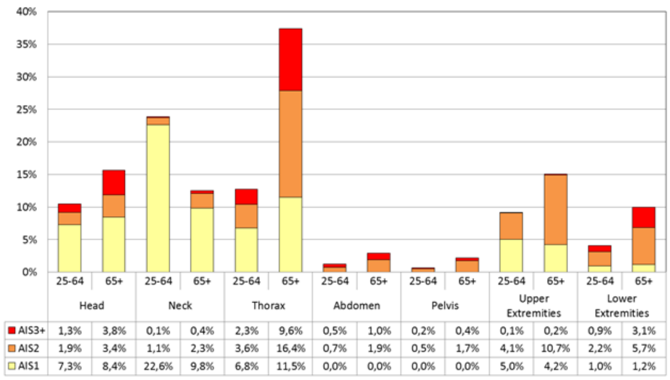


Fig. 4. Car occupants – Injury severity per body region and age group, STRADA, N = 49,125.

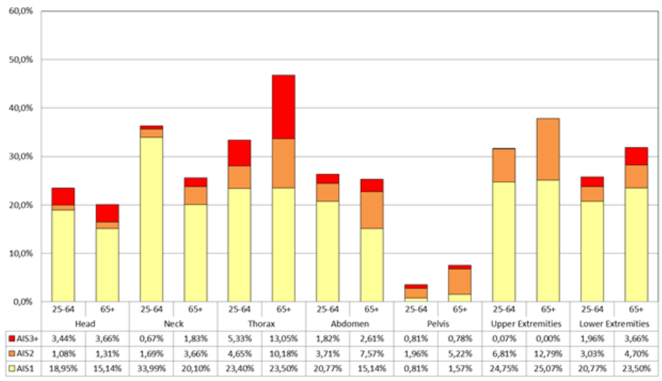


Fig. 5. Car occupants – Injury severity per body region and age group, RAIDS, N = 1,866.

(Note: each column sums up to 100%, not shown shares account for AIS 0)

Other body regions across all databases were not showing such high values as observed by the thorax injury data. Based on the available figures a ranking of most affected mAIS2+ and mAIS3+ injured body regions of car occupants could be made by comparing their relative risks seen in the available datasets leading to similar results for the different age groups, see Table II.

TABLE II

RANKING OF MOST AFFECTED INJURED BODY REGIONS OF CAR OCCUPANTS

	All (25+ years)	Mid-aged	Older	All (25+ years)	Mid-aged	Older
	mAIS2+			mAIS3+		
1	Thorax	Thorax	Thorax	Thorax	Thorax	Thorax
2	Upper Extr.	Upper Extr.	Upper Extr.	Head	Head	Head
3	Lower Extr.	Lower Extr.	Head	Lower Extr.	Lower Extr.	Lower Extr.

The parameter *principle direction of force (PDOF)* was used to compare injury outcomes for frontal, side and rear crashes using GIDAS as the database with most available casualty information. As the thorax was identified as being most important, its injury level was compared for the car's impact direction and age groups. Overall, it was found that car occupants (N = 701) in modern cars suffered most often from AIS1 and less often from AIS2+ injuries to the thorax. The frontal crash still dominated the crash occurrence followed by side crashes. Since the number of AIS2 and AIS3+ thorax injury cases went below 10 for side and rear crashes, no further analysis was meaningful for these load cases. In the respective analysis no AIS2+ injury to the thorax was found for casualties involved in rear crashes. For frontal crash involved casualties (N = 451), the dataset contained 384 car occupants (thereof 87 older ones) with mAIS1, 48 car occupants (thereof 13 older ones) with mAIS2 and 19 car occupants (thereof 6 older ones) with mAIS3+ thorax injuries. According to that, a small increase of the thorax injury severity could be seen by age for frontal crashes but no statement could be made for side and rear crashes.

Injury risk

The probability for car occupants for sustaining an injury of MAIS1 or MAIS2+ or being uninjured over the collision speed is shown in Fig. 6. The presented curves were based on GIDAS data as described before for frontal collisions. It can be seen that the likelihood of older car occupants seated in cars manufactured in 2005 or later and suffering from MAIS2+ injuries in frontal car collisions is much higher than for mid-aged ones.

Further, the probit model was applied to the thorax region, see Fig. 7. Similar to the overall injury severity (MAIS) the probability of a thorax mAIS2+ injury increases noticeably by higher delta-v values and for older than for mid-aged car occupants. For example, for a delta-v of 60 km/h the probability of a thorax AIS2+ injury was found as being around 35 percentage points higher for older compared to mid-aged car occupants.

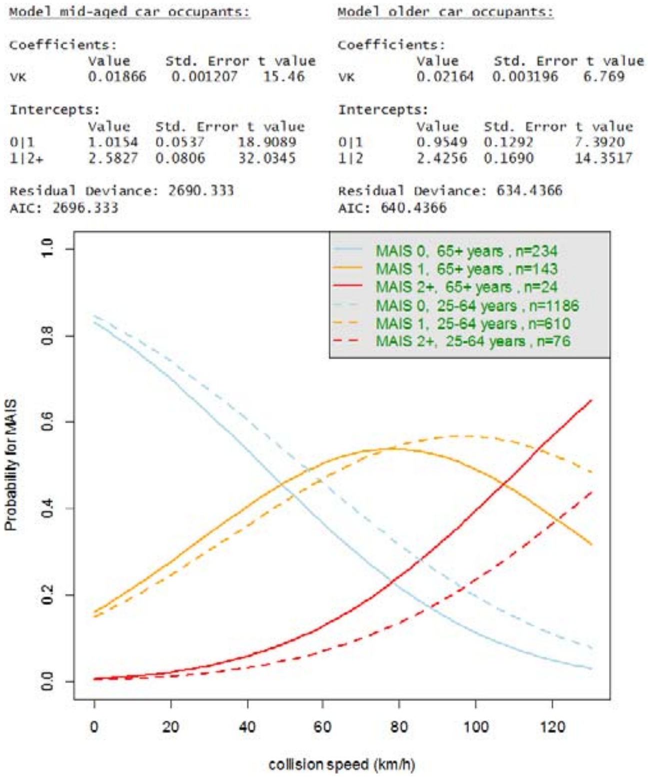


Fig. 6. Probability of MAIS over the collision speed of the car for mid-aged and older car occupants in frontal collisions, GIDAS, cars manufactured in 2005 or later.

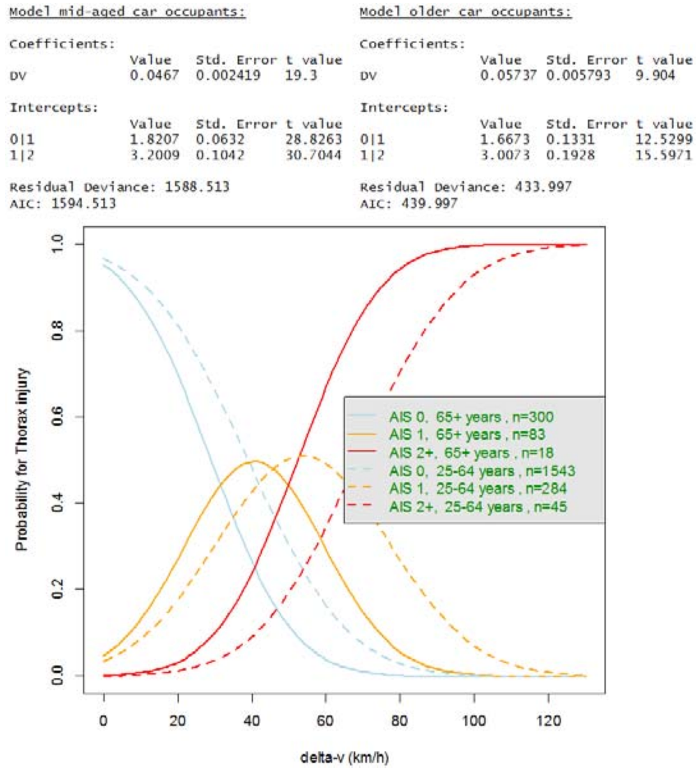


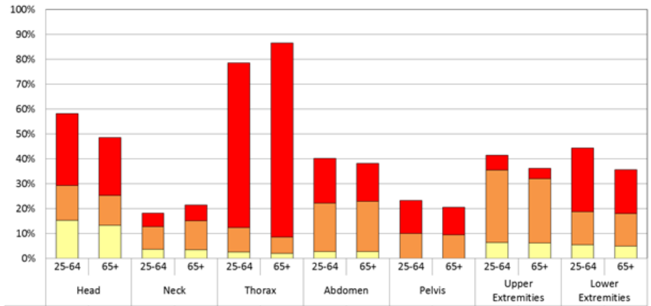
Fig. 7. Probability of thorax injury severity (mAIS) over delta-v for mid-aged and older car occupants in frontal collisions, GIDAS, cars manufactured in 2005 or later.

Hospital statistics

The TraumaRegister DGU® collects data on every patient, in need of intensive care, admitted to the emergency room of a participating hospital. Regarding *car occupants*, it needs to be noted that this group might also include truck drivers. Further, casualties who got killed at the crash scene were not part of this dataset. Due to the inclusion criteria the dataset had a strong bias towards serious injuries. Overall, 13,665 male and 7,425 female car occupants were analysed (males in particular in the age groups 18-24 and 25-49 years). Older males suffered more often from fatal injuries. The body regions most often seriously affected were: thorax, followed by the head, lower extremities, abdomen and the pelvis, see Fig. 8.

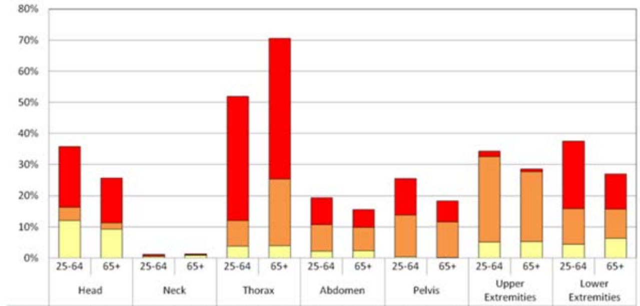
The Trauma Audit and Research Network (TARN) database includes patient information from participating Trauma centres (hospitals) in England and Wales. Fig. 9 shows a comparison between mid-aged and older car occupants regarding their injury severities for different body regions. The most affected body regions were the thorax, followed by the lower extremities and the head. The pelvis region and the upper extremities stand out for their high AIS2 injury share. According to this analysis, differences in the injury severity by body region between younger and older car occupants were rather marginal. Note: this was expected as the dataset contained mostly MAIS3+ casualties.

In contrast to many other hospital statistics TARN also allows for a distinction to the different seated positions within a passenger car, i.e., it was possible to distinguish between drivers, front seat passengers and rear seat passengers. Whereas the picture for car drivers is very similar to the one for all car occupants, as shown in Fig. 9, there were a few differences seen for front seat passengers and rear seat passengers. In particular the share of AIS2 thorax injuries was around 10 percentage points higher for occupants seated in the front than on the rear seats. However, head injuries were seen more often (~5 percentage points) for rear seated persons compared to the front.



	Head 25-64	Head 65+	Neck 25-64	Neck 65+	Thorax 25-64	Thorax 65+	Abdomen 25-64	Abdomen 65+	Pelvis 25-64	Pelvis 65+	Upper Extremities 25-64	Upper Extremities 65+	Lower Extremities 25-64	Lower Extremities 65+
AIS3+	28,8%	23,3%	5,3%	6,3%	66,2%	77,9%	18,1%	15,4%	13,2%	11,3%	6,1%	4,3%	25,7%	17,8%
AIS2	14,1%	11,9%	9,1%	11,7%	9,9%	6,7%	19,5%	20,1%	10,0%	9,4%	29,0%	25,8%	13,1%	13,1%
AIS1	15,2%	13,4%	3,7%	3,4%	2,5%	1,9%	2,7%	2,8%	0,0%	0,0%	6,4%	6,3%	5,5%	4,9%

Fig. 8. Car occupants – Injury severity per body region and age group, TraumaRegister DGU®, N = 21,090.



	Head 25-64	Head 65+	Neck 25-64	Neck 65+	Thorax 25-64	Thorax 65+	Abdomen 25-64	Abdomen 65+	Pelvis 25-64	Pelvis 65+	Upper Extremities 25-64	Upper Extremities 65+	Lower Extremities 25-64	Lower Extremities 65+
AIS3+	19,5%	14,3%	0,4%	0,2%	39,9%	45,3%	8,6%	5,8%	11,7%	6,8%	1,7%	0,9%	21,7%	11,4%
AIS2	4,2%	2,1%	0,3%	0,3%	8,3%	21,3%	8,5%	7,3%	13,4%	11,3%	27,5%	22,4%	11,5%	9,3%
AIS1	12,0%	9,2%	0,5%	0,8%	3,7%	4,0%	2,2%	2,4%	0,4%	0,2%	5,1%	5,2%	4,3%	6,3%

Fig. 9. Car occupants – Injury severity per body region and age group, TARN, N = 16,014.

Injuries

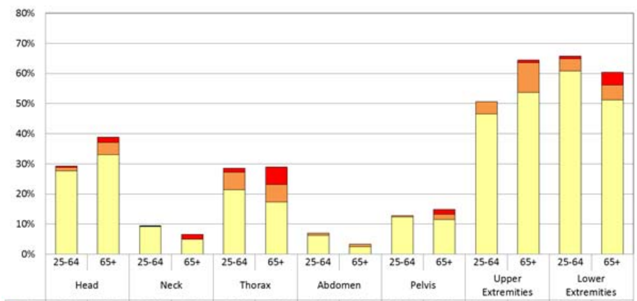
The TraumaRegister DGU® offers the possibility for analysing the recorded injuries per casualty. However, an aggregated set of injuries with 420 AIS coded injuries (instead of about 2,400 injuries in the AIS dictionary) was used based on the specific purposes of the TraumaRegister DGU® (not for collision analysis). Considering this limitation, the top five injuries of car(/truck) occupants were analysed by listing all injuries in the dataset and determining the share of each single injury to all injuries of the specified age group. This resulted in the rank orders of injuries listed in Table AIV and Table AV. Overall, thorax injuries (with three or more ribs broken) were most prominent. Whereas skeletal injuries of the femur followed for mid-aged car occupants, the older casualty suffered more often from other thorax injuries. Further, the spine was also often affected (vertebra fractures).

The same approach was taken for a GIDAS analysis (status of January 2017). However, the inclusion criteria were further specified by the year of manufacturing (2005 or later) of the passenger car and at least injuries of AIS2. Due to the overall low number of cases and hence injuries to be analysed the rank orders were stopped at different positions, thus Table AVI and Table AVII list nine and seven top counted injuries, respectively. For both mid-aged and older car occupants sternum fractures were most prominent. Besides this thorax injury, rib cage fractures with three or more ribs broken played a dominant role. Lumbar spine and pelvic ring fractures were also often found for both mid-aged and older car occupants.

V. DETAILED FINDINGS ON CYCLISTS

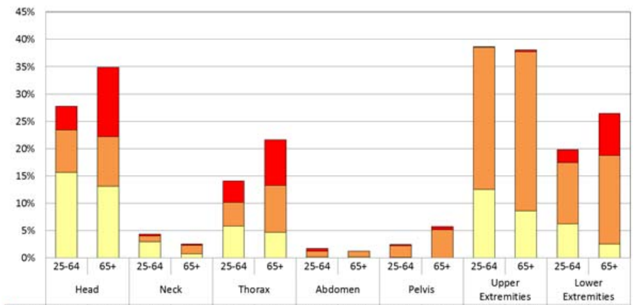
Body regions

The injury distributions of cyclists in crashes with cars per body region and age group from GIDAS and STRADA are shown in Fig. 10 and Fig. 11, respectively. Most mAIS2 and mAIS3+ injuries have been found for the head, thorax and lower extremities, in particular regarding the elderly group.



	Head 25-64	Head 65+	Neck 25-64	Neck 65+	Thorax 25-64	Thorax 65+	Abdomen 25-64	Abdomen 65+	Pelvis 25-64	Pelvis 65+	Upper Extremities 25-64	Upper Extremities 65+	Lower Extremities 25-64	Lower Extremities 65+
AIS3+	0,4%	1,7%	0,2%	1,7%	1,3%	5,8%	0,0%	0,0%	0,0%	1,7%	0,0%	0,8%	0,9%	4,1%
AIS2	1,3%	4,1%	0,2%	0,0%	5,9%	5,8%	0,7%	0,8%	0,4%	1,7%	4,0%	9,9%	4,0%	5,0%
AIS1	27,6%	33,1%	9,1%	5,0%	21,4%	17,4%	6,2%	2,5%	12,4%	11,6%	46,6%	53,7%	60,9%	51,2%

Fig. 10. Injury distribution of cyclists in crashes with cars per body region and age group, GIDAS, N = 916.



	Head 25-64	Head 65+	Neck 25-64	Neck 65+	Thorax 25-64	Thorax 65+	Abdomen 25-64	Abdomen 65+	Pelvis 25-64	Pelvis 65+	Upper Extremities 25-64	Upper Extremities 65+	Lower Extremities 25-64	Lower Extremities 65+
AIS3+	4,3%	12,7%	0,3%	0,3%	3,9%	8,3%	0,5%	0,0%	0,3%	0,6%	0,1%	0,3%	2,4%	7,7%
AIS2	7,8%	9,1%	1,1%	1,5%	4,4%	8,6%	1,0%	1,1%	2,1%	5,1%	26,0%	29,2%	11,1%	16,2%
AIS1	15,6%	13,1%	2,9%	0,8%	5,8%	4,7%	0,2%	0,2%	0,1%	0,0%	12,5%	8,6%	6,3%	2,6%

Fig. 11. Injury distribution of cyclists in crashes with cars per body region and age group, STRADA, N=3,443.

The analysis of RAIDS and IGLAD confirmed the general findings from GIDAS and STRADA, despite the low number of available cases, e.g., RAIDS n=75. However, various deviations of the injury severities and the distributions between the body regions were found in these databases. For example, a high proportion of AIS2+ Upper Extremity injuries have been identified in STRADA. Based on these figures ranking of most affected mAIS2+ and mAIS3+ injured body regions of cyclists were determined for the different age groups, see Table III.

TABLE III
RANKING OF MOST AFFECTED INJURED BODY REGIONS OF CYCLISTS

	All (25+ years)	Mid-aged	Older	All (25+ years)	Mid-aged	Older
	mAIS2+			mAIS3+		
1	Thorax	Thorax	Upper Extr.	Head	Head	Thorax
2	Upper Extr.	Upper Extr.	Lower Extr.	Thorax	Thorax	Head
3	Lower extr.	Lower extr.	Head	Lower Extr.	Lower Extr.	Lower Extr.

Injury risk

The probability for cyclists sustaining an injury of MAIS1 or MAIS2+ over the collision speed of the passenger car is shown in Fig. 14. The presented curves were based on GIDAS data including solely injured cyclists. It can be seen that the likelihood of older cyclists hitting a car's front (car manufactured in 2006 or later) and suffering from MAIS2+ injuries is considerably higher than for mid-aged cyclists.

Injuries

The TraumaRegister DGU® database was analysed to define the top five injuries of cyclists in road traffic crashes by listing all injuries in the dataset and determining the share of each single injury to all injuries of the specified age group. This resulted in the rank orders of injuries listed in Table AII and Table AIII. Overall, thorax injuries (with three or more ribs broken) were most prominent followed by severe head injuries with a similar share. However, a subarachnoid haemorrhage of the cerebrum was more often recorded for older cyclists than for younger ones. Data showed also that severe injuries to the head replaced the importance of serious clavicle injuries for older cyclists.

VI. DETAILED FINDINGS ON PEDESTRIANS

Body regions

The Pedestrians showed higher shares of AIS3+ injuries within each body region compared to car occupants and cyclists. According to GIDAS (N=360), the head, thorax, lower extremities and pelvis were identified having most frequently AIS2 and AIS3+ injuries for older pedestrians in crashes with modern cars, see Fig. 12. The analysis of RAIDS (N=739) showed similar findings, see Fig. 13.

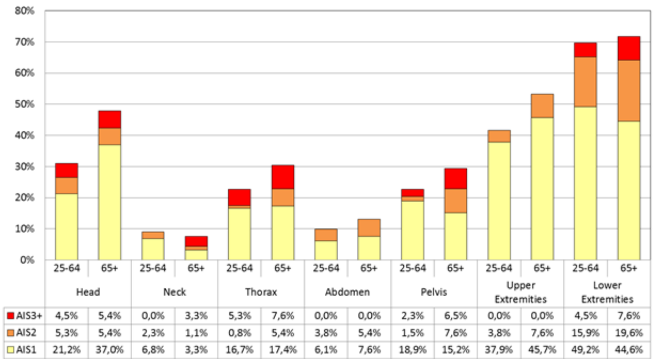


Fig. 12. Injury distribution of pedestrians in crashes with cars per body region and age group, GIDAS, N= 360.

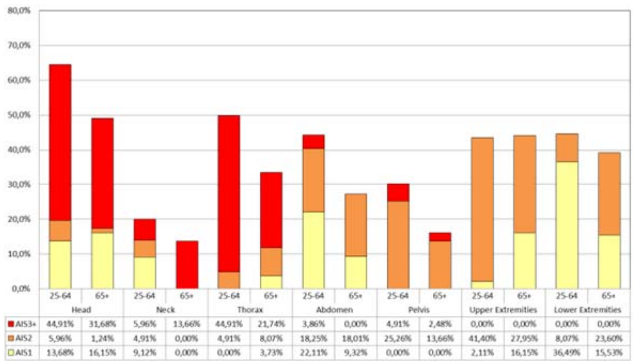


Fig. 13. Injury distribution of pedestrians in crashes with cars per body region and age group, RAIDS, N = 739.

The analysis of STRADA and IGLAD confirmed these general findings. However, various deviations of the injury severities and the distributions between the body regions were found in these databases. For example, a high proportion of AIS2+ Upper Extremity injuries have been identified in STRADA but also high shares of AIS3+

injuries in RAIDS and IGLAD. Based on these figures rankings of most affected mAIS2+ and mAIS3+ injured body regions of pedestrians were determined for the different age groups, see Table IV.

TABLE IV
RANKING OF MOST AFFECTED INJURED BODY REGIONS OF PEDESTRIANS

	All (25+ years)	Mid-aged	Older	All (25+ years)	Mid-aged	Older
	mAIS2+			mAIS3+		
1	Lower Extr.	Lower Extr.	Lower Extr.	Head	Lower Extr.	Head
2	Head	Head	Head	Thorax	Head	Thorax
3	Thorax	Upper Extr.	Thorax	Lower Extr.	Thorax	Lower Extr.

Injury risk

The probability for pedestrians sustaining an injury of MAIS1 or MAIS2+ over the collision speed of a car based on GIDAS data including solely injured pedestrians is shown in Fig. 15. It can be seen that the likelihood of older pedestrians hitting a car's front (car manufactured in 2006 or later) and suffering MAIS2+ injuries is constantly considerably higher than for mid-aged pedestrians by around 10 percentage points.

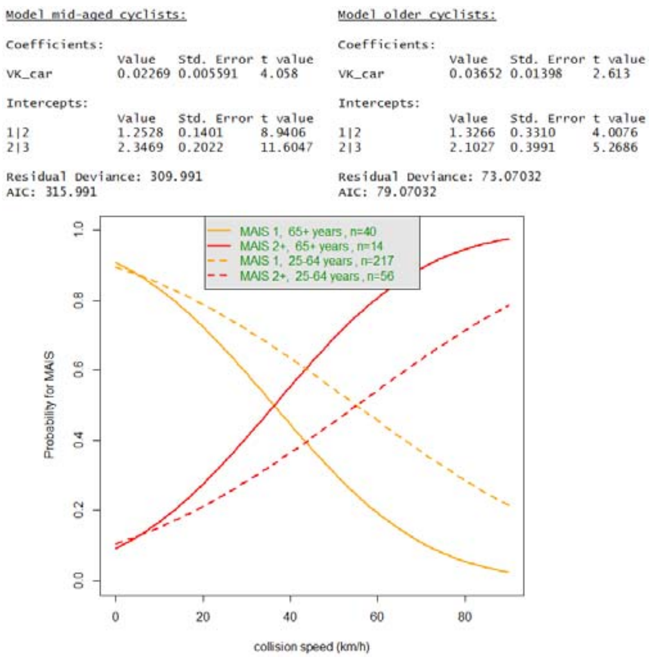


Fig. 14. Probability of MAIS for mid-aged and older cyclists in collisions with car fronts, GIDAS, cars manufactured in 2006 or later.

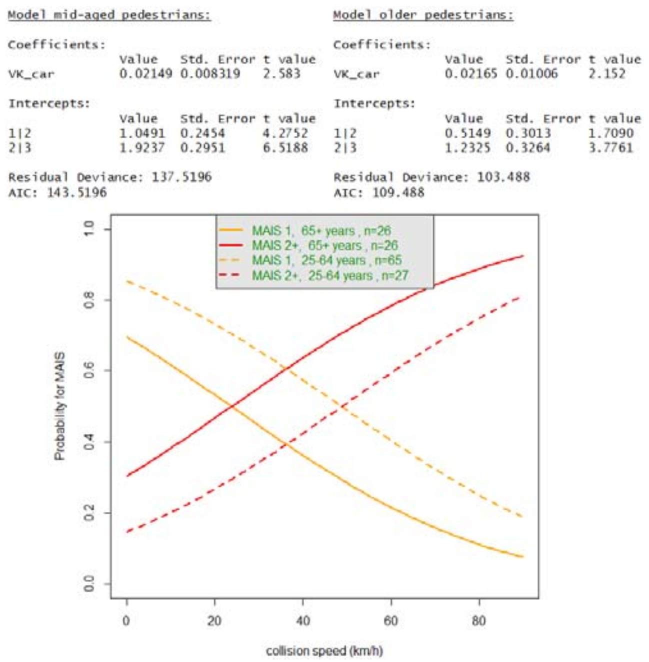
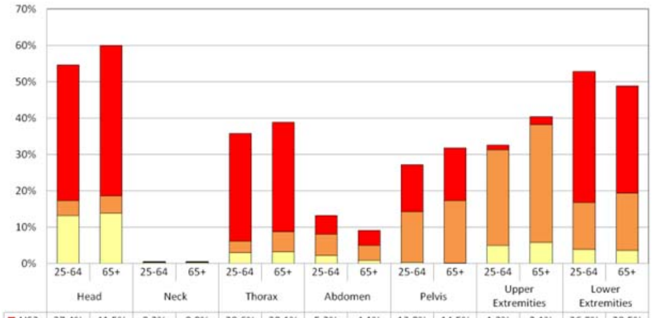


Fig. 15. Probability of MAIS for mid-aged and older pedestrians in collisions with car fronts, GIDAS, cars manufactured in 2006 or later.

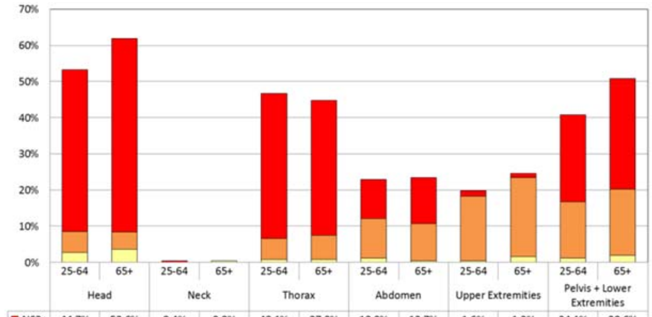
Hospital statistics

Analysing TARN and the Italian Register of Acute Traumas (RITG) for injury severities per body region showed that the body regions most often seriously affected were: the head followed by (to similar extents) the thorax and the lower extremities and to the pelvis, see Fig. 16 and Fig. 17. In the case of an injury to the abdomen, these injuries were most often of AIS2 or higher. Neck injuries played a minor role for pedestrians. Comparing the recorded injured pedestrians in the TARN dataset by sex, the body regions thorax, pelvis and head revealed greatest differences. Male pedestrians more often had AIS3+ thorax injuries (plus ~10 percentage points) and less often pelvis injuries (minus ~5 percentage points) in comparison to females. In addition, females suffered less often from AIS3+ head injuries (minus ~5 percentage points) compared to male pedestrians.



	Head 25-64	Head 65+	Neck 25-64	Neck 65+	Thorax 25-64	Thorax 65+	Abdomen 25-64	Abdomen 65+	Pelvis 25-64	Pelvis 65+	Upper Extremities 25-64	Upper Extremities 65+	Lower Extremities 25-64	Lower Extremities 65+
AIS3+	37,4%	41,5%	0,2%	0,0%	29,6%	30,1%	5,2%	4,1%	13,0%	14,5%	1,3%	2,1%	36,0%	29,5%
AIS2	4,1%	4,6%	0,1%	0,1%	3,2%	5,6%	5,8%	4,1%	13,9%	17,1%	26,3%	32,5%	13,0%	15,8%
AIS1	13,1%	13,9%	0,2%	0,2%	3,0%	3,1%	2,2%	0,9%	0,3%	0,1%	5,0%	5,7%	3,8%	3,6%

Fig. 16. Pedestrians – Injury severity per body region and age group, TARN, N = 9,093, excluding spine injuries.



	Head 25-64	Head 65+	Neck 25-64	Neck 65+	Thorax 25-64	Thorax 65+	Abdomen 25-64	Abdomen 65+	Upper Extremities 25-64	Upper Extremities 65+	Pelvis + Lower Extremities 25-64	Pelvis + Lower Extremities 65+
AIS3+	44,7%	53,6%	0,4%	0,0%	40,1%	37,3%	10,9%	12,7%	1,6%	1,2%	24,1%	30,6%
AIS2	5,8%	4,8%	0,0%	0,0%	5,8%	6,7%	10,9%	10,3%	17,9%	21,8%	15,6%	18,3%
AIS1	2,7%	3,6%	0,0%	0,4%	0,8%	0,8%	1,2%	0,4%	0,4%	1,6%	1,2%	2,0%

Fig. 17. Pedestrians – Injury severity per body region and age group, RITG, N = 509.

Injuries

The TraumaRegister DGU® database was analysed to define the top five injuries of pedestrians in road traffic crashes by listing all injuries in the dataset and determining the share of each single injury to all injuries of the specified age group. This resulted in the rank orders of injuries listed in Table AVIII and Table AIX. Overall, skeletal leg (tibia) and thorax injuries (with three or more ribs broken) were most prominent followed by other severe head (base) and leg injuries (fibula and tibia). Differences can be observed comparing the ranking of the injuries recorded. Older pedestrians suffered more from subarachnoid haemorrhages of the cerebrum than younger ones.

The same approach was taken for a GIDAS analysis (status of January 2017). However, the inclusion criteria were further specified by the collision partner *passenger car*, its year of manufacturing (2005 or later) and at least injuries of AIS2. Due to the overall low number of cases and hence pedestrian injuries to be analysed more complete lists of injuries are provided in Table AX and Table AXI. Whereas for mid-aged pedestrians fibula fractures were most prominent, older pedestrians suffered most often from pelvic ring fractures (up to AIS4). Both groups commonly showed head injuries (cerebral concussion and subarachnoid hemorrhage and vault fractures, respectively) as of high importance. Further, lumbar spine fractures were recorded frequently for the mid-aged and thoracic spine fractures for the older pedestrians.

VII. DISCUSSION

Crash and hospital data

Based on the results from the crash data analyses, older persons were found suffering more often from higher injury severities compared to mid-aged road users. However, the analyses of the hospital datasets showed that, for example, the shares of the injury severity per body region did not differ largely between older and mid-aged car occupants. It was assumed that this is because of the inclusion criteria that, i.e., only casualties with a very high injury severity were included in these datasets, e.g., MAIS3+, and thus, the AIS injury severity levels do not differ apparently.

Nevertheless, for car occupants, the priorities were very similar to those shown by the in-depth crash data. This included both the body regions and specific injuries. For example, three or more rib fractures was the most common injury type, with the risk being approximately 1.5 times greater for the 65+ compared with the 25-64 age group. However, at the body region level there was no clear indication that the risk was higher for older occupants, possibly due to confounding effects of the sampling criteria.

Comparing the injuries of pedestrians most frequently recorded in hospital statistics (Traumaregister DGU®) and in crash data (GIDAS) showed that the importance of body regions in terms of injury severity was the same for mid-aged and older pedestrians, but specific injuries were more prominent than others.

Specific injuries recorded in GIDAS have been reported. As the absolute numbers are sometimes small (<10), there is low confidence in the exact order of these injuries, but there is a lot of common ground between the TraumaRegister DGU® and GIDAS lists, which gives confidence in the results.

Injury severity

Historically, the first and still the most reliable variable for the comparison on accident situation between countries is the number of fatalities in road crashes. Comparing the number of slightly or seriously injured people among European countries yields less reliable results as such comparisons are affected by a large number of factors, including different definitions (mostly driven by the time of hospitalization), different health care systems, different organizational issues of rescue services and alert chains, different organizations of police, different insurance-practice and -culture, different traffic laws and also the different definitions of injury severity. A more detailed discussion of this topic is provided in Reference [14].

Casualties have been assigned to one MAIS for their entire body or on body region level (mAIS). However, the disadvantage of such comparisons is that long-term consequences cannot be reflected with this scale as for example, five severe injuries can lead to a MAIS3, but also only a single injury with this severity. In particular, with regard to older road users and their high vulnerability, the effects of trauma injuries need to be investigated further.

Car Occupants

The thorax was identified as the most critical body region for car occupants. Despite of the deviations in the datasets, ranking of the most frequently affected mAIS2+ and mAIS3+ injured body regions of older car occupants was determined. This resulted in the order of the thorax, followed by the upper extremities and lower extremities for mAIS2+ cases and in the order of the thorax, head and lower extremities for mAIS3+ injured body regions.

The probability of a mAIS2+ thorax injury was found to increase noticeably by higher delta-v values and for older than for mid-aged car occupants. For example, at a delta-v of 60 km/h the probability of a thorax AIS2+ injury was found as being about 35 percentage points higher for older compared to mid-aged car occupants.

Overall, thorax injuries (with three or more ribs broken) were most prominent. Whereas skeletal injuries of the femur followed for mid-aged car occupants, the older casualties suffered more often from various injuries to the thorax region. However, the spine was also often affected (vertebra fracture).

It was also found that car occupants in modern cars suffered most often from AIS1 and less often from AIS2+ injuries to the thorax. The frontal crash still dominated the crash occurrence followed by side crashes. In the respective GIDAS analysis no AIS2+ injury to the thorax was found for casualties involved in rear crashes.

Cyclists

Despite of the various deviations in the datasets, rankings for the most frequently affected mAIS2+ and mAIS3+ injured body regions of older cyclists were determined. This resulted in the order of the thorax, followed by the upper extremities and lower extremities for mAIS2+ cases and in the order of the head, thorax and lower extremities for mAIS3+ injured body regions.

Regarding injuries, thorax injuries (with three or more ribs broken) were most prominent followed by severe head injuries with a similar share. However, a subarachnoid haemorrhage of the cerebrum was more often recorded for older than for younger cyclists. Data also showed that severe injuries to the head replaced the importance of serious clavicle injuries for older cyclists.

By applying the probit model to the available GIDAS data showed that the likelihood of older cyclists hitting a car’s front (car manufactured in 2006 or later) and suffering from MAIS2+ injuries was considerably higher than for mid-aged cyclists.

Overall, severe cyclist injuries were heavily biased towards males. The Spanish national crash data showed proportionally the lowest number of female cyclist casualties. Potential reasons might be that the use of bicycles was often limited to sport activities, since Spanish towns were not prepared for any cycling activity for leisure or daily trips to work. In addition, mainly men have been practicing cycling sports. This tendency changed meanwhile, but primarily in younger age groups. In recent years also women used pedal cycles more and more people cycled as a means of transport; however, this is not yet reflected in the crash data.

Pedestrians

Despite the various deviations in the datasets, rankings for the most frequently affected mAIS2+ and mAIS3+ injured body regions of older pedestrians were determined. This resulted in the order of the lower extremities, followed by the head and upper extremities for mAIS2+ cases and in the order of the lower extremities, head and thorax for mAIS3+ injured body regions.

By applying the probit model to the available GIDAS data showed that the likelihood of older pedestrians hitting a car's front (car manufactured in 2006 or later) and suffering from MAIS2+ injuries was constantly considerably higher than for mid-aged pedestrians.

Overall, skeletal leg and thorax injuries (with three or more ribs broken) were most prominent followed by severe head and leg injuries. Older pedestrians suffered more often from subarachnoid haemorrhages of the cerebrum than younger ones. In the case of an injury to the abdomen, these injuries were most often of AIS2 or higher. Neck injuries played a minor role for pedestrians.

Male pedestrians had more often AIS3+ thorax injuries and less often pelvis in comparison to females. In addition, females suffered less often from AIS3+ head injuries compared to male pedestrians. Overall, severe injuries to older pedestrians were strongly biased towards females.

Injury risk functions

The presented injury risk functions need to be handled with care as they were based on injured casualty data from GIDAS only and therefore, do not represent all European countries. Further, the statistical probit models used would require further adaptations regarding their model quality, as for example the Akaike information criterion (AIC) was often rather marginal due to the input data.

VIII. CONCLUSIONS

The results shown in this paper and described further in [1] confirmed largely earlier findings from the literature for older car occupants. By now, injury distributions of older pedestrians or cyclists in crashes with passenger cars were less investigated. Shown injury risk functions are subject to the described limitations.

Car Occupants

The thorax was consistently identified as the most frequently injured body region for car occupants, at both AIS2+ and AIS3+ levels, and the risk of thorax injury was at least two times greater for the older car occupants than for the mid-aged ones. Probit injury probability functions based on GIDAS data also supported a markedly elevated risk of serious (AIS2+) injury, and especially thorax injury, for older occupants. Serious head and lower extremity injuries were also relatively frequent and of elevated risk for the older age group. This confirms the findings from the literature review that thorax injuries are a priority for prevention for injury in car occupants, particularly for older car occupants. Where more detailed information was available, the greatest proportion of thorax injuries occurred in frontal impacts, which supports the injury criteria development tasks within the SENIORS project, and skeletal fractures were the most common non-trivial injury.

Cyclists

For cyclists, head, thorax and lower extremity injuries were seen to be the priority at the AIS3+ level, with upper extremity injuries also common at the AIS2+ level. For all of these body regions, the risk was greater for the 65+ age group than for the 25-64 age group. An increased risk of AIS2+ injury for the older age group was also supported by probit injury probability functions, but the sample size was too small to allow the risk for individual body regions to be modelled for different age groups. Where more detailed information was available, specific head, thorax and lower extremity injury types were also identified.

Pedestrians

Similar injury priorities were observed for pedestrians as for cyclists, with lower extremity injuries being the priority at the AIS2+ level and head and thorax injuries being the priority at the AIS3+ level. Unusually (compared to other road user groups), injury proportions were not always greater for the older age group at the body region level, although the probit injury probability function showed a greater total risk of MAIS2+ risk of injury for the 65+ group compared with the 25-64 age group. Specific injuries to each body region were also identified.

Aligning different data sources

This paper aimed to link information from crash databases with hospital statistics. Crash data is often recorded by the police. In-depth crash studies are only available in a few countries. Hospital statistics are usually recorded by medical staff only, contain comprehensive medical data and sometimes offer the possibility to distinguish casualties involved in road crashes. Combining both types of data is possible, but requires a broad understanding of the different patient inclusion criteria and definitions, e.g., the lists of injuries most frequently recorded in hospital statistics cannot be directly compared with those of the crash data. This paper and [1] gave an insight into the difficulties of handling different databases and would like to motivate other researchers continuing this work.

IX. ACKNOWLEDGEMENT

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XI. APPENDIX

TABLE AI

OVERVIEW OF ANALYSED DATASETS (TYPE: M – MULTINATIONAL, N – NATIONAL, I – IN-DEPTH, H – HOSPITAL)

No.	*Common Name of Data Source*	Country	Type	Years	Injury severity coding
1	*IRTAD + CARE*	International	M	2009-2013	slightly, serious and fatal injuries
2	*STRADA*	Sweden	N	2008-2014	AIS 2005 update 2008
3	*DESTATIS*	Germany	N	2013-2015	slightly, serious and fatal injuries
4	*ACI-ISTAT*	Italy	N	2008-2014	slightly, serious and fatal injuries
5	*DGT*	Spain	N	2011-2013	slightly, serious and fatal injuries
6	*STATS19*	UK	N	2004-2014	slightly, serious and fatal injuries
7	*GIDAS*	Germany	I	2005-2015	AIS 2005 update 2008
8	*IGLAD*	International	I	2007-2013	AIS 90 with update 1998
9	*RAIDS*	UK	I	2004-2010 & 2013-2015	AIS 2005 update 2008
10	*TraumaRegister DGU®*	Germany	H	2008-2014	AIS 2005 update 2008 (shortened)
11	*TARN*	UK	H	2004-2015	AIS 2005 update 2008
12	*Hospital Database Barcelona*	Spain	H	2010-2014	slightly, serious and fatal injuries
13	*Italian Register Of Acute Traumas*	Italy	H	2004-2014	AIS 90 with update 1998

TABLE AII

TRAUMAREGISTER DGU® - TOP FIVE INJURIES OF MID-AGED CYCLISTS (* OF ALL INJURIES OF THIS AGE GROUP)

AIS	Injuries	n*	%*
450203.3	thorax, fracture, ≥ 3 ribs	876	4.3
150200.3	head, skeletal injury, base (basilar) fracture (incl. orbital roof)	839	4.1
750500.2	arm, skeletal Injury, clavicle	839	4.1
140693.2	head, cerebrum, subarachnoid haemorrhage	645	3.1
150402.2	head, skeletal injury, vault fracture, closed	598	2.9

TABLE AIII

TRAUMAREGISTER DGU® - TOP FIVE INJURIES OF OLDER CYCLISTS (* OF ALL INJURIES OF THIS AGE GROUP)

AIS	Injuries	n*	%*
450203.3	thorax, fracture, ≥ 3 ribs	558	4.4
140693.2	head, cerebrum, subarachnoid haemorrhage	538	4.3
150200.3	head, skeletal injury, base (basilar) fracture (incl. orbital roof)	441	3.5
150402.2	head, skeletal injury, vault fracture, closed	408	3.2
750500.2	arm, skeletal Injury, clavicle	364	2.9

TABLE AIV

TRAUMAREGISTER DGU® - TOP FIVE INJURIES OF MID-AGED OCCUPANTS (* OF ALL INJURIES OF THIS AGE GROUP)

AIS	Injuries	n*	%*
450203.3	thorax, fracture, ≥ 3 ribs	3,013	4.6
853000.3	leg, skeletal Injury, femur	2,728	4.2
441411.3	thorax, lung, contusion, bilateral, minor, < 1 lobe	2,250	3.4
650616.2	spine, vertebra fracture (with no cord involvement)	1,770	2.7
450804.2	thorax, sternum, fracture	1,511	2.3

TABLE AV

TRAUMAREGISTER DGU® - TOP FIVE INJURIES OF OLDER CAR OCCUPANTS (* OF ALL INJURIES OF THIS AGE GROUP)

AIS	Injuries	n*	%*
450203.3	thorax, fracture, ≥ 3 ribs	1,278	6.9
450804.2	thorax, sternum, fracture	937	5.1
441411.3	thorax, lung, contusion, bilateral, minor, < 1 lobe	579	3.1
853000.3	leg, skeletal Injury, femur	552	3.0
650616.2	spine, vertebra fracture (with no cord involvement)	549	3.0

TABLE AVI

GIDAS - TOP NINE AIS2+ INJURIES OF MID-AGED CAR OCCUPANTS (* OF ALL INJURIES OF THIS AGE GROUP, N = 506)

AIS	Injuries	n*	%*
450804.2	Sternum fracture	38	7.5
650616.2	Lumbar Spine, Fracture with or without dislocation but no cord involvement NFS	18	3.6
450203.3	Rib cage, fracture(s) without flail, any location unilateral or bilateral, =>3 ribs	15	3.0
650216.2	Cervical spine, Fracture with or without dislocation but no cord involvement NFS	14	2.8
650620.2	Lumbar spine, Fracture with or without dislocation, transverse process	13	2.6
856151.2	Pelvic ring fracture, posterior arch intact; isolated fracture not destroying the integrity of the pelvic ring	11	2.2
150200.3	Base (basilar) fracture NFS	9	1.8
441410.3	Lung contusion, bilateral NFS	9	1.8
750500.2	Clavicle fracture NFS	9	1.8

TABLE AVII

GIDAS - TOP SEVEN AIS2+ INJURIES OF OLDER CAR OCCUPANTS (* OF ALL INJURIES OF THIS AGE GROUP, N = 122)

AIS	Injuries	n*	%*
450804.2	Sternum fracture	23	18.9
450203.3	Rib cage, fracture(s) without flail, any location unilateral or bilateral, =>3 ribs	10	8.2
856151.2	Pelvic ring fracture, posterior arch intact; isolated fracture not destroying the integrity of the pelvic ring	7	5.7
650616.2	Lumbar Spine, Fracture with or without dislocation but no cord involvement NFS	3	2.5
650632.2	Lumbar Spine, vertebral body NFS [*burst fracture*], minor compression (=< 20% loss of anterior height)	3	2.5
750500.2	Clavicle fracture NFS	3	2.5
856161.3	Pelvic ring fracture, incomplete disruption of posterior arch NFS	3	2.5

TABLE AVIII

TRAUMAREGISTER DGU® - TOP FIVE INJURIES OF MID-AGED PEDESTRIANS (* OF ALL INJURIES OF THIS AGE GROUP)

AIS	Injuries	n*	%*
854000.2	leg, skeletal Injury, tibia	526	3.4
450203.3	thorax, fracture, ≥ 3 ribs	517	3.3
854001.3	leg, skeletal Injury, tibia, open	446	2.9
150200.3	head, skeletal injury, base (basilar) fracture (incl. orbital roof)	392	2.5
854441.2	leg, skeletal Injury, fibula [malleoli]	389	2.5

TABLE AIX

TRAUMAREGISTER DGU® - TOP FIVE INJURIES OF OLDER PEDESTRIANS (* OF ALL INJURIES OF THIS AGE GROUP)

AIS	Injuries	n*	%*
854000.2	leg, skeletal Injury, tibia	557	4.2
450203.3	thorax, fracture, ≥ 3 ribs	500	3.8
140693.2	head, cerebrum, subarachnoid haemorrhage	400	3.0
854441.2	leg, skeletal Injury, fibula	359	2.7
110600.1	soft tissue injury, scalp, minor laceration	314	2.4

TABLE AX

GIDAS - TOP 15 AIS2+ INJURIES OF MID-AGED PEDESTRIANS (* OF ALL INJURIES OF THIS AGE GROUP, N = 183)

AIS	Injuries	n*	%*
650620.2	Lumbar spine, Fracture with or without dislocation, transverse process	7	3.8
161004.2	Cerebral Concussion, loss of consciousness =< 30 mins	5	2.7
854471.2	Fibula [malleoli] fracture, above joint (suprasyndesmotic); isolated shaft, head or neck	5	2.7
854463.2	Fibula [malleoli] fracture, through joint (transsyndesmotic), lateral and medial malleoli (bimalleolar)	4	2.2
150000.2	Skull fracture NFS	3	1.6
441410.3	Lung contusion, bilateral NFS	3	1.6
650216.2	Cervical spine, Fracture with or without dislocation but no cord involvement NFS	3	1.6
710604.2	Skin/subcutaneous/muscle, laceration, major; >10cm long on hand or >20cm long on entire extremity	3	1.6
840405.2	Collateral ligament tear, knee	3	1.6
854000.2	Tibia fracture NFS	3	1.6
854361.2	Distal Tibia fracture, partial articular	3	1.6
854441.2	Fibula [malleoli] fracture NFS	3	1.6
854461.2	Fibula [malleoli] fracture, through joint (transsyndesmotic)	3	1.6
856151.2	Pelvic ring fracture, posterior arch intact; isolated fracture not destroying the integrity of the pelvic ring	3	1.6
858163.2	Metatarsal fracture, One of Four Lateral, partial articular	3	1.6

TABLE AXI

GIDAS - TOP 15 AIS2+ INJURIES OF OLDER PEDESTRIANS (* OF ALL INJURIES OF THIS AGE GROUP, N = 165)

AIS	Injuries	n*	%*
856151.2	Pelvic ring fracture, posterior arch intact; isolated fracture not destroying the integrity of the pelvic ring	5	3.0
856171.4	Pelvic ring fracture, complete disruption of posterior arch and pelvic floor NFS	5	3.0
140693.2	Cerebrum, subarachnoid hemorrhage NFS	4	2.4
150402.2	Vault fracture, closed; simple; undisplaced; diastatic; linear	4	2.4
210604.2	Skin/subcutaneous/muscle, laceration, major; > 10cm long and into subcutaneous tissue	4	2.4
450203.3	Rib cage, fracture(s) without flail, any location unilateral or bilateral, =>3 ribs	4	2.4
650432.2	Thoracic spine, Fracture with or without dislocation, vertebral body, minor compression	4	2.4
854161.2	Proximal Tibia fracture, partial articular	4	2.4
854471.2	Fibula [malleoli] fracture, above joint (suprasyndesmotic); isolated shaft	4	2.4
856100.2	Pelvic ring fracture NFS	4	2.4
450804.2	Sternum fracture	3	1.8
640276.6	Cord laceration, complete cord syndrome, C-3 or above, with both fracture and dislocation	3	1.8
853161.3	Proximal Femur fracture, femoral neck	3	1.8
854472.2	Fibula [malleoli] fracture, above joint (suprasyndesmotic); isolated shaft, head or neck; open	3	1.8
858163.2	Metatarsal fracture, One of Four Lateral, partial articular	3	1.8