

ROAD TRAFFIC CRASHES IN EUROPE INVOLVING OLDER CAR OCCUPANTS, OLDER PEDESTRIANS OR CYCLISTS IN CRASHES WITH PASSENGER CARS – RESULTS FROM SENIORS

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ABSTRACT

A reduction of around 48% of all road fatalities was achieved in Europe in the past years including a reduced number of fatalities with an older age. However, among all road fatalities, the proportion of elderly is steadily increasing. In an ageing society, the European (Horizon2020) project SENIORS aims to improve the safe mobility of older road users, who have different transportation habits compared to other age groups. To increase their level of safe mobility by determining appropriate requirements for vehicle safety systems, the characteristics of current road traffic collisions involving the elderly and the injuries that they sustain need to be understood in detail.

Hereby, the paper focuses on their traffic participation as pedestrian, cyclist or passenger car occupant. Following a literature review, several national and international crash databases and hospital statistics have been analysed to determine the body regions most frequently and severely injured, specific injuries sustained and types of crashes involved, always comparing older road users (65 years and more) with mid-aged road users (25-64 years). The most important crash scenarios were highlighted.

The data sources included European statistics from CARE, data on national level from Germany, Sweden, Italy, United Kingdom and Spain as well as in-depth crash information from GIDAS (Germany), RAIDS (UK), CIREN and NASS-CDS (US). In addition, familiar hospital data from Germany (TraumaRegister DGU®), Italy (Italian Register of Acute Traumas) and UK hospital statistics (TARN) were included in the study to gain further insight into specific injury patterns.

Comprehensive data analyses were performed showing injury patterns of older road users in crashes. When comparing with mid-aged road users, all databases showed that the thorax body region is of particularly high importance for the older car occupant with injury severities of AIS 2 or AIS 3+, whereas the body regions lower extremities, head and thorax need to be considered for the older pedestrians and cyclists. Besides these comparisons, the most frequent and severe top 5 injuries were highlighted per road user group. Further, the most important crash configurations were identified and injury risk functions are provided per age group and road user group.

Although several databases have been analysed, the picture on the road safety situation of older road users in Europe was not complete, as only Western European data was available. The linkage between crash data and hospital data could only be made on a general level as their inclusion criteria were quite different.

INTRODUCTION

The SENIORS (Safety ENhanced Innovations for Older Road users) project (funded by the European Commission) aims to improve the safe mobility of the elderly, and persons who are overweight, using an integrated approach that covers the main modes of transport as well as the 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 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 EU-24 countries based on CARE¹ data from 2010 [2]. Further, almost two-thirds of elderly fatalities in EU-24 were men. Women made up a higher proportion of fatalities among the elderly (36%) than within the whole population (24%). The age group 75-84 was shown to have the highest fatality rate while the 65-74 group had the lowest. These differences were put down to reduced personal mobility with increasing age and the higher frailty of elderly persons. 38% of elderly fatalities were pedestrians in the EU-24 countries. Among the larger countries, the percentage of elderly fatalities who were pedestrians 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 aim of CONSOL was to promote and ensure safe mobility for ageing European populations as well investigating the mobility needs and safety issues for these groups. It was concluded that in the future, older persons will be more mobile and car-reliant. In terms of safety, the major hazard to older road users relates to those that are less protected - pedestrians and cyclists [3].

The COVER project [4] found that older occupants receive more often thoracic injuries than younger ones. In the data approximately 50% of the 17 to

25 year olds had no torso injury compared with 33% of the 46 to 65 year olds. From 66 years and older, the percentage of occupants with no injury to the wider thorax remained at about 31%, but the proportion of MAIS 2 and MAIS 3+ torso injuries increased. Another view was that young occupants tended to receive skeletal injuries less frequently than the older occupant groups. Further, older persons showed more skeletal injuries associated with internal injuries rather than younger persons who often have internal injuries without rib fractures. It was also noted that 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 AIS 3+ lung injuries without a series of rib fractures.

Elderly drivers' collisions 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, Breker et al. [5]. Accidents reflect exposure: elderly choose the time and condition when driving is less trying.

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, Levin et al. [6]. In fatal crashes at intersections where the crash severity was within survivable limits, senior occupants were found to be overrepresented, Sunnevång et al. [7]. Other common accident types were:

- Collisions with pedestrians crossing the street on a straight piece of road;
- Collisions when vehicles make a left turn onto main road and cross the opposite lane;
- Collisions at three-way intersections; and
- Collisions when an intersection is regulated with a give way sign.

Many of the collisions occurred on dry roads in good visibility conditions. In addition, older drivers were also less likely to be involved in rear impact incidents. Older drivers seem to be involved in accidents in which traffic signs had to be read and followed.

¹ European centralised database on road accidents which result in death or injury across the EU

A study of frontal impact crashes in Europe from Carroll [8] 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 AIS 2+ torso injury, and 2.8 times more likely to receive an AIS 3+ torso injury than younger occupants (12 to 52 years).

Rib and sternum fractures are similar in elderly occupants injured in motor vehicle crashes whether they are 65 or 85 years old. The three most common chest injuries of the elderly victims were rib fractures (24%), flail chest (10%), and sternum fractures (6%), Yee et al. [9].

Kent et al. found that seniors tend to die from chest injuries while young people tend to die from head injuries [10]. According to another study by Kent [11] 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 to often be caused by safety belts, Bansal et al. [12].

Otte and Wiese compared injury rates for elderly versus young car drivers wearing a seatbelt in road traffic crashes (GIDAS, years 1999-2009) [13]. Several conclusions have been made towards older car drivers (50 years and older) comparing to young drivers (17-30 years) such as:

- They are not injured more frequently in the case of a crash; and don't suffer from a higher injury severity statistically;
- They suffer less often from head injuries; but have more trauma injuries of the thorax and legs, especially above a delta-v of 50 km/h;
- Their legs show a seven times higher risk of AIS 2+ injury;
- Their risk of cervical spine injuries is low;
- They suffer more often from rib fractures;
- Age, vehicle mass, delta-v and deformations influence significantly the injury severity;
- Body height and Body-Mass-Index do 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.

METHOD

Databases and Accident Data Query

Collated European, national and in-depth crash databases of latest years as well as hospital statistics have been analysed towards injured car occupants, pedestrians and cyclists. **Table 3** lists the analysed datasets, their country of origin and specifies their types. Detailed descriptions of each database can be found in [1].

The analysis was divided into three major steps. First, the international and national crash datasets were used to provide a broader overview on the injury distributions for different age groups and the road traffic participants "car occupants", "pedestrians" and "cyclists". Second, the aim of the in-depth crash dataset analysis was to identify crash scenarios, their characteristics including injury probability functions and most critical injury levels per body region and road user type. Third, hospital statistics have been analysed to complement the information gained by additional cases and listing of most frequent single injuries. Injuries were described using the common injury severity classifications "slightly", "seriously" and "fatally" injured (according to country-specific definitions) as well as 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 detailed 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 behaviour patterns in road traffic and biomechanical properties.

Car occupants

The filter criteria for the first analysis step were:

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

The second analysis step used in-depth crash data sets to describe differences in injury levels for different seating positions and frequent injuries.

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;
- 2) Known sex and age of occupants.

The car's manufacturing 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.

It has to be noted that the above-mentioned filters could not be applied to all databases. Also, this paper focuses on selected key results. Further findings can be found in [1].

Injury risk functions

To specify the probability of sustaining a certain injury severity (expressed as AIS level) the Probit regression (or probit model) was applied using R [14] 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.

GENERAL FINDINGS OF CRASH ANALYSIS

The analysis of the collated European and high level national crash datasets confirmed largely earlier 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.

Europe

Crash data on a European level is collated in databases such as CARE and IRTAD² and was analysed in SENIORS.

Figure 1 shows the injury distributions for different age groups and road user types in all kinds of road traffic crashes. Overall, it can be seen that the injury severity increases with age. Highest absolute numbers for seriously injured casualties and also 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.

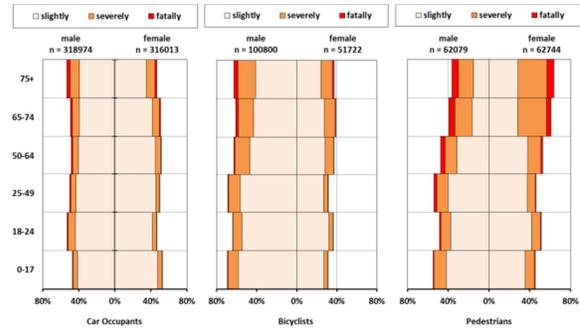


Figure 1: Injury severity distributions in the EU28 countries by age group and road user type, Source: IRTAD and CARE, year 2014, including latest available data from Bulgaria (2009), Greece (2013), Ireland (2013), Malta 2010, Poland 2013, Slovakia (2010), Slovenia 2013 and Sweden (2014).

Italy

In Italy the accident statistics and the related database are run by the Central Institute of Statistics (ISTAT). **Figure 2** shows the distribution of the recorded injury severities for car occupants, pedestrians and cyclists.

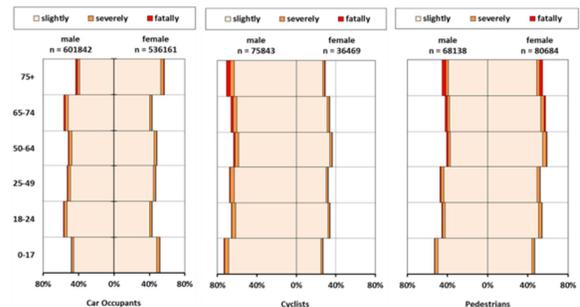


Figure 2: Injury severity distributions in Italy by age group and road user type, ACI-ISTAT, 2008 - 2014

Car occupants

Overall, it can be seen that the injury severity increased slightly with age and female casualties made up around 47% of the dataset. Male casualties above 65 years recorded highest shares of serious or fatal injuries compared to any other age group or females.

Pedal cyclists

The number of male cyclist casualties was nearly twice as high as for females. Above the age of 50

² International Road Traffic and Accident Database

years a considerable increase of the injury severity was recorded, in particular for males.

Pedestrians

Female pedestrians made up around 54% of the casualties. Above the age of 25 years a considerable increase of the injury severity was recorded; however, for both males and females.

Spain

National crash data from the Dirección General de Tránsito (DGT) was analysed. **Figure 3** shows the distribution of the recorded injury severities for car occupants, pedestrians and cyclists.

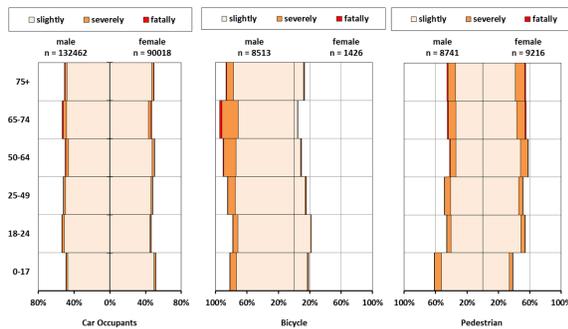


Figure 3: Injury severity distributions in Spain by age group and road user type, DGT, 2011-2013

Car occupants

The percentage of serious or fatal injuries increased slightly with age (except for young men between 18 and 24 years). The age group of 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.

Pedal cyclists

It was found that the injury severity increased with age. However, cyclists of the age group 75 years and older showed less often severe injury outcomes. For these persons it was assumed that they are using less often a bicycle and if, they do, behave less dangerously.

Pedestrians

It was seen that the injury severity increased slightly with age. Whereas male children suffer more frequent from a higher injury severity than females, after the age of 50 years women showed more often serious or fatal injuries than men.

DETAILED FINDINGS 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 AIS 1.

Body regions

The thorax was identified as the most critical body region for car occupants. The thorax showed the highest share of AIS 3+ injuries of all body regions; see exemplarily results from Sweden in **Figure 4**. This is the case for the mid-aged (25-64) and for the elderly group (65+).

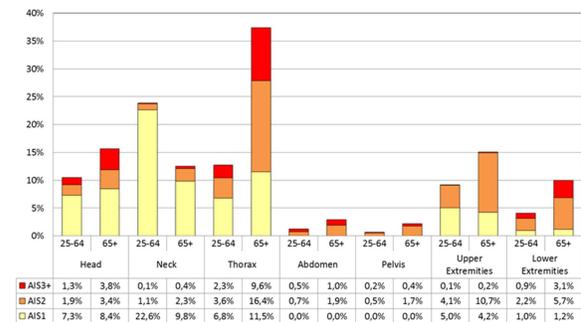


Figure 4: Car occupants – Injury severity per body region and age group, STRADA, N = 49,125 (note: each column sums up to 100%, not shown shares account for AIS 0)

The analysis of all other data sources supported the selection of the body region thorax as most critical for car occupants, see **Table 8**. Although on a low level, GIDAS showed the highest numbers for AIS 2 and AIS 3+ injuries of older car occupants in the thorax compared to other body regions. Similar to this, RAIDS data confirmed the importance of the thorax. An especially high share of AIS 1, AIS 2 and AIS 3+ thorax injuries was found in IGLAD compared to other body regions.

Other body regions across all databases were not showing such high values as observed by the thorax injury data. However, based on the figures above a ranking of most affected mAIS 2+ and mAIS 3+ 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 1**.

Table 1: Ranking of most affected mAIS 2+ / mAIS 3+ injured body regions of car occupants

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

The parameter “principle direction of force” (PDF) was used to compare injury outcomes for frontal, side and rear crashes. As the thorax was identified as being most important, the injury level of this body region was compared for the car’s impact direction and age group, see **Table 9** for GIDAS results. Overall, it was found that car occupants in modern cars suffered most often from AIS 1 and less often from AIS 2+ injuries to the thorax. The frontal crash still dominated the crash occurrence followed by side crashes. In the respective analysis no AIS 2+ injury to the thorax was found for casualties involved in rear crashes.

Injury risk

The probability for car occupants for sustaining an injury of MAIS 1 or MAIS 2+ or being uninjured over the collision speed is shown in **Figure 5**. 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 sitting in cars manufactured in 2005 or later and suffering from MAIS 2+ injuries in frontal car collisions is much higher than for mid-aged ones.

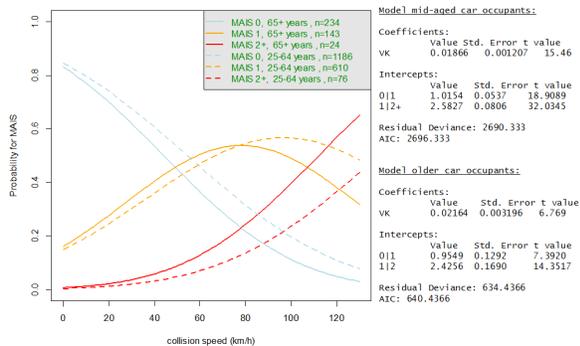


Figure 5: Probability of the overall injury severity (MAIS) over the car's collision speed for mid-aged and older car occupants in frontal collisions, GIDAS, cars manufactured in 2005 or later

Further, the probit model was applied to the thorax region, see **Figure 6**. Similar to the overall injury severity (MAIS) the probability of a thorax mAIS 2+ 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 AIS 2+ injury was found as being around 35 percentage points higher for older compared to mid-aged car occupants.

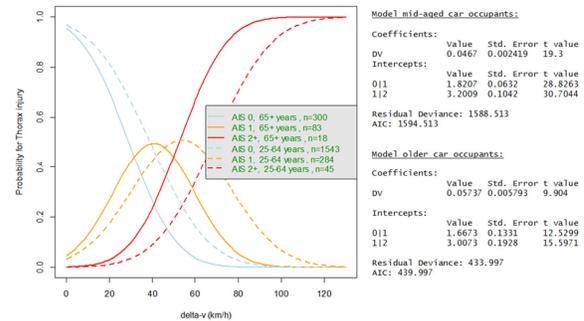


Figure 6: Probability of thorax injury severity (mAIS) over delta-v for mid-aged and older car occupants in frontal collisions, GIDAS, cars manufactured in 2005 or later

Hospital data analysis

The TraumaRegister DGU® collects data on every patient admitted to the emergency room of a participating hospital who was in need of intensive care. 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. Besides the fact that more male persons were recorded than female (in particular in the age groups 18-24 and 25-49 years), older males also 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 **Figure 7**.

The TraumaRegister DGU® database offers the possibility for analysing the recorded injuries per casualty. However, a comparison to other databases is difficult because an aggregated set of injuries is used (based on the specific purposes of the TraumaRegister DGU®, not for collision analysis) ending up with 420 AIS coded injuries instead of ~2,400 injuries in the AIS dictionary.

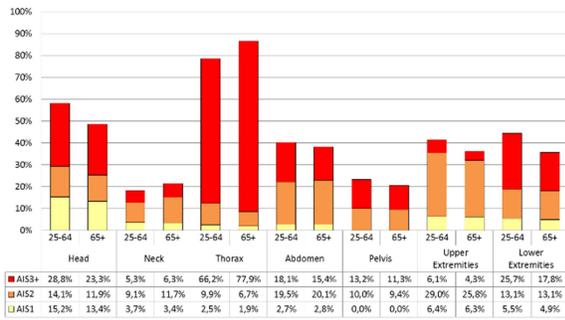


Figure 7: Car occupants – Injury severity per body region and age group, TraumaRegister DGU®, N = 21,090 (note: each column sums up to 100%, not shown shares account for AIS 0)

Considering this limitation, the top 5 injuries of car/(truck) occupants could be 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 ranking of injuries listed in **Table 2**. 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 injuries to the thorax region. However, the spine was also often affected (vertebra fracture).

Table 2: TraumaRegister DGU® - top 5 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

The TARN (Trauma Audit and Research Network) database includes patient information from participating Trauma centres (hospitals) in England and Wales.

Figure 8 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 AIS 2 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 MAIS 3+ casualties.

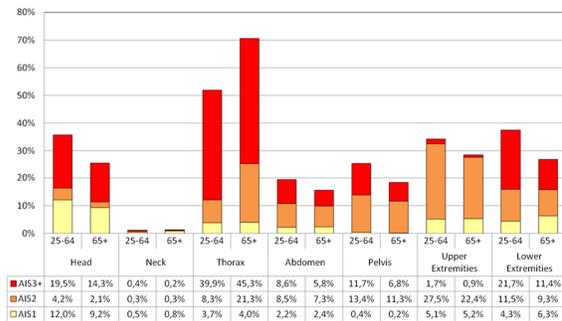


Figure 8: Car occupants – Injury severity per body region and age group, TARN, N = 16,014 (note: each column sums up to 100%, not shown shares account for AIS 0)

In contrast to many other hospital statistics TARN also allows for a distinction to the different seating 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 **Figure 8**, there were a few differences seen for front seat passengers and rear seat passengers. In particular the share of AIS 2 thorax injuries was around 10 percentage points higher for occupants sitting in the front than on the rear seats. However, head injuries were seen more often (~5%) for rear sitting persons compared to the front.

DETAILED FINDINGS FOR CYCLISTS

Cyclists constituted to a rather small group in the selected data sets of each database (except GIDAS). For example the RAIDS dataset showed only 75 cyclists in total (female + male).

Body regions

The injury distribution of cyclists in crashes with cars per body region and age group from GIDAS is shown in **Figure 9**. Most mAIS 2 and mAIS 3+ injuries have been found for the head, thorax and the lower extremities. Especially for the elderly group these body regions showed high shares.

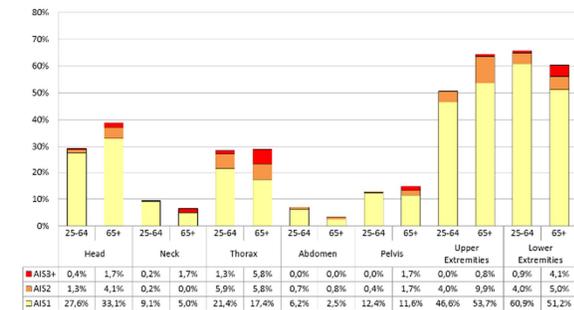


Figure 9: Injury distribution of cyclists in crashes with cars per body region and age group, GIDAS, N = 916 (note: each column sums up to 100%, not shown shares account for AIS 0)

The analysis of STRADA, RAIDS and IGLAD confirmed the findings from GIDAS, see **Table 10**. 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 AIS 2+ Upper Extremity injuries has been identified in STRADA.

Based on these figures rankings of most affected mAIS 2+ and mAIS 3+ injured body regions of cyclists were determined for the different age groups, see **Table 3**.

Injury risk

The probability for cyclists sustaining an injury of MAIS 1 or MAIS 2+ over the passenger car's collision speed is shown in **Figure 10**. 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 MAIS 2+ injuries is considerably higher than for mid-aged cyclists.

Table 3: Ranking of most affected mAIS 2+ / mAIS 3+ injured body regions of cyclists

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

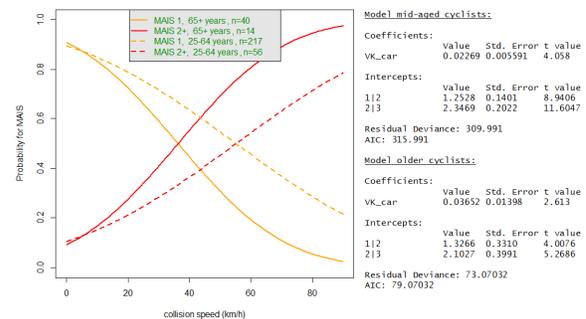


Figure 10: Probability of the overall injury severity (MAIS) for mid-aged and older cyclists in collisions with car fronts, GIDAS, cars manufactured in 2006 or later

Hospital data analysis

The Italian Acute Trauma Registry (RITG) contains files from trauma patients (ISS>15) admitted to emergency care units after a road accident. In the available dataset 401 cyclists were included. Around 85% of them were male.

Figure 11 shows a comparison between mid-aged and older cyclists regarding their injury severities for different body regions. The most affected body regions were the head, followed by thorax and the pelvis + lower extremities (note: no further distinction was possible). According to this analysis, older cyclists suffered more often from AIS 3+ injuries to the head, thorax and to the pelvis + lower extremities region compared to mid-aged cyclists. Among these cyclists, head trauma was observed in 39 of the 47 observed deaths (83%), with many of them that have been reported also concomitant thorax trauma (60%) and pelvis or lower extremities injuries (45%).

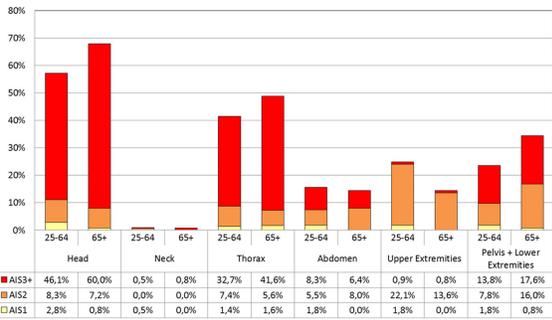


Figure 11: Cyclists – Injury severity per body region and age group, RITG, N = 401 (note: each column sums up to 100%, not shown shares account for AIS 0)

The TraumaRegister DGU® database was analysed towards the top 5 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 ranking of injuries listed in **Table 4**. 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.

Table 4: TraumaRegister DGU® - top 5 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

DETAILED FINDINGS FOR PEDESTRIANS

Body regions

Pedestrians showed higher shares of AIS 3+ injuries within each body region compared to car occupants and cyclists. According to GIDAS (N=360), the head, thorax and lower extremities were identified having most frequently AIS 2 and AIS 3+ injuries for older pedestrians in crashes with modern cars. The analysis of RAIDS (N=739) showed similar findings, see **Figure 12**.

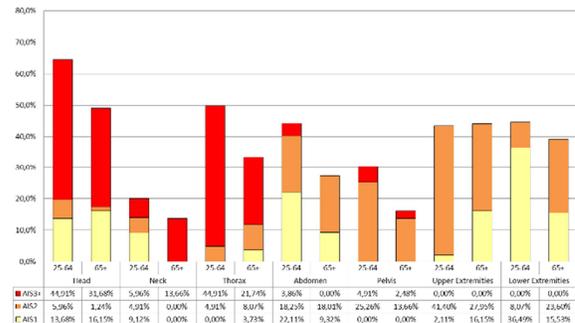


Figure 12: Injury distribution of pedestrians in crashes with cars per body region and age group, RAIDS, N = 739 (note: each column sums up to 100%, not shown shares account for AIS 0)

The analysis of STRADA and IGLAD confirmed these findings, see **Table 11**. 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 AIS 2+ Upper Extremity injuries have been identified in STRADA but also high shares of AIS 3+ injuries in RAIDS and IGLAD.

Based on these figures rankings of most affected mAIS 2+ and mAIS 3+ injured body regions of cyclists were determined for the different age groups, see **Table 5**.

Table 5: Ranking of most affected mAIS 2+ / mAIS 3+ injured body regions of pedestrians

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

Injury risk

The probability for pedestrians sustaining an injury of MAIS 1 or MAIS 2+ over the car’s collision speed based on GIDAS data including solely injured pedestrians is shown in **Figure 13**. It can be seen that the likelihood of older pedestrians hitting a car’s front (car manufactured in 2006 or later) and suffering from MAIS 2+ injuries is constantly considerably higher than for mid-aged pedestrians by around 10 percentage points.

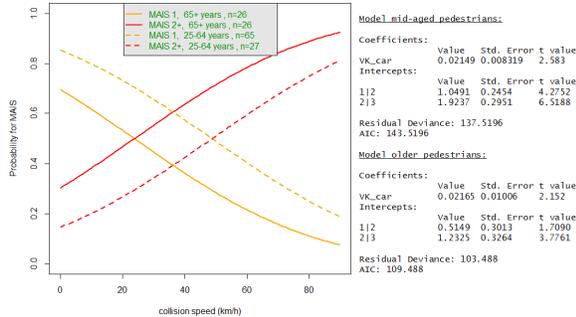


Figure 13: Probability of the overall injury severity (MAIS) for mid-aged and older pedestrians in collisions with car fronts, GIDAS, cars manufactured in 2006 or later

Hospital data analysis

Analysing TARN 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 **Figure 14**. In the case of an injury to the abdomen, these injuries were most often of AIS 2 or higher. Neck injuries play 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 had more often AIS 3+ 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 AIS 3+ head injuries (minus ~5 percentage points) compared to male pedestrians.

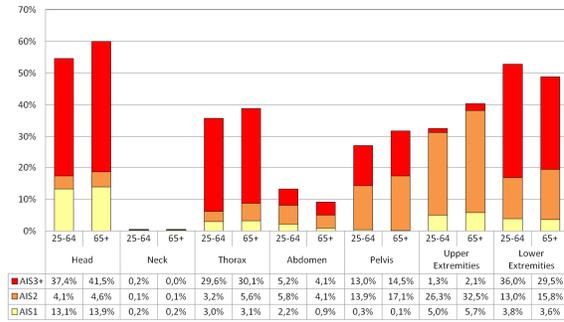


Figure 14: Pedestrians – Injury severity per body region and age group, TARN, N = 9,093, excluding spine injuries (note: each column sums up to 100%, thus not shown shares account for “not injured” – AIS 0)

The TraumaRegister DGU® database was analysed towards the top 5 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 ranking of injuries listed in **Table 6**. Overall, skeletal leg and thorax injuries (with three or more ribs broken) were most prominent followed by other severe head and leg injuries. Differences can be observed comparing the ranking of the injuries recorded. Older pedestrians suffered more from subarachnoid haemorrhages of the cerebrum than younger ones.

Table 6: TraumaRegister DGU® - top 5 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 7: 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 8: Car occupants – Comparison of injury severities per body region and age group

STRADA					GIDAS			RAIDS			IGLAD		
Car Occupants (female + male)	Age Group	AIS1	AIS2	AIS3+	AIS1	AIS2	AIS3+	AIS1	AIS2	AIS3+	AIS1	AIS2	AIS3+
		Head	25-64	7.3%	1.9%	1.3%	7.5%	0.4%	0.2%	18.9%	1.1%	3.4%	4.8%
	65+	8.4%	3.4%	3.8%	7.1%	0.1%	0.0%	15.1%	1.3%	3.7%	5.4%	3.0%	3.0%
Neck	25-64	22.6%	1.1%	0.1%	19.5%	0.2%	0.0%	34.0%	1.7%	0.7%	6.2%	0.6%	1.0%
	65+	9.8%	2.3%	0.4%	11.9%	0.2%	0.0%	20.1%	3.7%	1.8%	1.2%	1.8%	0.0%
Thorax	25-64	6.8%	3.6%	2.3%	10.4%	0.9%	0.4%	23.4%	4.7%	5.3%	8.5%	1.6%	4.6%
	65+	11.5%	16.4%	9.6%	15.4%	1.6%	0.9%	23.5%	10.2%	13.1%	21.6%	4.2%	6.6%
Abdomen	25-64	0.0%	0.7%	0.5%	2.4%	0.4%	0.1%	20.8%	3.7%	1.8%	1.5%	1.1%	2.5%
	65+	0.0%	1.9%	1.0%	2.1%	0.8%	0.0%	15.1%	7.6%	2.6%	5.4%	1.2%	1.2%
Pelvis or Spine for NASS/CDS, CIREN, IGLAD	25-64	0.0%	0.5%	0.2%	1.4%	0.3%	0.0%	0.8%	2.0%	0.8%	14.3%	0.6%	1.1%
	65+	0.0%	1.7%	0.4%	1.3%	0.2%	0.1%	1.6%	5.2%	0.8%	13.2%	2.4%	1.8%
Upper Extremities	25-64	5.0%	4.1%	0.1%	8.4%	0.6%	0.0%	24.7%	6.8%	0.1%	11.7%	3.8%	1.3%
	65+	4.2%	10.7%	0.2%	9.0%	1.4%	0.0%	25.1%	12.8%	0.0%	13.8%	6.0%	1.8%
Lower Extremities	25-64	1.0%	2.2%	0.9%	5.7%	0.3%	0.2%	20.8%	3.0%	2.0%	7.2%	1.6%	2.4%
	65+	1.2%	5.7%	3.1%	5.9%	0.8%	0.0%	23.5%	4.7%	3.7%	6.6%	2.4%	5.4%

Table 9: Car Occupants in GIDAS who suffered from thorax injuries per impact direction and age group

Car Occupants			Thorax, AIS code							
Impact	Age G.	AIS 1		AIS 2		AIS 3+		AIS 1+		
		n	%	n	%	n	%	n	%	
Front	25-64	297	86.1%	35	10.1%	13	3.8%	345	100.0%	
	65+	87	82.1%	13	12.3%	6	5.7%	106	100.0%	
subtotal: Front		384	85.1%	48	10.6%	19	4.2%	451	100.0%	
Side	25-64	103	88.0%	7	6.0%	7	6.0%	117	100.0%	
	65+	32	91.4%	1	2.9%	2	5.7%	35	100.0%	
subtotal: Side		135	88.8%	8	5.3%	9	5.9%	152	100.0%	
Rear	25-64	83	100.0%	0	0.0%	0	0.0%	83	100.0%	
	65+	15	100.0%	0	0.0%	0	0.0%	15	100.0%	
subtotal: Rear		98	100.0%	0	0.0%	0	0.0%	98	100.0%	
Total		617	88.0%	56	8.0%	28	4.0%	701	100.0%	

Table 10: Cyclists – Comparison of injury severities per body region and age group

STRADA					GIDAS			RAIDS			IGLAD		
Cyclists (female + male)	Age Group	AIS1	AIS2	AIS3+	AIS1	AIS2	AIS3+	AIS1	AIS2	AIS3+	AIS1	AIS2	AIS3+
		Head	25-64	15.6%	7.8%	4.3%	27.6%	1.3%	0.4%	17.4%	0.0%	2.2%	8.9%
	65+	13.1%	9.1%	12.7%	35.1%	4.1%	1.7%	0.0%	0.0%	0.0%	10.9%	8.7%	34.8%
Neck	25-64	2.9%	1.1%	0.3%	9.1%	0.2%	0.2%	4.3%	0.0%	2.2%	1.8%	0.0%	2.4%
	65+	0.8%	1.5%	0.3%	5.0%	0.0%	1.7%	0.0%	0.0%	0.0%	0.0%	4.3%	4.3%
Thorax	25-64	5.8%	4.4%	3.9%	21.4%	5.9%	1.3%	8.7%	0.0%	2.2%	10.5%	1.6%	0.8%
	65+	4.7%	8.8%	8.3%	17.4%	5.8%	5.8%	0.0%	16.7%	0.0%	6.5%	6.5%	21.7%
Abdomen	25-64	0.2%	1.0%	0.5%	6.2%	0.7%	0.0%	6.5%	2.2%	0.0%	1.8%	0.8%	0.0%
	65+	0.2%	1.1%	0.0%	2.5%	0.8%	0.0%	0.0%	0.0%	0.0%	0.0%	2.2%	4.3%
Pelvis or Spine for NASS/CDS, CIREN, IGLAD	25-64	0.1%	2.1%	0.3%	12.4%	0.4%	0.0%	0.0%	4.3%	0.0%	8.1%	0.8%	0.8%
	65+	0.0%	5.1%	0.6%	11.6%	1.7%	1.7%	0.0%	0.0%	16.7%	0.0%	6.5%	2.2%
Upper Extremities	25-64	12.5%	26.0%	0.1%	46.6%	4.0%	0.0%	8.7%	8.7%	0.0%	43.5%	8.1%	0.0%
	65+	8.6%	29.2%	0.3%	53.7%	9.9%	0.8%	0.0%	0.0%	0.0%	32.6%	19.6%	6.5%
Lower Extremities	25-64	6.3%	11.1%	2.4%	60.9%	4.0%	0.9%	22.0%	2.4%	2.4%	81.3%	3.2%	4.0%
	65+	2.6%	16.2%	7.7%	51.2%	5.0%	4.1%	0.0%	0.0%	0.0%	47.8%	13.0%	8.7%

Table 11: Pedestrians – Comparison of injury severities per body region and age group

STRADA					GIDAS			RAIDS			IGLAD		
Pedestrians (female + male)	Age Group	AIS1	AIS2	AIS3+									
		Head	25-64	13.5%	8.1%	7.2%	21.2%	5.3%	4.5%	13.7%	6.0%	44.9%	7.8%
	65+	9.1%	8.8%	10.8%	37.0%	5.4%	5.4%	16.1%	1.2%	31.7%	2.1%	10.6%	25.5%
Neck	25-64	2.9%	0.4%	0.2%	6.8%	2.3%	0.0%	9.1%	4.9%	6.0%	0.9%	1.7%	0.0%
	65+	0.7%	1.4%	0.5%	3.3%	1.1%	3.3%	0.0%	0.0%	13.7%	0.0%	0.0%	0.0%
Thorax	25-64	4.0%	3.5%	7.1%	16.7%	0.8%	5.3%	0.0%	4.9%	44.9%	3.5%	0.9%	21.7%
	65+	3.4%	4.6%	8.7%	17.4%	5.4%	7.6%	3.7%	8.1%	21.7%	2.1%	4.3%	14.9%
Abdomen	25-64	0.1%	2.5%	1.3%	6.1%	3.8%	0.0%	22.1%	18.2%	3.9%	2.6%	3.5%	8.7%
	65+	0.0%	2.2%	1.2%	7.6%	5.4%	0.0%	9.3%	18.0%	0.0%	1.1%	1.1%	8.5%
Pelvis or Spine for NASS/CDS, CIREN, IGLAD	25-64	0.0%	3.0%	1.8%	18.9%	1.5%	2.3%	0.0%	25.3%	4.9%	1.7%	5.2%	6.1%
	65+	0.0%	7.0%	2.4%	15.2%	7.6%	6.5%	0.0%	13.7%	2.5%	3.2%	5.3%	7.4%
Upper Extremities	25-64	8.4%	19.2%	0.4%	37.9%	3.8%	0.0%	2.1%	41.3%	0.0%	17.4%	10.4%	1.7%
	65+	5.6%	29.9%	0.9%	45.7%	7.6%	0.0%	16.1%	28.0%	0.0%	13.6%	13.8%	4.3%
Lower Extremities	25-64	10.7%	26.8%	5.5%	49.2%	15.9%	4.5%	36.5%	8.1%	0.0%	20.9%	21.7%	13.0%
	65+	3.7%	28.0%	14.6%	44.6%	19.6%	7.6%	15.5%	23.6%	0.0%	18.1%	11.7%	18.1%

DISCUSSION

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.

Overall, 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 e.g., only casualties with a very high injury severity were included in these datasets 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 region and specific injury levels. For example, three or more rib fractures were the most common injury type, with the risk being approximately 1.5 times greater for the 65+ age group compared with the 25-64 age group. However, at the body region level there was not a clear indication that the risk was higher for older occupants, possibly due to confounding effects of the sampling criteria.

Car Occupants

The thorax was identified as the most critical body region of car occupants.

Despite of the various deviations in the datasets, rankings for the most frequently affected mAIS 2+ and mAIS 3+ injured body regions of older car occupants 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 Thorax, Head and Lower Extremities for mAIS 3+ injured body regions.

The probability of suffering a thorax mAIS 2+ injury was found to increase 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 AIS 2+ injury was found as being around 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 casualty suffered more often from various injuries to the thorax region. However, the spine was also often affected (vertebra fracture).

Regarding seating positions, a few differences were seen for front and rear seat passengers. In particular the share of AIS 2 thorax injuries was around 10 percentage points higher for occupants sitting in the front than on the rear seats. However, head injuries were seen more often (~5%) for rear sitting persons compared to the front.

It was also found that car occupants in modern cars suffered most often from AIS 1 and less often from AIS 2+ injuries to the thorax. The frontal crash still dominated the crash occurrence followed by side crashes. In the respective GIDAS analysis no AIS 2+ 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 mAIS 2+ and mAIS 3+ 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 mAIS 3+ 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 (head injury) was more often recorded for older cyclists than for younger ones. 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 MAIS 2+ injuries is considerably higher than for mid-aged cyclists.

Compared to all datasets analysed, 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.

Overall, severe cyclist injuries were heavily biased towards males.

Pedestrians

Despite of the various deviations in the datasets, rankings for the most frequently affected mAIS 2+ and mAIS 3+ 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 mAIS 3+ 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 MAIS 2+ injuries is 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 (head injury) than younger ones. In the case of an injury to the abdomen, these injuries were most often of AIS 2 or higher. Neck injuries play a minor role for pedestrians.

Male pedestrians had more often AIS 3+ thorax injuries and less often pelvis in comparison to females. In addition, females suffered less often from AIS 3+ 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, can't 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.

CONCLUSIONS

The present work confirmed largely earlier findings from the literature for older car occupants and complemented information on injury distributions of older pedestrians or cyclists in crashes with passenger cars which were by now less investigated.

Car Occupants

The thorax was consistently identified as the most frequently injured body region for car occupants, at both AIS 2+ and AIS 3+ levels, and the risk of thorax injury was at least twice 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 (AIS 2+) 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 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 AIS 3+ level, with upper extremity injuries also common at the AIS 2+ 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 AIS 2+ 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 AIS 2+ level and head & thorax injuries being the priority at the AIS 3+ level. Unusually (compared with 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 MAIS 2+ risk of injury for the 65+ group compared with the 25-64 age group. Specific injury types 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 for 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. This paper and the SENIORS Deliverable 1.2 [1] gave an insight into the difficulties of handling with different databases and would like to motivate other researchers continuing this work.

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RECOMMENDATION

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, 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. Therefore, it would be important to have a common definition for “road traffic crashes” and for injury severities in order to remove part of the uncertainty.

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