ACCIDENT AND INJURY RISKS OF ELDERLY CAR OCCUPANTS

Heiko Johannsen
Technische Universität Berlin
Gerd Müller
Verein für Fahrzeugsicherheit Berlin e.V.
Germany
Paper Number 13-0223

ABSTRACT

The demographic change and the expected change in driving patterns of elderly require adoption of cars in larger scale to this group than it was the case in the past. This study focusses on the special situation of elderly as car driver (w.r.t. accident risk) and car occupant (w.r.t. injury risks).

The main data sources for this study were accident studies from the literature (mainly CCIS and GIDAS focusing on frontal impacts with newer cars), German national accident data and general literature. Based on the findings from literature possibilities for adoption of cars for elderly drivers were developed.

In addition to the accident situation additional needs of elderly w.r.t. car design and ergonomics were analysed. This analysis is also based on German national car registration statistics.

Elderly car drivers have more often accidents in situations that are complex, e.g., crossings. In addition to that reaction time seems to cause additional risks. However, it needs to be stated that elderly are a very heterogenic group w.r.t. the ability to drive a car.

Looking at the injury risks it is clear that elderly obtain more often severe injuries than younger occupants, e.g., the death rate in relation to the number of involved accidents is much higher. Looking at different body regions the main problem is associated to rip fractures.

The impact speed is almost similar to this of younger drivers excluding very young drivers.

Elderly car owners are using mainly three different groups of cars. The first group is composed of top seller cars; the second group are cars with a higher seating position that allows easier access into the car and suggests a better overview; finally premium cars are often registered for elderly.

In order to improve car safety for elderly special conditioned driver assistance systems (e.g., crossing assistant) and smart restraint systems are required.

BACKGROUND

The demographic change of our society is also an issue for the mobility behaviour. It can be stated that not only the number of people who are older than 60 years is increasing, but also that the mobility of elderly people increases. Owning a driving license is normally in this generation even for women. These factors mean that more and more elderly use a car. Consequently, two fundamental questions follow from these facts: Are there characteristics of a vehicle, which should be adjusted specifically for senior drivers, here are primarily the vehicle manufacturers asked and how must be physical limitations addressed, which are widely common for elderly people. To answer these questions it is necessary to look at specific injury risks of elderly people and to understand their behaviour in the traffic. For that an accident study was conducted. It was also investigated whether or not there are typical cars, which are preferred by senior drivers.

INJURY RISKS

The following analysis is based on German and UK national accident data and the in-depth data bases GIDAS and CCIS. GIDAS data sampling is optimised to be representative for Germany [Hautzinger, 2006] while for CCIS bias towards newer cars, more severe accidents and overrepresentation of elderly occupants is reported [Thompson, 2011].

Injury severity is coded in the national statistics as

- killed (all persons who died within 30 days after the accident as a direct result of the accident),
- severely injured (all persons who were taken to hospital immediately after the accident for medical treatment for more than 24 hours),
- slightly injured (all other injured persons),
- uninjured.

The German national data from 2011 shows that the risk of being involved in an accident decreases (by using the number of slightly injured occupants as an indicator for the number of accidents) with age but the risk of being severely injured or killed when an accident happens is increasing, see *Figure **1***.

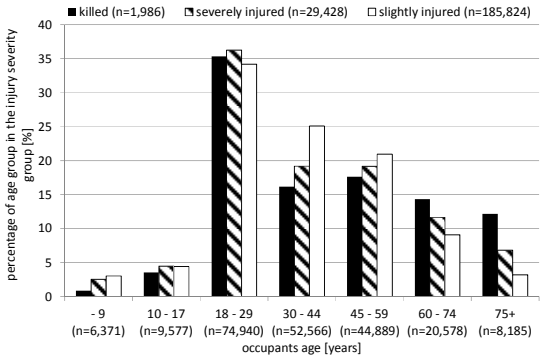

Figure 1. Injury severity dependent on age in German national accident data 2011 [DESTATIS, 2012].

The analysis of the national UK accident data of 2008 involving occupants of cars with registration data October 2003 or later shows a similar picture, *Figure **2***.

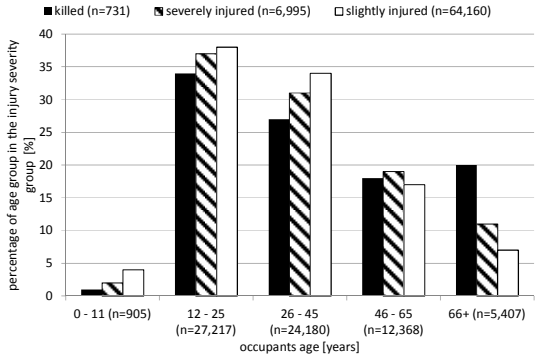

Figure 2. Injury severity dependent on age in UK national accident data 2008 (only cars with first registration October 2003 or later) [Richards, 2010].

The analysis of frontal impact accidents involving ECE R94 compliant cars also shows a higher injury risk for elderly than for younger occupants. The proportion of killed and seriously injured people is considerably larger for occupants older than 45 years compared to the younger ones, see *Figure **3***. The tendency is getting worse with age.

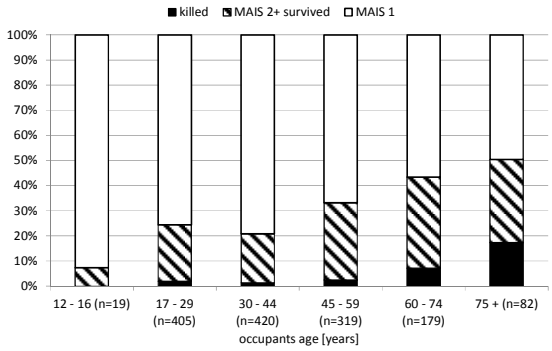

Figure 3. Injury severity dependent on age in CCIS data base, frontal impacts, ECE R94 compliant cars [Thompson, 2011].

Based on the same CCIS data set Thompson et al. [Thompson, 2012] analysed the injured body regions dependent on age. This analysis shows that for most of the body regions age seems not to influence the occurrence of AIS 2+ injuries except for chest and legs, see *Figure **4***. The decrease of leg AIS 2+ injuries with age seems not to be based on physiological differences between younger and older subjects but more a result of the individual accidents. Ridella et al. [Ridella, 2012] showed a considerably higher injury risk for legs in occupants above 75 years based on US accident data.

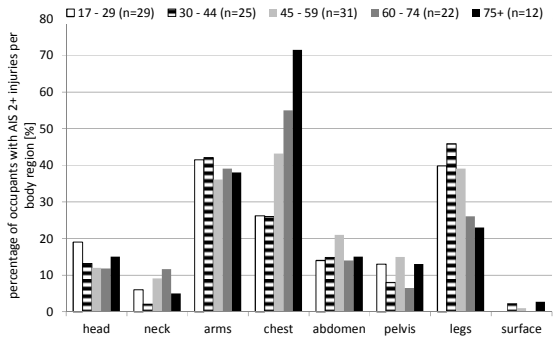

Figure 4. Injury body region dependent on age, CCIS data base, frontal impacts, ECE R94 compliant cars [Thompson, 2011].

In contrast, the considerable increase of chest injuries can be explained with physiological developments while aging. The bone structure changes its mechanical properties and becomes brittle with age [Hardy, 2005]. The hypothesis can be confirmed when looking more in detail into the chest injuries. Especially the risk for rib fractures and sternum fractures increases with age, see *Figure **5***.

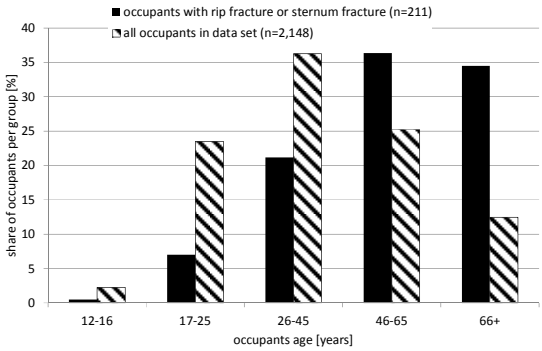

Figure 5. Share of occupants with rip fractures or sternum fractures dependent on age, CCIS frontal impact data involving cars with first registration date 2000 or later [Carroll, 2009].

Chest injuries are mainly caused by contact with the restraint systems (belt, airbag) – in contrast to injuries caused by intrusion. Following that it appears as expected that the injury causation by restraint system increases for occupants with an age above 45, see *Figure **6***. It is important to note that „injury caused by restraint system“ does not mean that the injury risk would be lower without restraint system but that it can be expected that the injury severity could be reduced by improvements of the restraint system or the cabin pulse.

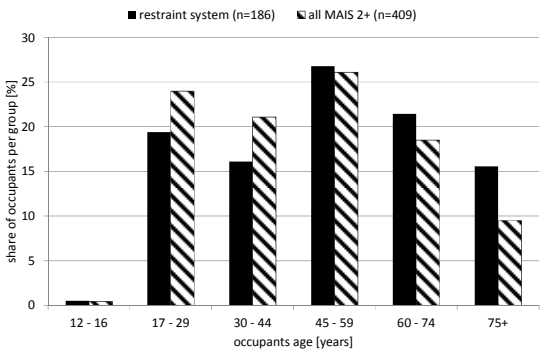

Figure 6. Injury caused by contact to the restraint system dependent on age in comparison to all MAIS 2+ injuries, CCIS frontal impact data involving ECE R94 compliant cars [Thompson, 2011].

Otte et al. [Otte, 2012] compared the occurrence of rib fractures between younger (17 to 30 YO) and elderly (50 years old or older) belted drivers in car-to-car or single car accidents. GIDAS data of the years 1999 to 2009 were used. The risk for sustaining chest injuries and in particular rib fractures or sternum fractures is significantly dependent on age. Rib fractures and rib series fracture already occured with an delta-v of 31 – 40 km/h in the 50+ group while these injuries were observed in the younger control group with delta-v exceeding 51 km/h, see *Figure **8***.

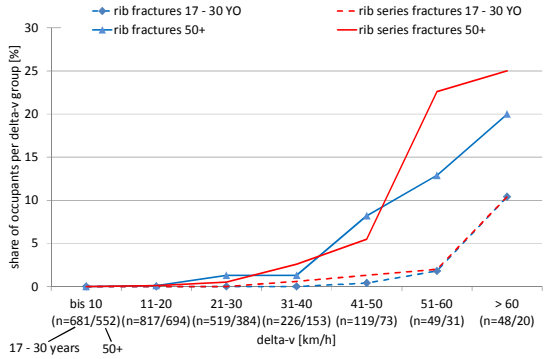

Figure 7. Comparison of the risk for rib fractures dependent on delta-v and age, GIDAS data 1999-2009, belted drivers [Otte, 2012].

Kent et al. [Kent, 2003] analysed the risk for rib fractures and rib series fractures (fracture of seven or more ribs) dependent on the chest compression (relative deflection) and came to similar results. The 50th percent rib fracture risk for 30 years old is related to approx. 35% chest compression while it is approx. 13% for 70 YO, see *Figure **7***. If the chest compression limits are transferred to Hybrid III 50%ile male dummy they would correspond to 80 mm for the 30 YO and 30 mm for the 70 YO, respectively. The rib deflection limit is today 50 mm in Europe and 76.2 mm in the US.

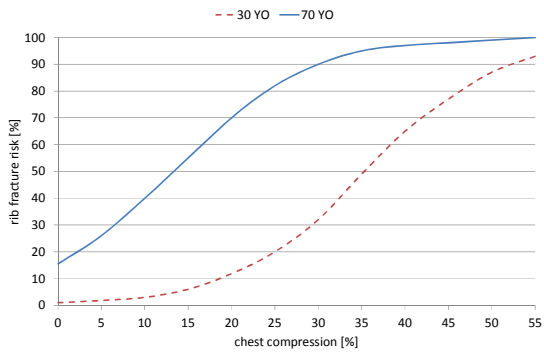

Figure 8. Comparison of rib fracture risk for 30 YO and 70 YO dependent on chest compression [data according to Kent, 2003].

In summary the injury risk increases with age which is mainly caused by physiological changes of the bones to which the restraint system cannot be adequately adjusted to. The main difference between elderly and younger can be seen for the risk for rib fractures.

TYPICAL ACCIDENT SITUATIONS OF ELDERLY DRIVERS

For the analysis of typical accident situation elderly drivers are involved in the German national accident data from 2010 was analysed more in detail. For the following analysis of kind of accident and type of accident it is important to note

that all car drivers were counted; that means that for multiple car accidents the accident was counted multiple times. This approach increases the number of car-to-car accidents artificially. Normally the analysis of type of accident and kind of accident is done for the driver that caused the accident according to police reports only. However, for this paper it was considered to be important to count all accidents elderly driver are involved in without concentrating on the "faulty" driver. Following that the overrepresentation of car-to-car accidents was accepted. Kind of accident and type of accident allow looking for critical situations depending on age. The kind of accident describes of the entire course of events in an accident the direction into which the vehicles involved were heading when they first collided on the carriageway or, if there was no collision, the first mechanical impact on a vehicle. The following 10 kinds of accidents can be distinguished [DESTATIS, 2011a]:

1) Collision with another vehicle which starts, stops or is stationary.
   - Starting or stopping are here to be seen in connection with a deliberate stopover which is not caused by the traffic situation. Stationary vehicles within the meaning of this kind of accident are vehicles which stop or park at the edge of a carriageway, on shoulders, on marked parking places directly at the edge of a carriageway, on footpaths or parking sites. The traffic to or from parking spaces with a separate driveway belongs to No. 5 kind of accidents.
2) Collision with another vehicle moving ahead or waiting.
   - Accidents caused by a rear-end collision with a vehicle which either was still moving or stopping due to the traffic situation. Rear-end collisions with starting or stopping vehicles belong to the No. 1 kind of accidents.
3) Collision with another vehicle moving laterally in the same direction.
   - Accidents occuring when driving side by side (sideswipe) or when changing lanes (cutting in on someone).
4) Collision with another oncoming vehicle.
   - Collisions with oncoming traffic, none of the colliding partners having had the intention to turn and cross over the opposite lane.
5) Collision with another vehicle which turns into or crosses a road.
   - This kind of accident includes collisions with crossing vehicles and with vehicles which are about to enter or leave from/to other roads, paths or premises. A rear-end collision with vehicles waiting to turn belongs to the No. 2 kind of accidents.
6) Collision between vehicle and pedestrian
   - Persons who work on the carriageway or still are in close connection with a vehicle, such as road workers, police officers directing the traffic, or vehicle occupants who got out of a broken down car are not considered to be pedestrians. Collisions with these persons are recorded under the No. 10 kind of accidents.
7) Collision with an obstacle in the carriageway.
   - These obstacles include for instance fallen trees, stones, lost freight as well as unleashed animals or game. Collisions with leashed animals or riders belong to the No. 10 kind of accidents.
8) Leaving the carriageway to the right or left.
   - These kinds of accidents do not involve a collision with other road users. There may however be further parties involved in the accident, e.g. when the vehicle involved in the accident veered off the road trying to avoid another road user and did not hit him.
9) Accident of another kind.
   - This category covers all accidents which cannot be allocated to one of the kinds of accidents listed before.

*Figure **9*** shows that especially crossing situations are challenging/risky for elderly drivers. The share of the kind of accident „collision with another vehicle that turns into or is crossing a road" significantly increases with age and is the kind of accident being most relevant for elderly. Furthermore "collisions with pedestrians" also occur more often with elderly drivers but the absolute numbers are relatively low. For collisions with vehicles that are driving in the same or opposite direction elderly drivers are underrepresented. However, in absolute numbers collisions with vehicles that are moving ahead or are waiting is also relevant for elderly.

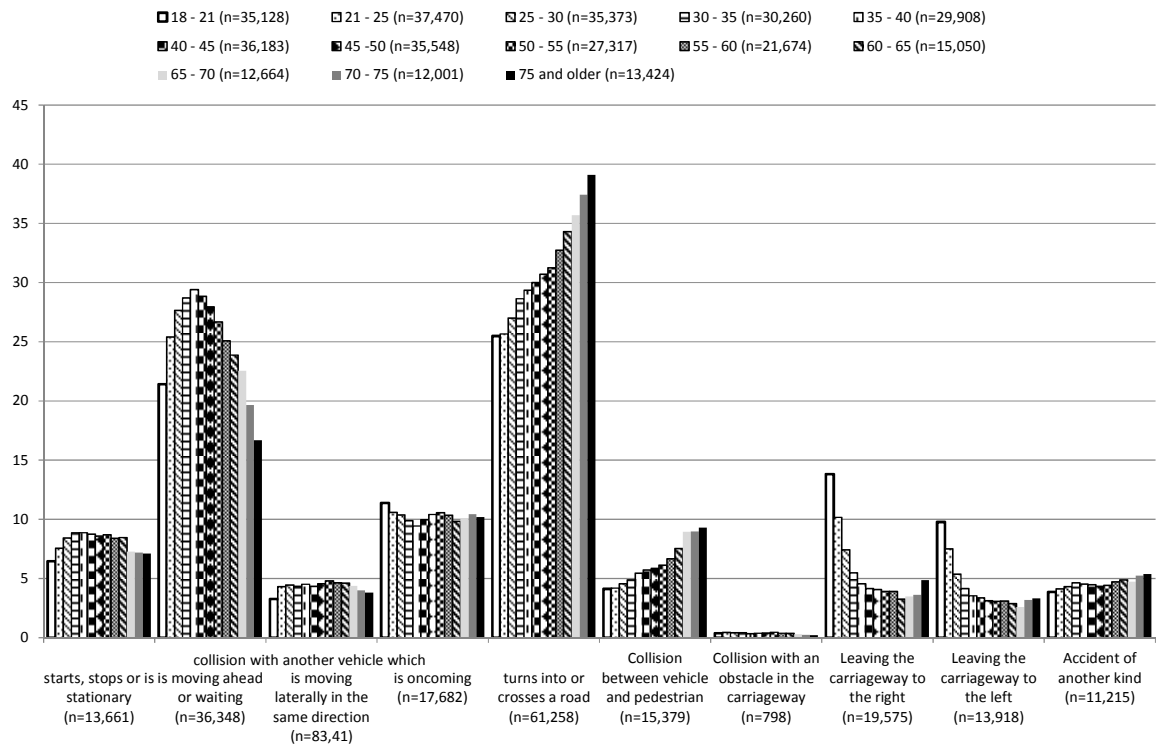

Figure 9. Kind of accident dependent on drivers age (multiple counting for car-to-car accidents).

The type of accident describes the conflict situation which resulted in the accident, i.e. a phase in the traffic situation where the further course of events could no longer be controlled because of improper action or some other cause. Unlike the kind of accident, the type of accident does not describe the actual collision but indicates how the conflict was touched off before this possible collision. The determination of the type of accident also plays an important role for local accident analysis since the type of accident is marked by coloured pins on the maps of the local police authorities. The following seven types of accidents are distinguished [DESTATIS, 2011a]:

1) Driving accident
   - The accident was caused by the driver's losing control of his vehicle (due to not adapted speed or misjudgement of the course or condition of the road, etc.), without other road users having contributed to this. As a result of uncontrolled vehicle movements, however, a collision with other road users may have happened. A driving accident however does not include accidents in which the driver lost control of his vehicle due to a conflict with another road user, an animal or an obstacle on the carriageway, or because of a sudden physical incapacity or a sudden defect of the vehicle. In the course of the driving accident, this vehicle may collide with other road users, so that this is not necessarily a single vehicle accident.
2) Accident caused by turning off the road
   - The accident was caused by a conflict between a vehicle turning off and another road user approaching from the same or opposite direction (incl. pedestrians) at crossings, junctions and entries to premises or car parks. Whoever follows the priority turn of a main road is not considered as turning off.
3) Accident caused by turning into a road or by crossing it
   - The accident was caused by a conflict between a road user turning into a road or crossing it and having to give way and a vehicle having the right of way at crossings, junctions, or exits from premises and car parks.
4) Accident caused by crossing the road
   - The accident was caused by a conflict between a vehicle and a pedestrian on the carriageway, unless the pedestrian walked along the carriage-way and unless the vehicle turned off the road. This applies also where the pedestrian was not hit by the vehicle. Even if the pedestrian who caused the accident was not hit, the accident is classified as caused by crossing the road. A collision with a pedestrian walking along the carriageway is recorded as a No. 6 type of accident.
5) Accident involving stationary vehicles
   - The accident was caused by a conflict between a moving vehicle and a

parked/stopping vehicle or a vehicle manoeuvred in connection with parking/ stopping. Accidents with vehicles waiting just because of the traffic situation are not included.

6) Accident between vehicles moving along in carriageway
   - The accident was caused by a conflict between road users moving in the same or opposite direction, unless this conflict belongs to a different type of accident.
7) Other accident
   - This includes all accidents that cannot be allocated to any other type of accident. Examples: U-turning, reversing, accidents between parked vehicles, obstacle or animal on the carriageway, sudden failure of the vehicle (brake failure, defective tyre, etc.).

When analysing the type of accident dependent on age the absolute and relative high number of "accident caused by turning into a road or by crossing it" is remarkable, see *Figure **10***. Accidents caused by turning off the road are also increasing with age but with much lower extend than the before mentioned type.

For the accident type "crossing accidents" there is a slight increase of the share of accidents with age, see *Figure **10***. However, the increase is smaller than it was expected based on the distribution of kind of accident "collision between vehicle and pedestrian". The other pedestrian accidents are likely included in the accident type "accident caused by turning off the road".

Driving accidents are mainly an issue for younger drivers as expected after the analysis of the kind of accident "leaving the road to the left or right".

Accidents with vehicles that are traveling in the same or opposite direction involve less elderly drivers than younger ones. This was also expected because of the distribution of the kinds of accident.

In summary the analysis of kind of accident and type of accident shows two important deficits for elderly drivers. These are

1) the correct perception of complex traffic situation (e.g., in crossings)
2) slower reaction time, as shown for example in the distribution of pedestrian accidents

In general these findings are supported by literature and also by the analysis of mistakes causing accidents.

According to Chaparro et al., [Chaparro, 2005], Staplin et al. [Staplin, 1998] and Weller et al. [Weller, 2008] elderly drivers often suffer from problems in situations that require divided attention. Being focused on one task is especially in complex situations an issue.

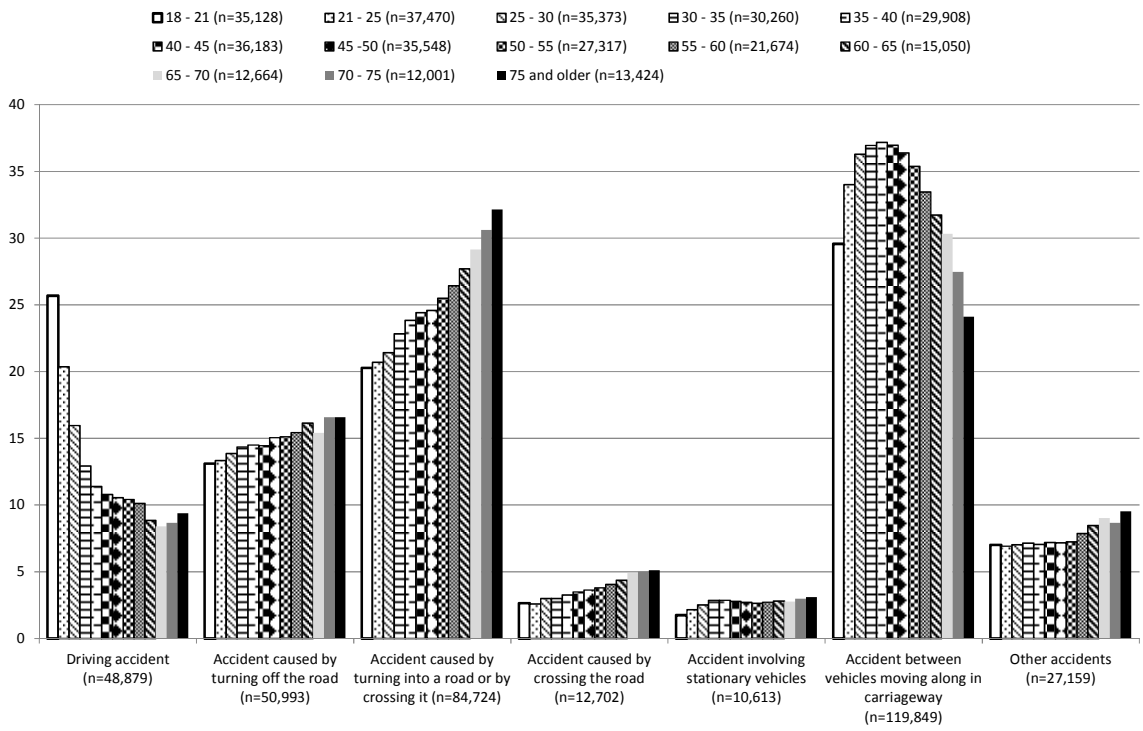

Figure 10. Type of accident dependent on drivers age (multiple counting for car-to-car accidents).

Reaction time between younger and elderly probands was analysed by Eder [Eder, 2005]. In average the reaction time of elderly was considerable longer in laboratory experiments and in driving trials.

However, it is important to note that the performance of elderly based on the literature mentioned above is very heterogenic. That means while the younger control group performed very equally for the elderly a large spread was observed. In general being old with respect to the mental capabilities to drive a car cannot be counted in years. It is more an issue of mental fitness than of actual age.

When looking into the cause of accidents for elderly drivers the main issues are right of way as well as turning, U-turns, reversing, pull-into the traffic, start-up (*Figure **11***). In addition fitness to drive without alcohol problems was detected more often for elderly than for others. However, this cause of accident is very seldom.

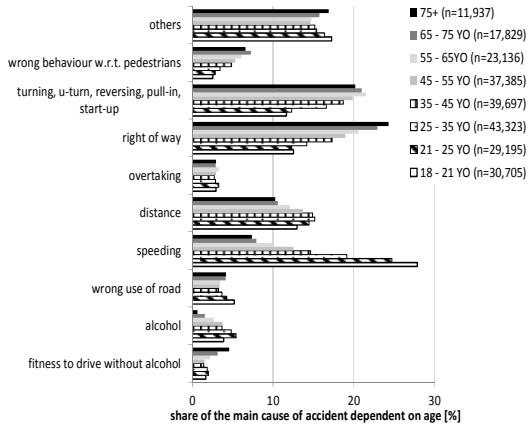

Figure 11. Accident causation dependent on age [DESTATIS, 2011b].

In order to achieve a more complete picture of the accident circumstances the time of accident and the location of accident are analysed in a last step. Elderly people seem to focus their time in traffic more than others to the time between 9:00 and 19:00 (*Figure **12***). Between 0:00 and 6:00 seniors are almost not present in accidents. The same is true for the time from 20:00 to 0:00. The main traffic activity time of elderly drivers appears to be the morning to early noon while for younger it is more the afternoon, evening and the night.

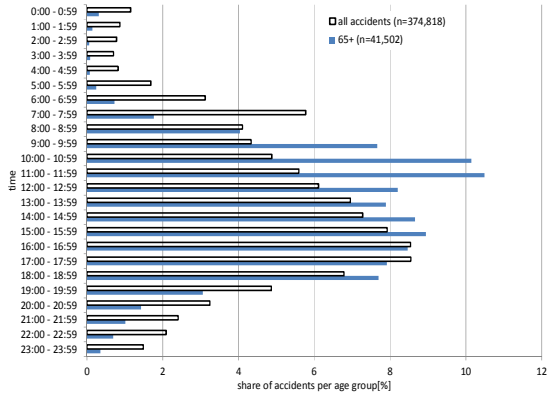

Figure 12. Time of accident in comparison between drivers with an age above 65 years and all drivers [data according to DESTATIS, 2011a and DESTATIS, 2011b].

When analysing the local distribution of accidents between elderly and younger drivers there is almost no difference for drivers with an age above 35 years, see *Figure **13***.

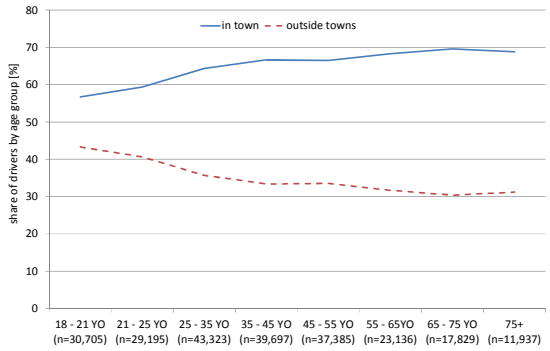

Figure 13. Location of accident in comparison between drivers with an age above 65 years and all drivers [data according to DESTATIS, 2011a and DESTATIS, 2011b].

In summary, most of the accidents involving elderly are happening inside towns in crossing situations and during daytime.

The two specific problems of elderly, complex situations and slower reaction time should be possible to be addressable by adopted driver assistance systems.

MEASURES TO ADDRESS THE NEEDS OF ELDERLY CAR OCCUPANTS

The main requirements for passive safety for European cars are defined by ECE R94 and ECE R95 as well as Euro NCAP. For frontal impact ECE R94 and Euro NCAP are currently looking into the safety performance of cars in accidents with relative high speed and moderate overlap in order to limit intrusions into the cabin. The injuries the elderly are mainly suffering from, chest

injuries, appear to be more a result of large overlap accidents with high acceleration loading. Furthermore the accident severity in the Euro NCAP test is quite high. The common idea of NCAP tests that a high accident severity would protect occupants in severe and less severe accidents equally is questionable. Especially elderly occupants seem to suffer from safety systems that are designed for good protection in high speed accidents.

Historically the car safety systems improved continuously. From static two-point belt in the beginning of car safety activities restraint systems with multiple stage airbags as well as belt systems with pretensioner and adaptable load limiter are available. However, todays smart restraint systems do not consider the vulnerability of the occupant, they just take into account a prediction of accident severity and the occupant's stature and weight. One could question why it is important to consider the vulnerability of the occupant as any measure in favor of vulnerable occupants would also improve the situation for less sensitive occupants. But there is a possibility to adjust safety margins for the risk to underestimate the accident severity based on vulnerability. That means for an optimum protection of elderly it might be acceptable to minimize the safety margin in order to keep the loads within the estimated accident severity as small as possible while increasing the safety margin for younger occupants because they are able to sustain larger loads, as shown above. A possibility to detect the vulnerability of the occupant by the scanning of the bone structure was presented by Hardy et al. [Hardy, 2005].

Furthermore it seems to be important to adjust the test severity and the dummy limits to the accident situation of elderly and the vulnerability of elderly. The limits of today seem to be more appropriate for younger occupants which was historically correct, as most of the car occupants were of this group. With the changing mobility pattern of elderly adjustments are necessary. However, the requirements for the passenger compartment integrity may not be compromised in while addressing the needs of elderly. ECE R94 and Euro NCAP had a very good influence on passive safety. That means that an additional test would be required, i.e. a full frontal test.

In addition to passive safety measures the adoption of driver assistance systems to the individual driver's needs is important. Driver assistance system can only exploit their maximum active safety performance if they are supporting the driver at an appropriate time. When warning or intervening to early they are becoming annoying for the driver and when acting too late the safety benefit is marginal. As individuals have different needs it is important to assess the individual needs of the driver in order to adopt the system. Especially the braking assistant system and a crossing assistant system are systems that are believed to have high benefit for elderly when they are adjusted.

Current Situation and Discussion Concerning Car Homologation

ESP and braking assistant system are already included in the legal framework. From 2014 all newly registered vehicles need to be equipped with ESP and from 2015 with braking assistant system, respectively.

The Informal Group on Frontal Impact of GRSP is working since 2008 on the development of a new frontal impact regulation. In the 2011 terms of reference of this group is asked to address amongst others an improved protection of elderly [GRSP, 2012]. This shall be achieved by the introduction of a full width restraint system test. However, it seems that the test speed will be fixed to 50 km/h. From the accident data mentioned above and the discussion concerning adjustable safety margins for different age groups a lower test severity might be appropriate.

VEHICLE SELECTION OF ELDERLY AND THEIR REQUIREMENTS

Even if the group of elderly drivers increases, and thus a customer group with certain needs, there is no car manufacturer who advertises directly with age-appropriate vehicles. Simply because of image reasons those "elderly peoples' cars" could not be sold well. Nevertheless, it is reality that most manufacturers offer vehicles, which are bought particularly by elderly and which obviously provide certain qualities that are important for them.

When looking into the statistics of the vehicle fleet in Germany and the age of the holder a clear preference of certain vehicle models becomes visible. For vehicle owners who are 60 years or older, on the one hand, the classic volume models from German manufacturers like VW Golf, Mercedes C-Class, Opel Astra and Audi A4 are strongly represented, on the other hand the small car segment (minis and super minis) with the Renault Clio, Opel Corsa and VW Polo plays an important role. A third category includes vehicles with a high seating position and a corresponding high entry. These cars are also very frequently represented (VW Golf Plus, Opel Meriva, Mercedes Class A) (Figure 14).

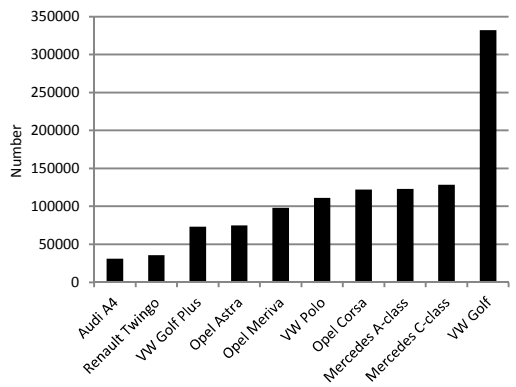

Figure 14. Most popular cars for holders with an age of 60+ [KBA, 2012].

Obviously, some vehicle models are very popular for customers who are 60 years or older. In Figure 15, vehicles are shown, where at least two-thirds of the holders are seniors. There are models included, which are practically because of their construction and size, but which find possibly less attention for younger customers because of their design. Furthermore, models are represented, who belong to the higher price segment (Mercedes C and E Class). Also well represented are vehicle models with a high seating position (Renault Modus, Renault Scenic, Mercedes B Class, Golf Plus, Citroen Xsara Picasso, Renault Megane Scenic).

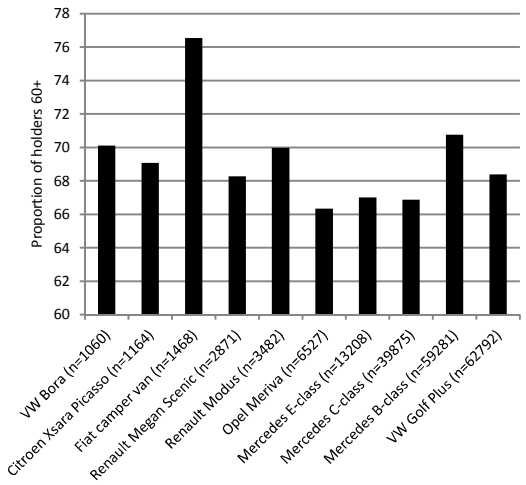

Figure 15. Vehicle models with at least 66% car holders 60+ [KBA, 2012].

With the elevated seating position generally a larger doorway and also a large angle of door opening is associated. These aspects allow a more convenient entry and exit also with limited mobility. Simultaneously the visibility out of the vehicle is improved.

The requirements for a senior-friendly car go far beyond a proper seating position. In addition to a good circumferential visibility, which should also be available with limited freedom of movement, all interfaces between driver and car should be designed in a way that they are easy to use and that they do not distract attention from the road. This means for all drivers, but especially for older drivers that operating devices should be designed large and to be easy available. Instrument readings and displays must be easy to read; the menu from the on-board computer should be intuitive and comprehensible [DVR, 2009]. Especially for driver assistant systems it is important that the messages a clear and the letters are large enough and with good contrast [Bunji, 2006]. If this is not the case the risk coming from distraction might be higher than the benefit. Furthermore an easy accessibility of the trunk and a bright headlight were mentioned as useful car equipment by elderly people.

In general, equipment, that is popular with seniors, is usually not disadvantageous for younger drivers. For example, the elevated seating position is well accepted by women and ergonomic arrangement of the controls is also welcome for younger drivers.

CONCLUSIONS

Elderly car occupants are at lower risk to be involved in accidents but when they are involved they have a considerably higher risk to be severely injured or killed than younger car occupants. The main difference in the vulnerability is coming from the chest fragility. Restraint systems that are better adjusted to the chest injury risk of elderly are expected to reduce the injury risk.

Elderly drivers are mainly involved in accidents that are occurring in complex situations (e.g., crossings). Driver assistant systems (especially a crossing assistant) would help to address the assistant needs of elderly drivers if their alarming and intervening levels can be adjusted to the individual driver.

There are three car categories that are especially of interest for elderly car owners in Germany. These are cars with a high seating position like MPVs, Vans and SUVs, small cars and high volume models. In addition the share of elderly owners for high price models is often also relatively high.

ACKNOWLEDGEMENTS

This paper is mainly based on the chapter “Anpassung des Straßenverkehrs an die Anforderungen älterer Menschen: Vertiefende Unfallanalysen und Fahrzeuggestaltung“ in the book „Mobilität und Demografische Entwicklung“ [Johannsen, 2013].

REFERENCES

Bunji, A.; Hitoshi, K.; Masako, O.; Masaru, M.: „Visual Cognitive Performance of Elderly People - Effects on reading time of age, character size an virtual distance-"; F2006D169; FISITA 2006; World Automotive Congress, 22-27. October 2006, Yokohama, Japan

Carroll, J.A.; Cuerden, R.; Richards, D.; Smith, S.; Cookson, R.; Hynd D.: "Cover Deliverable D5.4a – Matrix of serious thorax injuries by occupant characteristics, impact conditions and restraint type and identification of the important injury mechanisms to be considered in Thorax and THOMO", 2009

Chaparro A, Wood JM, & Carberry T. (2005) Effects of Age and Auditory and Visual Dual Tasks on Closed-Road Driving Performance. Optometry and Vision Science 82(8): 747–754.

DESTATIS (Statistisches Bundesamt): „Fachserie 8 Reihe 7 Verkehrsunfälle 2010", Juli 2011a (in German)

DESTATIS (Statistisches Bundesamt): „Verkehrsunfälle – Unfälle von Senioren im Straßenverkehr", 2011b (in German)

DESTATIS (Statistisches Bundesamt): „Fachserie 8 Reihe 7 Verkehrsunfälle 2011", Juli 2012 (in German)

DVR (Deutscher Verkehrssicherheitsrat) „Kriterien für ein Seniorengerechtes Auto", Auswertung einer Befragung von DVR-Moderatoren, DVR-Informationen zu den Seniorenprogrammennr. 7/2009; Deutscher Verkehrssicherheitsrat e.V.; Bonn, 2009 (in German)

Eder, K.: "Experimentelle Untersuchung des Reaktionsverhaltens älterer Pkw-Lenker", Diploma Thesis Department Automotive Engineering TU Berlin, 2005 (in German)

GRSP: „Report of the Working Party on Passive Safety on its fiftieth session", UNECE, World Forum for Harmonization of Vehicle Regulations Geneva 6–9 December 2011, February 2012

Hardy, R.N.; Watson, J.W.; Cook, R.; Zioupos, P.; Forrester, B.; Frampton, R.; Page, M.; Kennedy, A.; Peach, S.; Sproston, P.; "Development and Assessment of a Bone Scanning Device to Enhance Restraint Performance", Proceedings to ESV Conference, 2005

Hautzinger, H.; Pfeifer, M.; Schmidt, J.: „Hochrechnung von Daten aus Erhebungen am Unfallort", BASt-Bericht F 59, Wirtschaftsverlag NW Verlag für neue Wissenschaft GmbH, Heilbronn/Mannheim, 2006 (in German)

Johannsen, H.; Müller, G.: „Anpassung des Straßenverkehrs an die Anforderungen älterer Menschen: Vertiefende Unfallanalysen und Fahrzeuggestaltung" in „Mobilität und Demografische Entwicklung" (Beckmann, Schlag Editors), Schriftenreihe Mobilität im Alter der Eugen-Otto-Butz-Stiftung, TÜV Media, Köln 2013 (in German)

KBA (Kraftfahrtbundesamt): „Fahrzeugzulassungen (FZ)"; Bestand an Kraftfahrzeugen und Kraftfahrzeuganhängern nach Herstellern und Handelsnamen; 1. Januar 2012; FZ 2; Kraftfahrt-Bundesamt (in German)

Kent R; Sherwood, C; Lessley, D; Overby, B; Matsuoka, F.: "Age-related Changes in the Effective Stiffness of the Human Thorax Using Four Loading Conditions" Proceedings to IRCOBI Conference on the Biomechanics of Impact, 2003

Otte, D.; Wiese, B.: "Injury Rates for Elderly versus Young Drivers as Car Occupants wearing Seatbelts in Road Traffic Accidents", SAE Paper 12B-0129, 2012

Richards, D.; Edwards, M.; Cookson, R.: "Technical assistance and economic analysis in the field of legislation pertinent to the issue of automotive safety: provision of information and services on the subject of accident analysis for the development of legislation on frontal impact protection – final report", 2010

Ridella, S.A.; Rupp, J.D.; Poland, K.: "Age Related Differences in AIS 3+ Crash Injury Risk, Types, Causation and Mechanisms" Proceedings to IRCOBI Conference on the Biomechanics of Impact, Dublin, 2012

Staplin, L.; Ball, K.; Park, D.; Decina, L.E.; Lococo, K.H.; Gish, K.W.; Kotwal, B.: "Synthesis of Human Factors Research on Older Drivers and Highway Safety. Vol. I: Older Driver Research Synthesis." FHWA-RD-97-094 1998

Thompson, A.; Edwards, M.; Wisch M.; Adolph, T.; Krusper, A.; Thomson, R.: "FIMCAR Deliverable D1.1 - Report detailing the analysis of national accident databases", 2011

Weller, G.; Geertsema K.: „Werden ältere Fahrer durch die Fahraufgabe stärker beansprucht als jüngere?" Schlag, B. ed. Leistungsfähigkeit und Mobilität im Alter. Pp 85-111, Köln: TÜV Media GmbH (Schriftenreihe „Mobilität und Alter" der Eugen-Otto-Butz Stiftung, 3), 2008 (in German)