A DETAILED ANALYSIS OF THE CHARACTERISTICS OF EUROPEAN REAR IMPACTS

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ABSTRACT

A detailed analysis of rear impacts was carried out using data from the German In-Depth Accident Study ("GIDAS") including accidents from 1996 to 2004. The frequency of rear impacts compared to other modes was investigated, followed by an in-depth review of single rear impacts and rear impacts in multiple impact crash sequences. Crash characteristics such as the distributions of crash severity, overlap and masses of striking and struck cars were examined. The effect of crash severity on injury severity was investigated for cases including soft tissue neck injuries and / or other injuries. The types of injuries sustained and the effects of occupant gender, age and height, seating position and restraint use were analysed.

This analysis has provided a valuable summary of the characteristics of rear impacts in Europe. In general, it was found that rear impacts did not result in high levels of severe (AIS3+) injuries but many occupants were reported as suffering AIS1 level soft tissue neck injuries, often in the absence of other injuries. Many of these injuries occurred at low crash severities and with high levels of overlap. Where they did occur, most of the more severe (AIS3+) injuries were to the head and thorax and included concussion and rib cage fractures. Moderately severe injuries to the upper and lower extremities also occurred, albeit with low frequency. This analysis has provided a useful new perspective on rear impacts and a better understanding of their characteristics.

BACKGROUND

In recent years, much attention has been given to the protection of car occupants in front, side and rollover crashes. Rear impact is regarded by many people as the next area for attention. However, apart from the large amount of analysis (e.g. [1][2][3][4]) carried out on soft tissue neck injuries ("whiplash"), very little published analysis of characteristics of rear impact has been published. This may due to the overall low accident severity of rear impact accidents.

This paper presents a detailed analysis of rear impacts carried out using data from the German In-Depth Accident Study ("GIDAS") including accidents from 1996 to 2004.

FREQUENCY OF REAR IMPACTS IN EUROPEAN TRAFFIC ACCIDENTS

To identify the characteristics of rear impacts in real world accidents, the impact configuration of each individual passenger car involved in a traffic accident is important. Three quarters of all passenger cars involved in accidents have only one impact, one quarter of the passenger cars have two or more impacts so called multiple impacts. The most frequently occurring impact type is the single frontal impact with 44 %. Single side impacts have a share of 20 % and only 10 % of the cars have a single rear impact. Multiple impacts can be further divided into multiple impacts without rear impact and multiple impacts with at least one rear impact. The latter have a share of 9 %, 16 % of the cars have multiple impacts but no rear impact (Figure 1). Finally 19 % of all passenger cars involved in an accident have at least one rear impact, regardless if single or multiple.

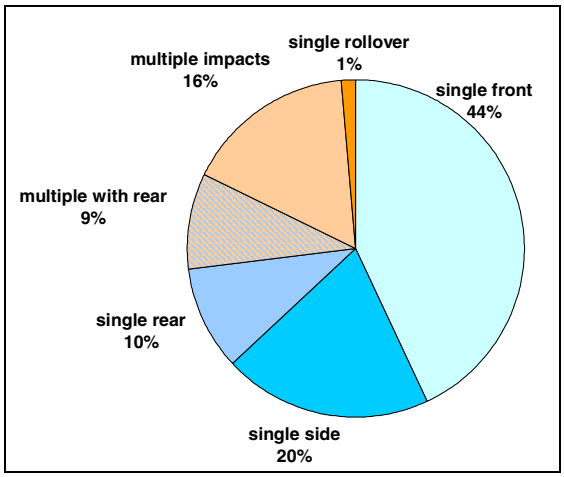

Figure 1. Distribution of impact types in passenger car accidents (n=12,968).

The overall injury level of rear impacts (as characterised by MAIS) is compared with other

impact modes in Figure 2. This analysis only covers occupants with MAIS2 to MAIS6 injuries.

Single rear impacts have the lowest proportion of MAIS3+ injuries. Only 11 % of the occupants with MAIS2+ injuries received MAIS3+ injuries compared with 32 % in single frontal impacts and 40 % in single side impacts. In multiple impacts the presence of the rear impact has no significant influence on injury severity. The share of occupants with MAIS3+ injuries (34 %) is as high as for occupants in cars involved in multiple impacts with no rear impact.

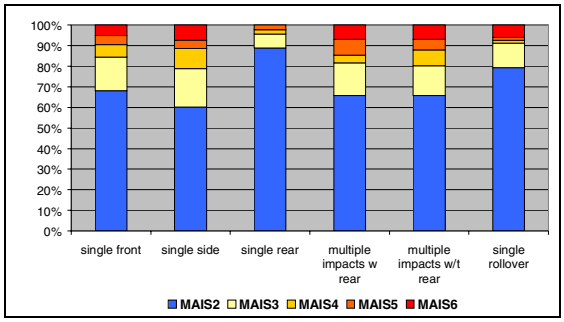

Figure 2. Injury severity (occupants with MAIS2+) of different accident types (n=1,917).

IN-DEPTH ANALYSIS OF SINGLE REAR IMPACTS

Impact configuration and impact severity

A deeper look into the individual data shows that more than 70 % of the passenger cars involved in a single rear impact have an impact to another passenger car (Figure 3). For 11.5 % of the passenger cars the collision partner is a commercial vehicle and 18.4 % collided with 2 wheelers, pedestrians or objects on or near the street.

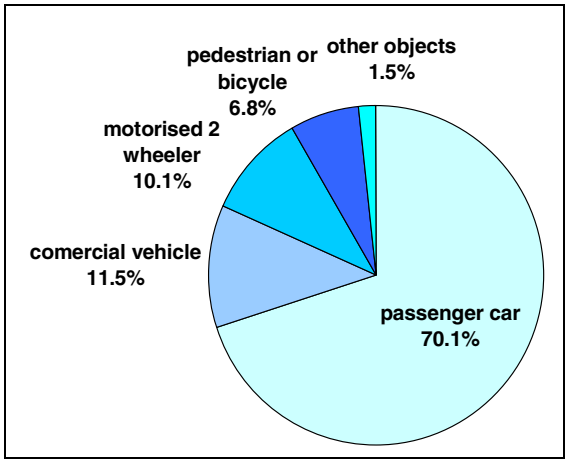

Figure 3. Collision partnerss of passenger cars in single rear impacts (n=1274).

In general, the impact severity in single rear impacts is relatively low. One indicator of the impact severity is velocity change (delta v). In single rear impacts 90 % of the cars received a delta v lower than 22 km/h, 50 % received a delta v lower than 10 km/h (Figure 4). In car-to-car collisions the share of delta v between 0 and 10 km/h is slightly lower.

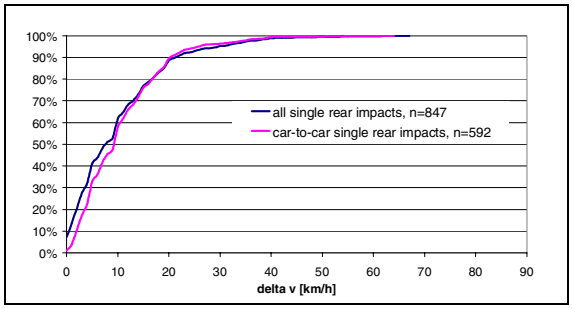

Figure 4. Delta v of the struck cars in single rear impacts.

70 % of the car-to-car single rear impacts occur in urban areas so that 90 % of the striking cars in single rear impacts have an impact speed lower than 55 km/h (Figure 5).

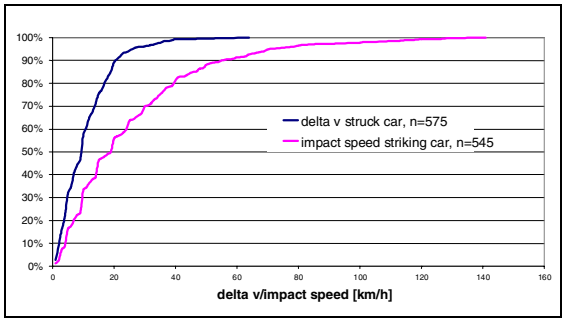

Figure 5. Delta v of the struck car and impact speed of the striking car in single rear, car-to-car impacts.

90 % of the cars have a kerb weight of 1500 kg or less (Figure 6). The average kerb weight for the struck cars (with rear impact) is 1143 kg, the striking cars are slightly lighter than the struck cars with 1096 kg on an average.

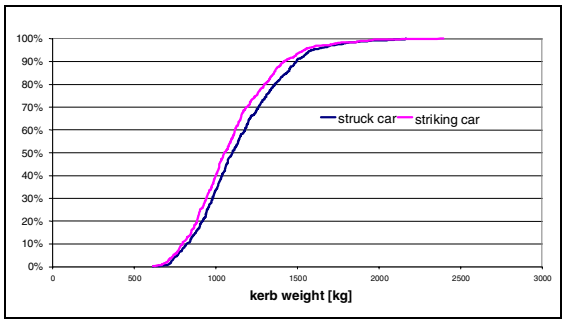

Figure 6. Kerb weight of the struck and the striking car in single rear, car-to-car impacts.

Typically most of the car-to-car impacts in single rear impacts occur between cars in the same lane. Well over half of the cars had an overlap >80 %, irrespective of whether they were the struck or striking car (Figure 7).

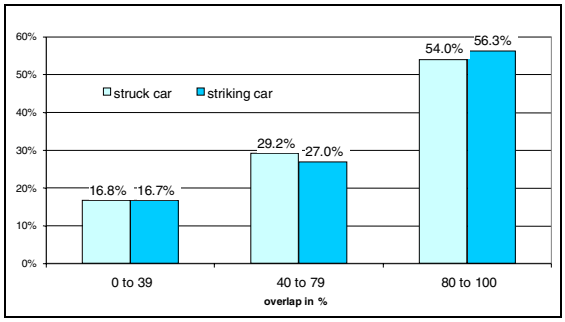

Figure 7. Overlap of the struck car and of the striking car in single rear, car-to-car impacts.

Injury severity of the front seat occupants in single rear impacts

To have an adequate number of occupants with comparable seat environment, the analysis of injury severity and description focuses on the front seat occupants. Due to the fact that the impact severity in single rear impacts is relatively low compared to the other impacts, almost 59 % of the front seat occupants in cars involved in a single rear impact were uninjured. 39.3 % of the front seat occupants had MAIS1 injuries and only 1,6 %/ 0.2 % of the front seat occupants received MAIS2/MAIS3+ injuries (Figure 8).

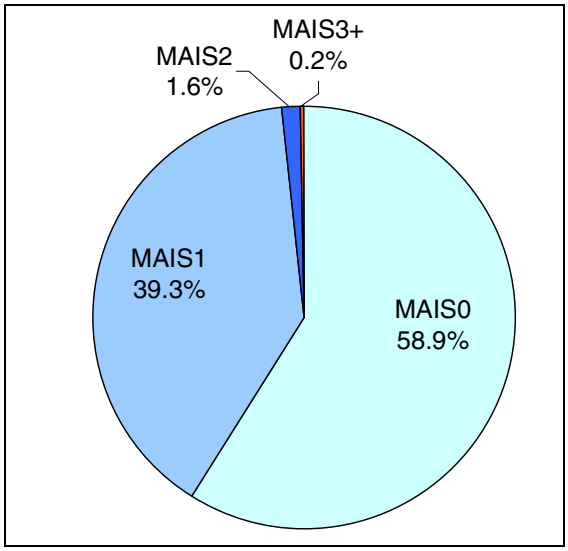

Figure 8. MAIS distribution of front seat occupants in single rear impacts (n=1724).

Because soft tissue neck injury plays an important role in rear impacts, the injured front seat occupants have been differentiated into 3 groups (Figure 9): occupants with soft tissue neck injury as their unique injury (only STNI); occupants with soft tissue neck injury and other injuries (STNI+), and occupants with no soft tissue neck injury but with other injuries (no STNI). Seventy-eight percent of the injured front seat occupants received a soft tissue neck injury, (65 % as unique injury), 13 % received a STNI and additional other injuries (STNI+), and only 22 % received no STNI but other injuries.

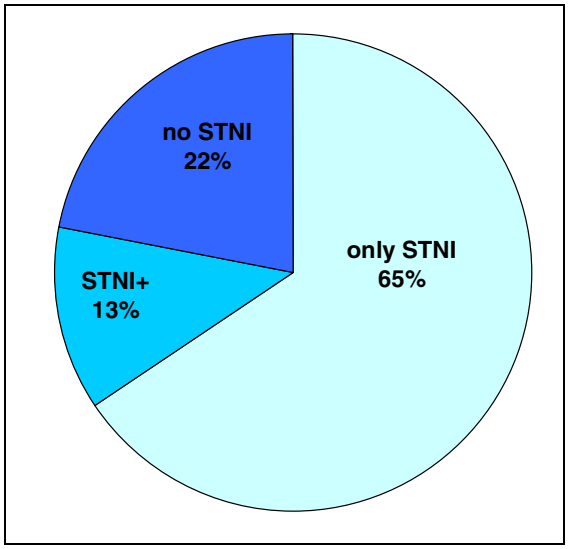

Figure 9. STNI distribution of injured front seat occupants in single rear, car-to-car impacts (n=718).

These three groups also differ regarding the impact severity of the rear impact. The group of front seat occupants who only received an STNI as a unique injury is the group with the lowest delta v level (Figure 10). For the group of occupants with no STNI but with other injuries, it can be stated that these occupants experienced the highest delta v level in this comparison.

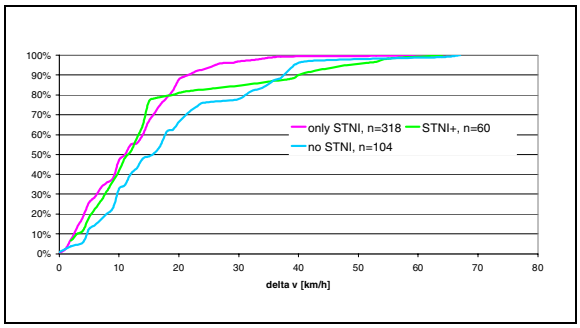

Figure 10. Delta v in single rear impacts and STNI specification of the front seat occupants.

Effects of occupant parameters on STNI

Seat belt use

The overall belt-wearing rate for front seat occupants in Germany has maintained a steady high level (between 90 % and 96 %) for many

years [5]. This explains the very low share of unbelted front seat occupants (1.3 % of the sample). However, for unbelted front seat occupants the risk of receiving a soft tissue neck injury is lower than for belted front seat occupants (Figure 11).

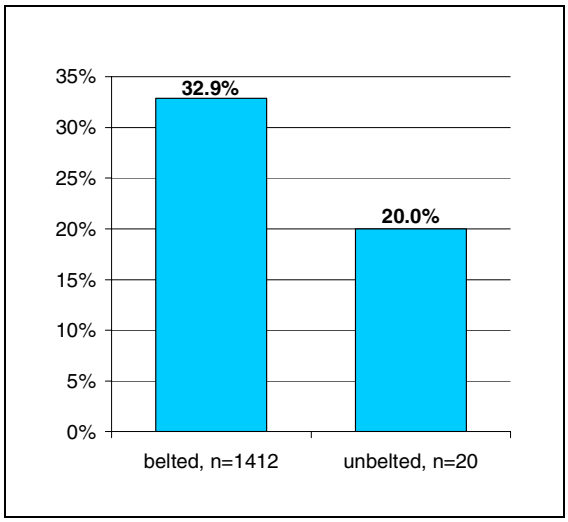

Figure 11. STNI risk of front seat occupants in single rear impacts by belt use.

Age

In the most frequent age groups between 18 and 45 years (66 % of the sample) the risk of receiving a soft tissue neck injury is at its highest level, between 35 % and 37 %, with no significant change with increasing age. For occupants older than 45 years the risk of receiving a soft tissue neck injury decreases with increasing age. This is particularly noticeable for occupants older than 65 years, who have a STNI risk of 16 % well below the average of 34 % (Figure 12).

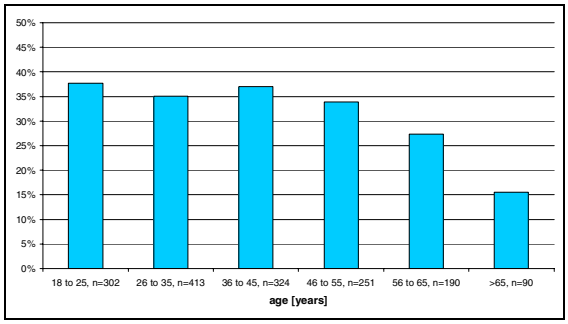

Figure 12. STNI risk of front seat occupants in single rear impacts by age.

Gender and seating position

Overall, female front seat occupants are at higher risk of receiving an STNI. It seems that the STNI risk for front seat passengers tends to be slightly higher than for the driver (Figure 13), regardless of the gender.

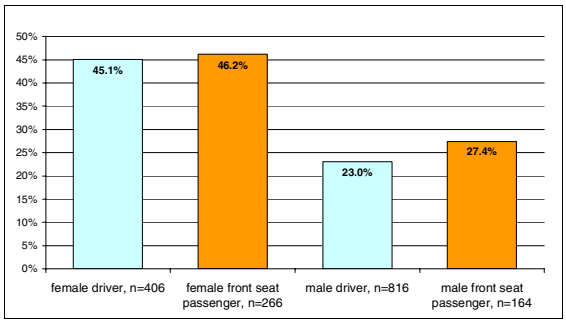

Figure 13. STNI risk of front seat occupants in single rear impacts by gender and seating position.

Body height

Regarding body height, no significant influence for male front seat occupants is detectable but for female front seat occupants the STNI risk seems to increase with body height (Figure 14). The taller the women are, the higher is their risk of receiving a soft tissue neck injury.

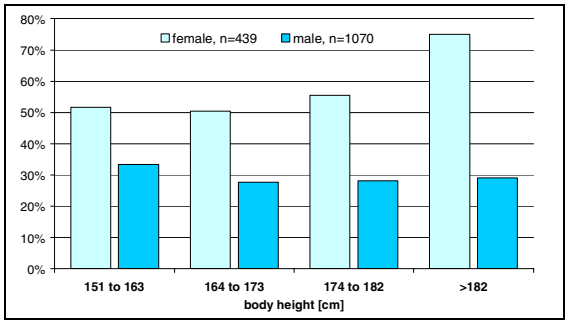

Figure 14. STNI risk of front seat occupants in single rear impacts by gender and body height.

Other injuries than STNI, severity and description

Soft tissue neck injuries are the most frequent injury type in single rear impacts. Other injuries especially those with higher severity (MAIS3+) occur rarely. The group of occupants with STNI and other injuries (STNI+) generally only have injuries of minor or moderate severity (AIS1 or AIS2). Head, thorax and upper and lower extremities are the most frequently affected body regions (Figure 14).

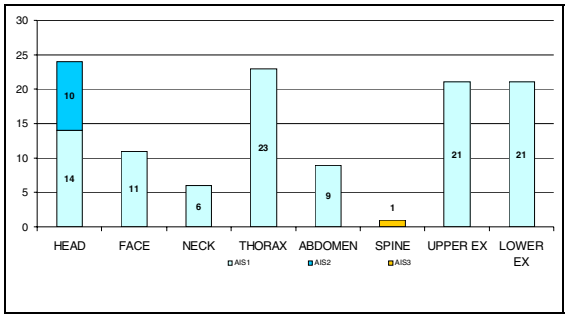

Figure 14. Injured body regions in single rear impacts, belted and unbelted occupants with STNI and other injuries (n=91 occupants).

The majority of the AIS1 injuries are skin contusions and abrasions (105 individual injuries). Concussions are the most frequent AIS2 injuries, other injuries are listed in table 1.

	AIS2/3	AIS1 (without skin contusions and abrasions)
Head/Neck/Face	• 10 concussions (AIS2) • 1 major laceration	• 2 minor lacerations • 1 broken tooth • 1 vagus nerve injury • 1 nasal bone fracture • 1 laceration of the ear
Thorax	-	• 1 rib contusion • 2 sternum contusions • 1 single rib fracture
Spine	• 1 spinal cord contusion (AIS3)	-
Upper Extremities	-	• 1 acromioclavicular joint contusion • 1 shoulder contusion

Table 1. Description of the injuries for belted and unbelted front seat occupants with STNI and other injuries (n=91).

Occupants with no STNI more frequently receive MAIS3+ injuries, possibly due to the fact that this group of occupants receive relatively higher velocity changes. The most frequently affected body parts are again head and thorax but, in addition, spine injuries have a higher frequency (Figure 15)

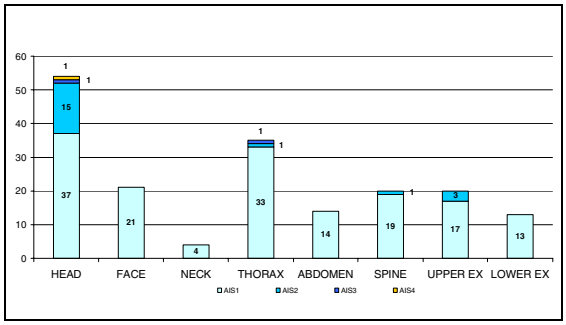

Figure 15. Injured body regions in single rear impacts, belted and unbelted front seat occupants with no STNI but with other injuries (n=157).

Apart from skin contusions and abrasions, minor lacerations and skeletal contusions are the most frequent type of injury. The main type of AIS2 injury is again concussion, but fractures of the upper extremities and spine also occur (Table 2). The three AIS3+ injuries are a contusion of the small cerebrum, a subarachnoidal bleeding and a multiple rib fracture.

	AIS3+	AIS2	AIS1 (without skin contusions and abrasions)
Head/Neck/Face	• 1 subarachnoidal bleeding (AIS4) • 1 small cerebrum contusion (AIS3)	• 14 concussions • 1 major scalp laceration	• 15 minor lacerations • 1 vagus nerve injury • 1 nasal bone fracture • 1 mandible joint injury NFS
Thorax	• 1 multiple fracture 4th to 8th rib (AIS3)	• 1 sternum fracture	• 7 rib contusions • 1 single rib fracture
Abdomen	-	-	• 2 uterus injuries NFS
Spine	-	• 1 minor compression fracture at thoracic vertebra	• 9 contusions • 3 strain injuries
Upper Extremities	-	• 2 clavicula fractures • 1 dislocation of acromioclavicular joint	• 1 tendon laceration
Lower Extremities	-	-	• 1 laceration • 1 knee contusion

Table 2. Description of the injuries for belted and unbelted occupants without STNI but with other injuries (n=157).

IN-DEPTH ANALYSIS OF REAR IMPACTS IN MULTIPLE IMPACTS

Impact configuration

In the total accident population, multiple impacts play an important role [6]. In the database used, we have similar numbers of passenger cars with single rear impacts (n=1274) and passenger cars with multiple impacts with at least one rear impact (n=1119). To consider the nature of the multiple impacts, the number of impacts in total is relevant. Approximately three quarters of the passenger cars with multiple impacts had only 2 impacts, 18 % had 3 impacts and only 10 % had more than 3 impacts (Figure 16).

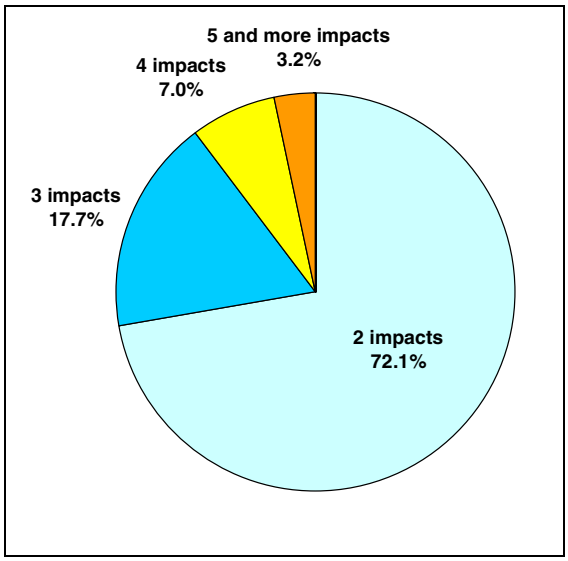

Figure 16. Number of impacts for cars with multiple impacts with at least one rear impact (n=1119).

The position of the rear impact in the multiple impact sequence is another important factor in characterising the impact situation. For more than half of the cars, the rear impact is the first impact. In 30 % of the cases the rear impact is the second impact and in 16 % the rear impacts follows two or more other impacts (Figure 17).

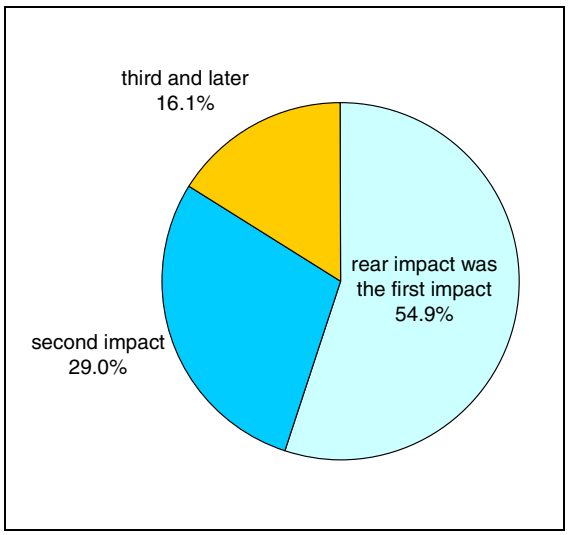

Figure 17. Sequence of the rear impact for cars with multiple impacts with at least one rear impact (n=1119).

The importance of the sequence is apparent in the delta v distributions for these impacts. When the rear impact is the first impact, the level of delta v is significantly higher than in single rear impacts. When the rear impact is not the first impact, the share of low speed impacts (up to 15 km/h) follows the curve for single impacts, but a higher proportion at the impacts occurred at higher delta v levels (Figure 18).

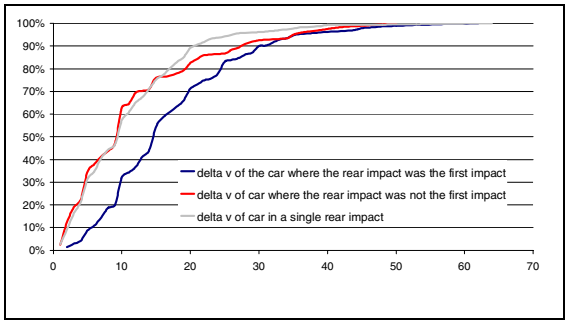

Figure 18. Delta v of the rear impact in multiple impacts with at least one rear impact

Considering only car-to-car rear impacts with multiple impacts where the rear impact occurred first, the cumulative delta v curves of the struck car and the cumulative impact speed of the striking car of cars are parallel to the cumulative values for single rear impacts, but on a much higher delta v (Figure 19). Multiple impacts with rear impact first occur with a share (52 %) on rural roads.

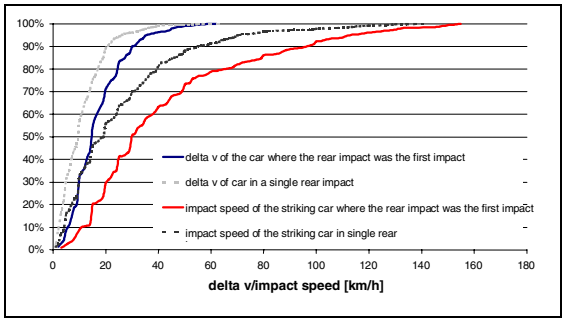

Figure 19. Delta v of the struck car and impact speed of the striking car in car-to-car rear impacts.

In terms of impact severity there is a significant difference between single rear impacts and rear impacts in multiple impacts with rear impact first. However there is only slight difference in the overlap distribution. More than the half of the cars, regardless if they are the struck car or striking car, had an overlap of more than 80 % (Figure 20).

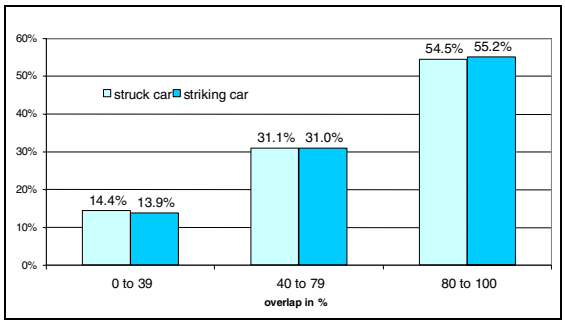

Figure 20. Overlap of the struck car and of the striking car in multiple impacts with at least one rear (rear was first impact).

Injury severity and injury description

The impact characteristics have also an effect on the injury severity. If the rear impact is the first impact, the injury severity of the front seat occupants is, on average, lower than for occupants in multiple impacts where the rear impact is the second or later impact (Figure 21).

Almost 42 % of the front seat occupants are uninjured if the rear is the first impact, but only 31.3 % are uninjured if the rear impact is not first. More significant is the difference in the share of occupants with MAIS2+ injury severity. Only 6 %/1.6 % of the occupants had MAIS2/MAIS3+ injuries if the rear impact is first, otherwise 11.4 %/7.2 % of the occupants have MAIS2/MAIS3+ injuries. The percentage of

occupants with MAIS2+ is more than doubled if the rear impact is not the first impact.

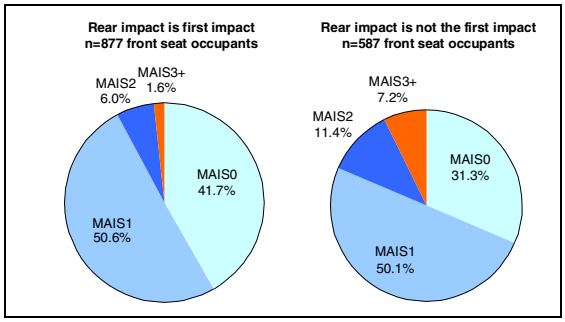

Figure 21. MAIS distribution of front seat occupants in multiple impacts with at least one rear.

Although there is no significant difference between the shares of occupants with MAIS1 in both groups, the shares of occupants with soft tissue neck injury are distributed differently.

When the rear impact is the first impact, two thirds of the injured front seat occupants received a soft tissue neck injury, 46.5 % as a unique injury. When the rear impact is not the first impact, only one third received this type of injury, 10.4 % as a unique injury. The other two thirds of the injured front seat occupants received no soft tissue neck injury but had other injuries (Figure 22).

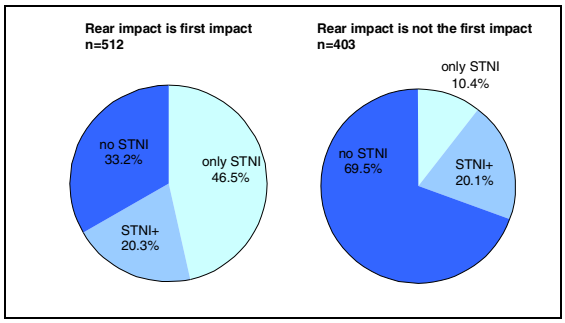

Figure 22. STNI distribution of injured front seat occupants in multiple impacts with at least one rear impact.

Effects of occupant parameters on STNI

Front seat occupants in cars with multiple impacts with at least one rear impact have only a slightly lower soft tissue neck injury risk (32 %) than occupants in cars with single rear impacts (34 %). As in the single rear impacts, the occupant parameters have a very similar influence on the STNI risk.

Seat belt use

The percentage of unbelted front seat occupants in multiple impacts with at least one rear impact is with 3 % higher than in single front impacts (1.4 %). However for unbelted front seat occupants the risk of receiving a soft tissue neck injury is lower than for belted front seat occupants (Figure 23).

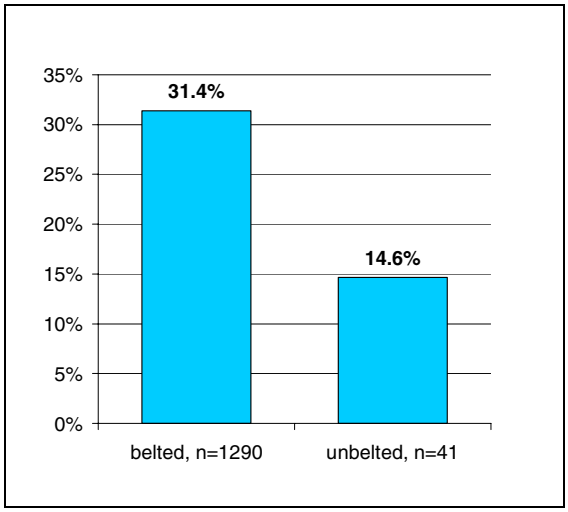

Figure 23. Belt use and STNI risk for front seat occupants in multiple impacts with at least one rear impact.

Age

The effect of age on STNI risk is not as significant as for occupants in single rear impacts. The STNI risk varies from 37 % to 21 % (Figure 24) compared with 38 % to 16 % in single rear impacts.

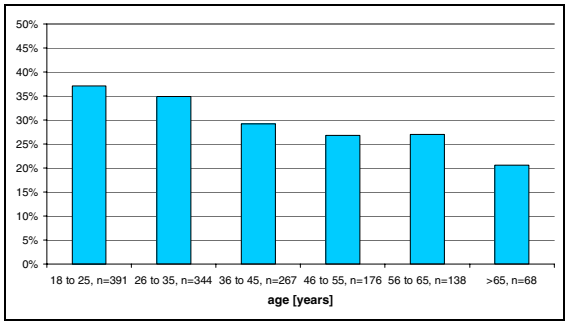

Figure 24. STNI risk of front seat occupants in multiple impacts with at least one rear impact by age.

Gender and seating position

In single rear impacts, the risk of receiving a soft tissue neck injury for female front seat occupants is significantly higher than for males. However there is no suggestion that front seat passengers seem to have a higher STNI risk than drivers in multiple impacts with at least one rear impact. The risk for female front seat occupants was significantly lower than for female drivers, but there is only a very slight difference for males (Figure 25).

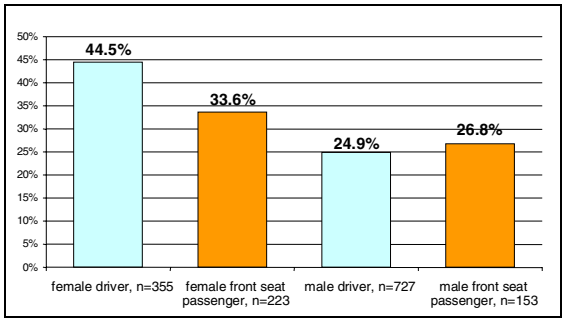

Figure 25. STNI risk of front seat occupants in multiple impacts with at least one rear impact by seating position and gender.

Body height

The results for multiple impacts with at least one rear impact show the same general trends for STNI risk by body height and gender as single rear impacts. The difference between male and female occupants is however not as high as for the occupants in single rear impacts (Figure 26).

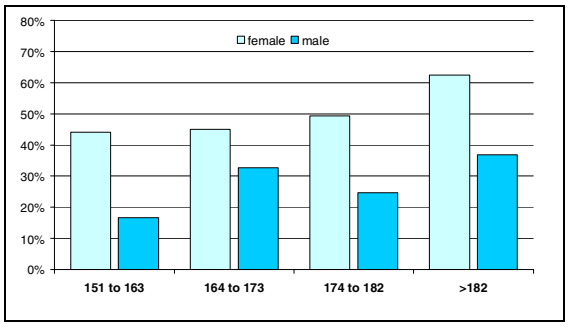

Figure 26. STNI risk of front seat occupants in multiple impacts with at least one rear impact by size and gender

Other injuries than STNI

In multiple impacts it is difficult to accurately determine which impact caused any individual injury. As the number of impacts increases, it becomes increasingly difficult. The final part of the analysis therefore looks only at which body regions are injured, without attempting to attribute the injuries to the rear impact itself.

Due to the higher impact severity of multiple impacts with at least one rear impact, compared to single rear impacts, the number of AIS2 and AIS3 injuries increases.

The most frequently affected body parts are the head, thorax and the extremities. Injuries to the face are more frequent than in single rear impacts and injuries to the abdomen are less frequent (Figure 27).

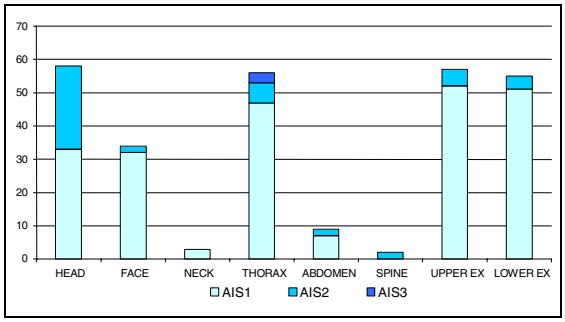

Figure 27. Injured body regions of front seat occupants with STNI and other injuries in multiple impacts with at least one rear.

For front seat occupants receiving no soft tissue neck injury, the most frequently affected body regions are the upper extremities, with a high share of fractures, and the head and thorax regions. In these body regions AIS4+ injuries also occur (Figure 28).

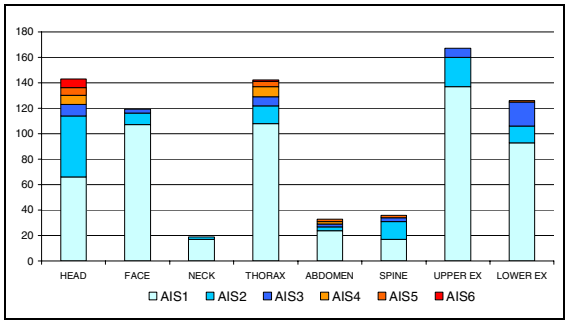

Figure 28. Injured body regions of front seat occupants with no STNI but other injuries in multiple impacts with at least one rear impact

CONCLUSIONS

This analysis included a wide range of information on the rear impacts of passenger cars in Europe.

Single rear impacts are the least frequent impact type for passenger cars and have the lowest impact and injury severity levels.

- Only 10 % of the passenger cars involved in accidents had a single rear impact
- 90 % of the passenger cars had a delta v < 22 km/h
- Only 0.2 % of the occupants received MAIS3+ injuries

Car-to-car impacts are the main group of single rear impacts (more than 70 % of total). Most of these impacts occur on urban roads, 90 % of the striking cars have an impact speed lower than 55 km/h. More than the half of the car-to-car impacts had an overlap level of more than 80 %.

Soft tissue neck injuries play an important role in single rear impacts.

- 78 % of the injured front seat occupants received a soft tissue neck injury, 65 % in absence of other injuries

With increasing age, especially from 65 years of age on, the risk of receiving a soft tissue neck injury decreases. Female front seat occupants are at significantly higher risk of receiving a whiplash than males, with an increasing risk as their height increases.

The most frequent AIS2 injury types in combination with whiplash are concussions. In the absence of soft tissue neck injuries the overall injury severity is higher, due to the relative higher delta v levels of the impacts. Concussions are the most frequent AIS2 injury type and the small number of AIS3+ injuries was found in the head and thorax.

With a quarter of all impact types of passenger cars multiple impacts are the second largest group. Multiple impacts have the highest injury severity level of all impact types. The present study focuses on multiple impacts with at least one rear impact, which are 9 % of all impact types, and therefore as big as the percentage of single rear impacts.

The injury severity of the front seat passengers in multiple impacts with at least one rear impact depends on the sequence of the rear impact. If the rear impact is the first impact, 55 % of the sample, the injury severity is significantly lower than in cars with multiple impacts where the rear was not the first impact.

The sequence of the rear impact also has an influence on the risk of receiving a soft tissue neck injury. Two thirds of the injured front seat occupants receive a soft tissue neck injury if the rear impact is the first impact, in contrast to only one third of the injured front seat occupants who had a rear impact as one of the following impacts.

The most injured body regions after soft tissue neck injury are head, thorax and the extremities. In the group of occupants without soft tissue neck injury the high percentage of injuries in the upper extremities is conspicuous. In head and thorax also MAIS4+ injuries occur.

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