Actual Restraint Systems: Reached their limits!?

Analyses of Accident data of frontal impacts, compared to consumer test results

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ABSTRACT

In the last 25 years the safety systems, such as seat belt, airbag, and a stable body shell saved thousands of people lives in traffic accidents. New test requirements from local road administrations and consumer protection programs (NCAPs) give the information of the performance of modern cars to the consumer and the way to improve safety to the automobile industry. So a lot of work has been done to implement safety systems in the complete vehicle fleet. This was the first and very efficient step to reduce the number of fatal injured passengers involved in a vehicle accident..

In Europe the number of killed people in traffic accidents decreased enormously. The number of victims in 2008 was 28.4% lower than 2001. In Germany the figures show a reduction of the fatalities in the same time period of 35.8%.

The new requirements on vehicle safety lead to very complex restraint systems and to very stiff passenger compartments, In case of an accident very stiff vehicle compartments are raising the deceleration of the vehicle body and the restraint systems had to working on a high level of pretension force at a very short time. Systems which were implemented to save lives could now be contra productive and become a problem for persons who are not able to withstand such high loads according their stature, age or mass.
On the background of the demographic change the number of elderly people driving cars is increasing. This issue is getting more and more important in the near future, because in the case of an accident their body is not able to withstand those high loadings induced by the restraint systems and the high deceleration. Multiple fractures of the chest with following injuries of internal organs and accelerations injuries of inner organs and soft tissue are the result of this high deceleration and loadings. Also smaller and even younger passengers will be affected by this dynamic behaviour due to the belt routing and positioning of the passenger according the vehicle interior. The data evaluation of the GIDAS [1] and ADAC [2] accident data base is showing a lot of real life crashes were injuries could be detected which are more severe than seen in consumer crash tests, while the accident parameters are comparable with those of the crash tests. Especially women, small and elderly people have a higher risk of injuries. New test methods and smarter restraint systems could help to indicate problems and safe lives in accidents.

INTRODUCTION

Starting in the 90´s, a lot of efforts were done to push the safety of passenger cars. Under the pressure of tests done by consumer test houses, mandatory crash tests were introduced by the government all over the world to make sure that only cars with basic safety behaviour will be sold Consumer crash test programs raised the bar on the requirements of the test results. Nowadays several NCAP´s (New Car Assessment Program) are established all around the world. Even in mid and low income countries safety is an aspect which is addressed by new programs such as the Latin NCAP. The following paper uses accident data for Germany, addressing the chest injuries in frontal impact crashes. but the results could be transferred to other Centre European countries, too.

The data evaluation of the accident data base of the ADAC accident research showed several accidents with passenger cars involved causing severe injuries of the vehicle passengers or even killed passengers while the performance of the car showed good results in consumer crash tests. With nearly the same boundary conditions, than in a consumer crash test, in impact velocity and overlap, the difference between the rated injuries and the real ones were significant.

With **GIDAS data** a deeper investigation was done on this issue using both data bases as source of information. GIDAS (German In-Depth Accident Study) is the largest accident study in Germany.

The data collected in the GIDAS project is very extensive, and serves as a basis of knowledge for different groups of interest. Representativity compared to the federal statistic is guaranteed due to several processes.

Since mid 1999, the GIDAS project collects about 2000 accidents in the areas of the cities Hanover and Dresden per year. The project is supported by the Federal Highway Research Institute (BASt) and the German

Association for Research in Automobile Technology (FAT). ".

The ADAC Accident Research Project

The "Yellow Angels" of the ADAC air rescue service (HEMS) give medical care to those injured in road accidents which is an essential part of their rescue missions.

Since June 2005, data of nine ADAC HEMS (Helicopter Emergency Medical Service) bases of road accidents is collected and have been closely examined.. Approx.1,600 road accidents per year are investigated. Each case is analysed retrospectively. The study is based on several pillars (Figure 1). With the information gathered from various sources, accidents can be accurately analysed and evaluated.

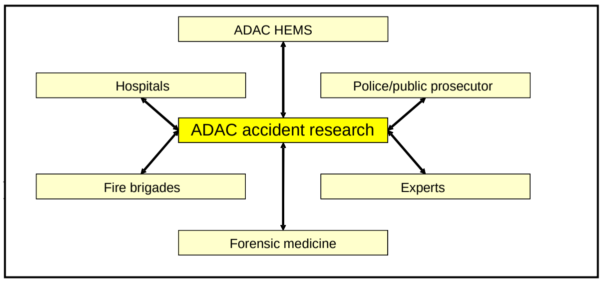

Figure 1. Structure of ADAC Accident research

Despite the fact that details, such as reason of the accident, injury patterns vehicle specifications are well known and medical data is available, this project has restrictions due to the fact that helicopters only work by daylight, on urban areas, seldom in cities and are called for severe accidents.

The combination of the results of both research activities delivers a very good data basis including representative accident data and a lot of accidents on urban roads were the more severe injuries occur.

ACCIDENT DATA ANALYSES

A detailed analysis of frontal impacts was carried out using data from the German In-Depth Accident Study, GIDAS including accidents from 1999 to 2010.

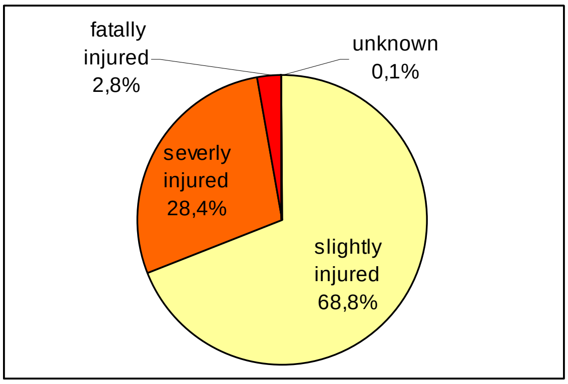

Figure 2. (GIDAS) Severity of accidents with passenger car involvement – Official classification, n=12967

Figure 2 shows a percentage of 2,8% fatal injuries in the last decade, while 28% were severely injured, expressed in MAIS, 19,3% had MAIS 2, 4,6% MAIS 3, 1,4% MAIS 4, 10% MAIS 5 and 0,6% MAIS 6 injuries. Focused on the life threatening and fatal injuries the related number of the ADAC database shows a comparable result, while the number of severely injured persons is quite higher depending on the scaling and the focus on severe accidents.

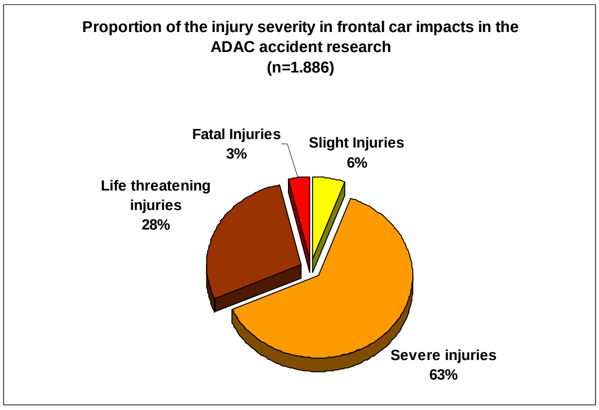

FIGURE 3. (ADAC) Severity of accidents with frontal car impacts – ADAC Classification, n=1886)

Both databases are showing a higher number of fatal injuries than the federal statistic, where the percentage of fatal injuries is close to 2%.

The issue to be investigated is the frontal impact and the restrain systems activated in this kind of accident, with the main focus on the seat belt and its function.
The distribution of impact types of passenger cars is listed in Figure 4. in 28% a single front accident occurs (n=5475) and in 73% the opponent is an other passenger car.

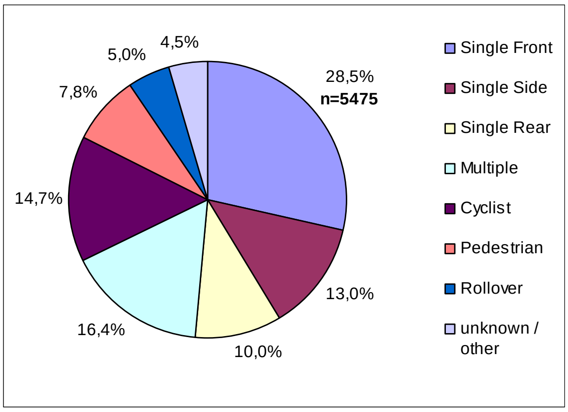

Figure 4 (GIDAS) Impact types of passenger cars, n=19195

While the percentage of the single front accidents with 45% is higher in the ADAC Database than in GIDAS the percentage of 77% in the car to car is quite close in comparison.

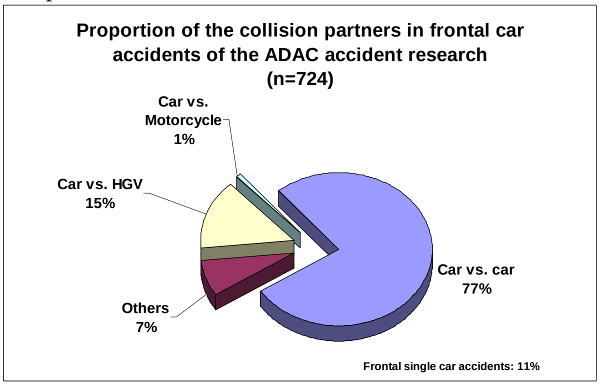

Figure 5 (ADAC) Constellation of impacts, n=724

A more detailed view on the type of cars involved in single frontal accidents with another vehicle show in 76% a kerb weight from 750 to 1500kg, respectively 84% in the ADAC database, so the compact, lower mid class and the mid class are the cars to be involved most common in a traffic accident. These cars will be deeper analysed in the chapter of Euro NCAP test evaluation.

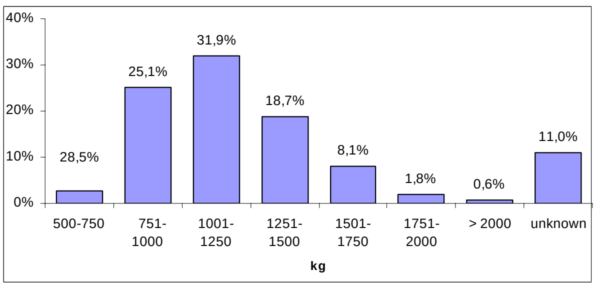

Figure 6. (GIDAS) Kerb weight of passenger cars in single frontal impacts, n=5475

A further interesting detail of the cars involved in a frontal impact is the year of first registration to take the safety standard into account. The distribution of first registration is shown in Figure 7. More than 50% of the cars involved in single frontal car to cars impacts are first registered after 1996 and even 15,8% are not older than 10 years and 58% are equipped with a frontal airbag in the GIDAS database.

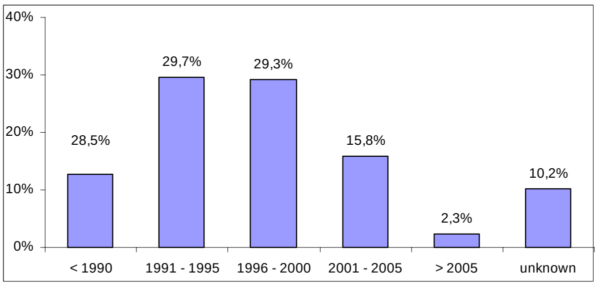

Figure 7. (GIDAS) Year of first registration of passenger cars in single frontal impacts, n=5475

In fact the numbers of fitment rate differs between the two databases. Instead of 58% fitment rate of frontal airbags the percentage in the ADAC database is 70% which is higher and maybe an indication of a newer vehicle fleet which is detected. The first registration is not captured by the research team of ADAC.

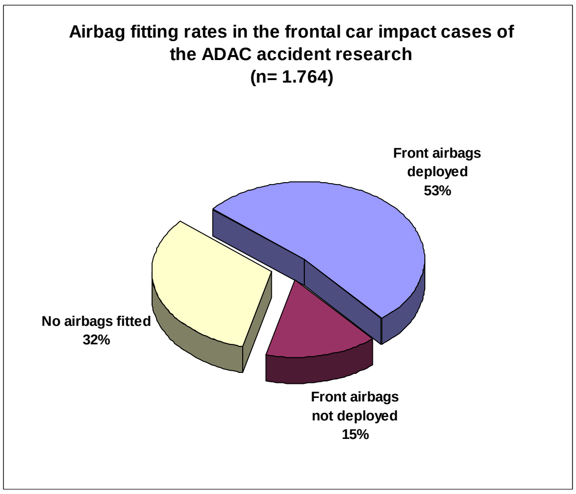

Figure 8. (ADAC) Airbags in passenger cars in frontal impacts

The MAIS distribution in the single frontal impact of belted occupants reflects a picture seen from the national accident statistics, were the number of severe and deadly injured car occupants is decreasing over the last decade. Most of the belted occupants have very minor injuries MAIS 0 or MAIS 1. MAIS 2 and MAIS 3+ representing the more sever injuries is only registered by 6.6% respectively 2%.

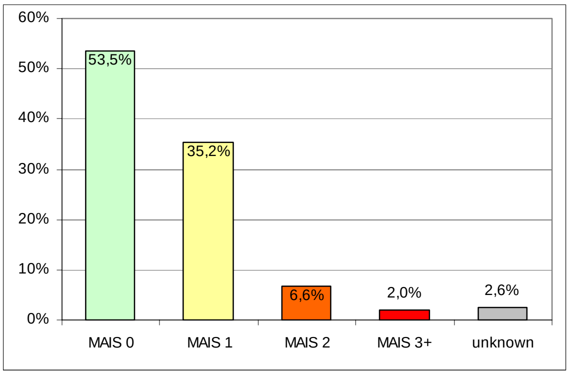

Figure 9. (GIDAS) MAIS distribution of belted front seat occupants in passenger cars in single frontal impacts, n=6102

Dividing up the MAIS 1 and MAIS 3+ into the year of registration and the age of the injured occupants the following graphs show some different tendencies. Figure 10 is showing the trend of less MAIS 1 injuries according the built level of the cars. The younger the vehicles built level the less percentage of minor injuries occurs. This trend could be seen for all injured occupants not depending on the age. All specific age groups are showing the same trend lines.

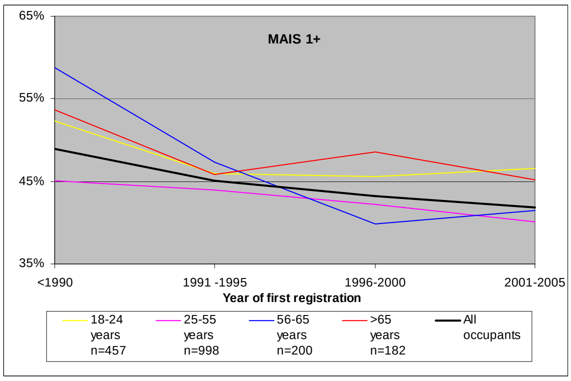

Figure 10. (GIDAS) Share of MAIS 1+ injured belted front seat occupants of passenger cars in single frontal impacts

This picture changes with the MAIS 3+ injuries divided up into the built level of the car and the age of the injured occupants. For the 25 to 65 year olds the trend of the reduction of MAIS3+ injuries seems so be equally to the MAIS 1+ injuries, but for young persons and especially for persons over the age of 65 the risk of a MAIS 3+ injury in a car of the built level 2000 and later is increasing. The trend of all MAIS 3+ injuries is therefore constant, with tendency of slightly rising than decreasing.

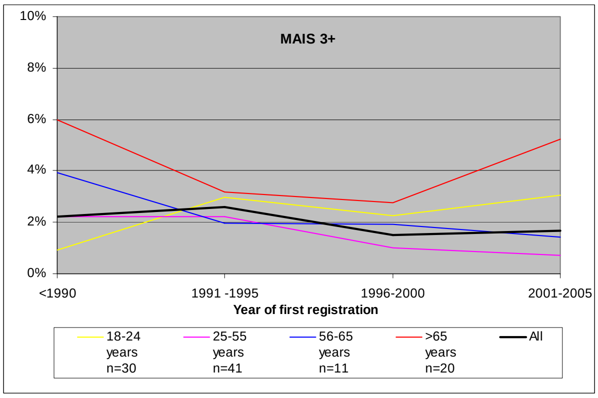

Figure 11.(GIDAS) Share of MAIS 3+ injured belted front seat occupants of passenger cars in single frontal impacts

A similar situation is documented in the ADAC database. While a decreasing number of life threatening injuries could be recognized in vehicles from 1991 till 2000 in comparison to vehicles of the model year before1990, the number of severe injury increased. So the injury severity could be reduced over all. The fatality rate was also reduced at the same time. But this positive trend could not be seen in the following model years from 2001 to 2005 and from 2006 to 2010 were a stagnation of the severe injuries could be recognized and on the other hand a slightly increase of the life threatening injuries could be also recognized. The percentage of fatalities is constant in that situation; taking into account the number of cases for the brand new car is less than the model year from 2001 to 2005. This effect seems to be caused by the more stable vehicle cells, which were an improvement in the mid end of the 90´s. Deeper investigation will be done later in this paper.

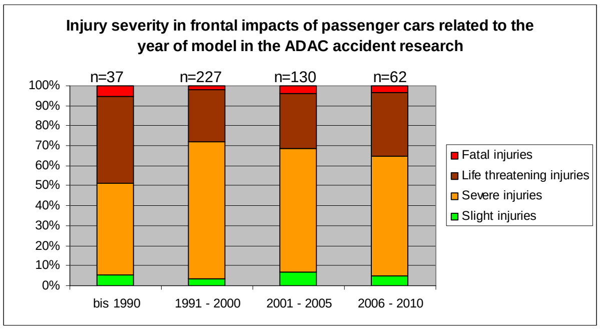

Figure12. (ADAC) injury severity in frontal impacts according the year of production

A more detailed look into the accident data dividing up the occupants according their age show that elderly people have a higher risk of fatal, life threatening and severe injuries, starting at the age of 30, were the numbers of injuries is increasing especially of severe injuries (04). From 70 years onwards the percentage of life threatening injuries is increasing as the fatal number does. This development is caused by the physical condition of the occupant due to his age, were the skeleton, muscles etc. are no resisting in the same way than in the age of 20 to 30. The classification of the ADAC accident data is the following:

The classification of the injury severity bases on 7 steps with:

01 = Slight Injury

02 = Ambulatory Treatment

03 = Stationary Treatment

04 = Possible imminent mortal danger

05 = Imminent mortal danger

06 = Sufficient cardiopulmonary resuscitation

07 = Exitus, insufficient cardiopulmonary resuscitation

This classification gives details about the overall situation of the accident victim comparable to MAIS.

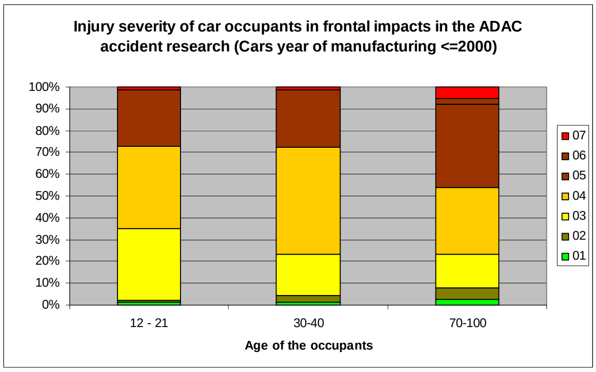

Figure13 (ADAC) injury severity in frontal impacts with cars of MY <=2000, related to the age of occupants,

But this fact seems to get a bigger problem in cars of model year 2001 onwards, were the percentage of fatal and life threatening injuries is increasing for the passengers of 70 years plus. The occupants of the age of 30 to 40 are still protected quite well and even better protected than in a car of an earlier built level. The number of no or only slightly injured young occupants is developing in a positive way, but at the same time the fatalities from occupants from 12 to 21 are increasing in the cars of a newer built level.

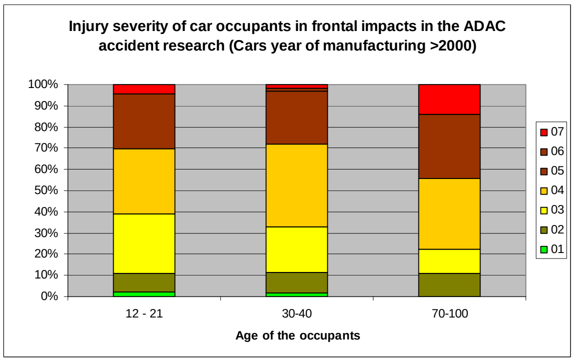

FIGURE14. (ADAC) injury severity in frontal impacts with cars of MY >2000, related to the age of occupants

The following data evaluation is focused on the Thorax area, because this area was seen the demanding one for higher injury risk, while the test results show nearly no problem at that area at all. The maximum thorax injury could be seen in the GIDAS data evaluation of Figure 15. The highest percentage of AIS 0 is fixed to the occupants of the age of 18 to 24, but up to the age of 18 and from 24 onwards the risk of an AIS 1 and AIS3+ injury is increasing. This might be transferred to the stress capacity of a human depending on the age. So a deeper look inside this data is needed to differentiate according the age and sex of the occupant and the age of the cars to deliver a better picture

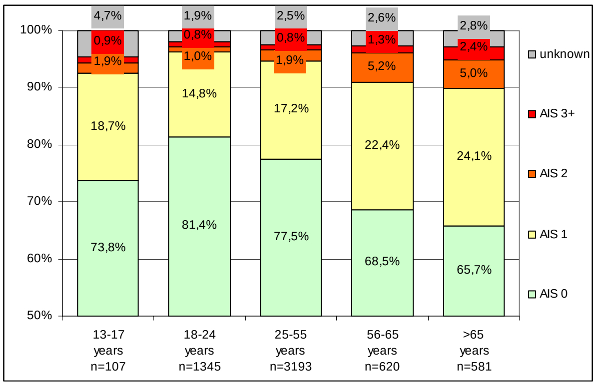

Figure 15 (GIDAS) Maximum thorax injury severity of belted front seat occupants of passenger cars in single frontal collisions by occupant age, n=5846

In accidents with cars of a built level before 1990 in comparison to cars younger than 2005 a continuous decrease of AIS 1,2 and 3+ for chest injuries could be seen for the group of occupants <=55years. This is a positive trend and shows the capability of modern cars compared to cars from an earlier decade. For elder occupants from 55 onwards the trend of a reduction of AIS 1, 2 and 3+ is obvious for cars with built level up to the end of the 90´s. The discrepancy between elderly and younger people is rising in cars of a built level from 2000 onwards.

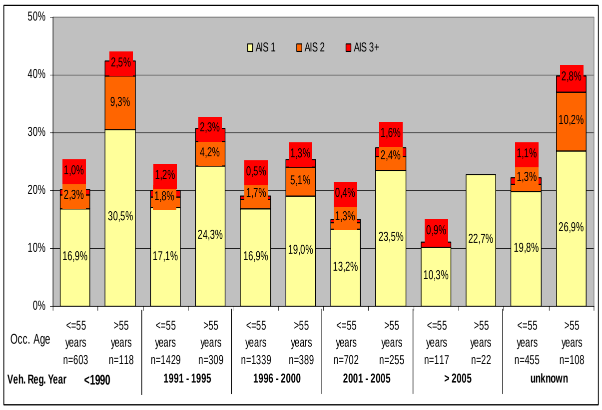

Figure 16.(GIDAS)Maximum thorax injury severity of elderly compared to younger belted front seat occupants of passenger cars in single frontal collisions, n=5846

A comparison on the same basis, built level of vehicles in accordance with the gender of the occupants show that there is a difference in the thorax injury between male and female. Starting at the built level of cars in the 90´s and younger the number of AIS 1 injuries for male is continuous decreasing and halved from 14.4% to 7.1% for cars of the built level 2005 and younger. At the same time the AIS 2 injures were reduced from 3.1% to 0.7%, while the AIS 3+ injuries are nearly constant or slightly increasing. Contrary to the male the females' numbers show no significant reduction of thorax injuries of the last decades. Neither the AIS 1 Injuries nor the AIS3+ injuries were reduced significantly with the younger built level of cars.

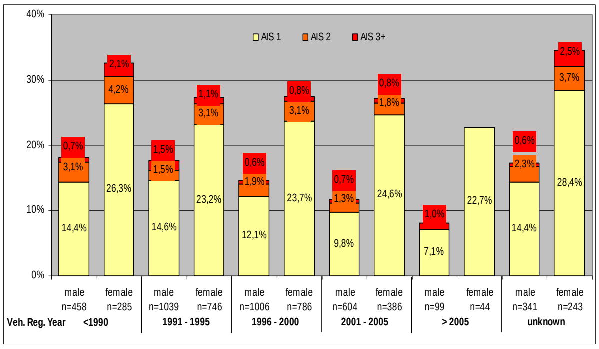

Figure 17 (GIDAS)Maximum thorax injury severity of male compared to female belted front seat occupants of passenger cars in single frontal collisions; N=6037

Comparable data could be found in the ADAC accident data. There the risk of severe, life threatening and deadly Thorax injuries is 30% higher for female than for male, while the percentage for deadly injuries is 4 times higher for male than for female.
The AIS 1 Thorax injuries have nearly the same percentage for each gender.

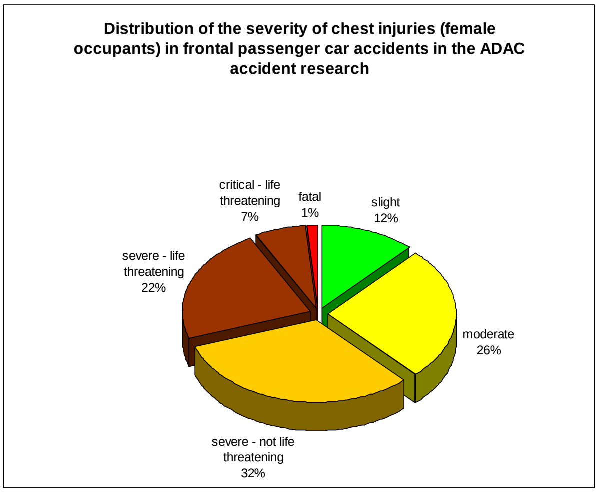

Figure 18. (ADAC) Thorax injury severity of female belted front seat occupants of passenger cars, n=80

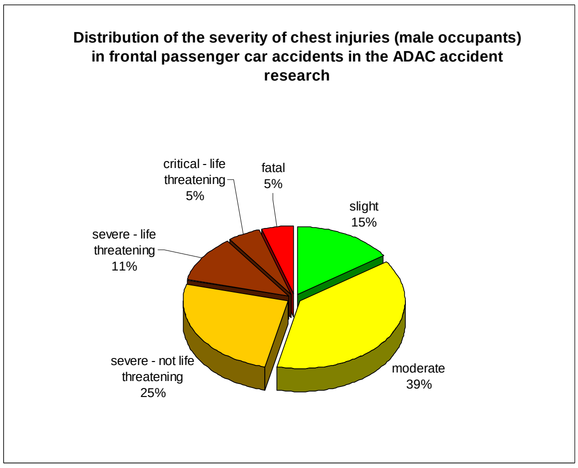

Figure 19 (ADAC)Thorax injury severity of male belted front seat occupants of passenger cars, n=99

A further comparison between the time of first registration and the height of occupants should give answer if there is a trend that young, midsized male occupants will have less risk of injuries in a frontal impact accident than other people of the population.
A constant decrease of AIS 1 injuries could be realized for persons below 165cm while the AIS 1 injuries for persons > 165cm are nearly constant up to a slightly decrease which is also the case for AIS 2 while AIS 3+ is decreasing over the building periods. This counts for vehicles of a built level up to the year 2000. But from the built level 2000 onwards the injury risk for smaller persons is increasing. So overall a higher risk for smaller occupants of Thorax injuries could be realized in cars of s younger built level.

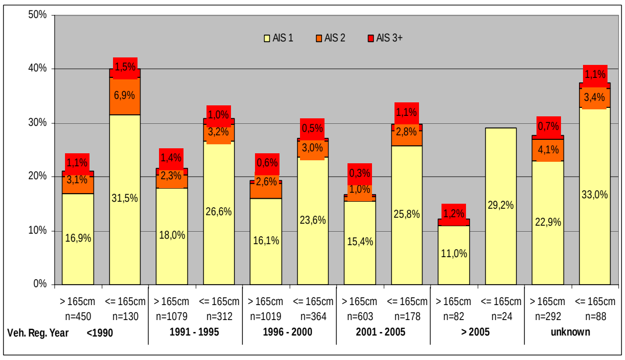

Figure 20 (GIDAS) Maximum thorax injury severity of tall (>165cm) compared to small (<=165cm) belted front seat occupants of passenger cars in single frontal collisions, n=4621

EVALUATION OF EURO NCAP TEST RESULTS COMPARED TO REAL LIFE ACCIDENTS

A stable vehicle body is the fist and important step toward a save vehicle**.** To minimize intrusions and deformation was a big step forward in the early 90´s and nowadays nearly 100 of the tested cars in Euro NCAP show no problems with cell stability at all. This trend could also be seen in the ADAC database, were nearly 70% of all frontal impacts have no deformation of the vehicle cell. The following figure shows the distribution in CDC level of deformation while deformation of the zones 1 to 6 will not affect the passenger cell.

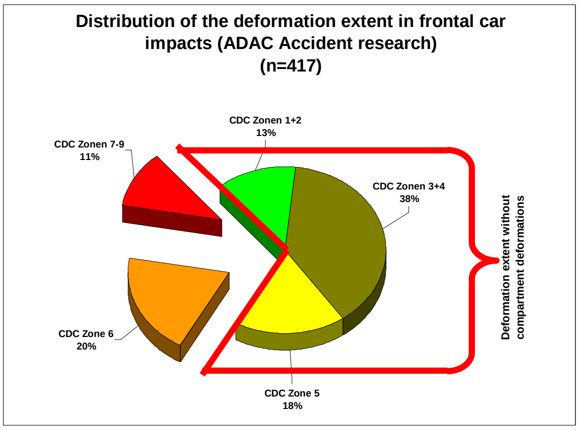

FIGURE 21 (ADAC), CDC LEVEL OF DEFORMATION IN FRONTAL IMPACT OF CARS

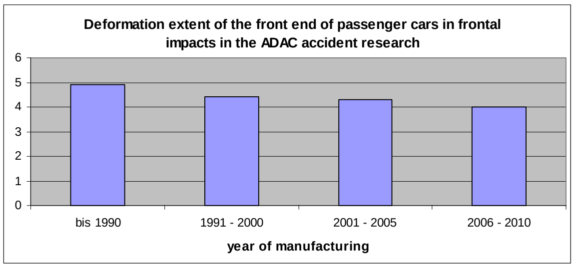

FIGURE 22 (ADAC), CDC LEVEL OF DEFORMATION ACCORING THE BUILT LEVEL

The result of stable passenger compartments and no intrusion in the vehicle interior is the reduction of the crumble zone to the vehicle front, while the length of the zone is limited towards the a-pillar.

The overall result out of this reduction of deformation area is a higher deceleration of the cars during an impact. This could also be found while analysing the vehicle decelerations of cars tested by Euro NCAP, especially the vehicles of the compact class and the vehicles of the small sized cars and SUV´s show higher decelerations of the latest model than the earlier built level ones. Not only the maximum deceleration rises, also the mid deceleration is higher.

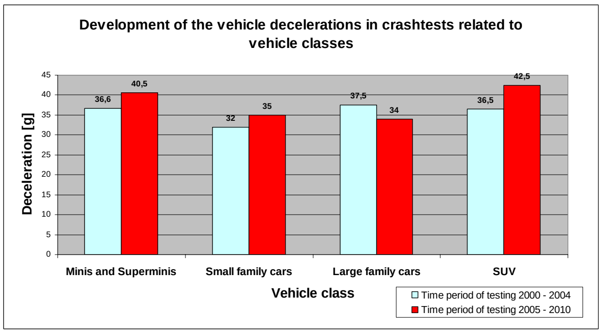

FIGURE 23 (ADAC), SHIFT OF VEHICLE ACCELERATIONS OVER THE YEARS

A more detailed look on several cars of this classes show a rising deceleration with the introduction of the new model.

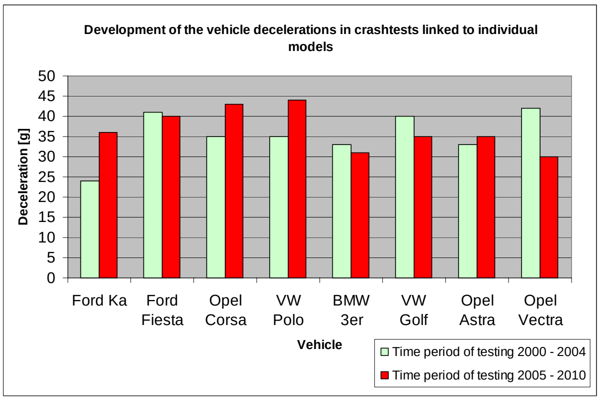

FIGURE 24 (ADAC), EXAMPLES OF THE SHIFTING OF ACCELERATION OF NEW MODELS

High accelerations could cause severe injuries. The analyses of the accidents including the reports from the medical rescue services and the hospitals are showing internal haemorrhaging due to injuries of the inner organs in the abdominal, lung and pelvic area. There are several reasons responsible for this kind of injuries. The most important point of all is the deceleration, which is responsible for the shifting of the inner organs. Only the blood vessels and the nerve fibres prevent them of further movement, resulting in damages of the nerves and the possibility of destruction of the arteries and veins this could cause the inner bleedings which could not be observed quite fast but in those cases very fast help is necessary.

Another mechanism of the deceleration is affecting the tissue fluids, such as water, blood etc. which is resulting in a higher intercellular pressure causing ruptures and other injuries of the tissue structures.

Figure 25 shows a comparison of chest acceleration of new cars tested in2004and before and after 2005.

It is obvious, that the accelerations measured in the chest area are significantly higher for superminis and SUV´s of a later built level.

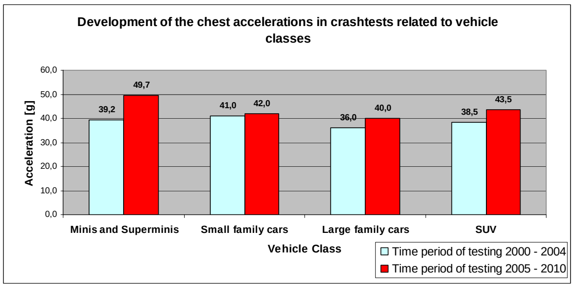

FIGURE 25 (ADAC), SHIFTING OF CHEST ACCELERATION OVER THE YEARS

The higher level of accelerations in the chest area seems to be responsible of the higher injury rate especially of elderly people.

But there is also an increase of risk for younger, smaller people, see Figure 13 and 14. This may be the result of safety systems working not perfect for all kind of humans. An adaption and optimization of the restraint systems to a certain group may be the reason fort his findings. The loading of the chest could be reduced by the load limiter, which is used in nearly every new car. Over the last years the limitation force in Euro NCAP tests is between 4 and 5 kN. In only a few cases the limitation force is higher, then up to 6kN or lower down to 3,5kN.

But even with the use of the limitation of 4 to 5kN the chest acceleration raised over the years causing acceleration injuries and fractures. A logical correlation between the belt forces, chest acceleration and chest deflexion could not be seen in the Euro NCAP data.

The following risk curves are showing the correlation between the forces, age and the risk of an AIS 3+ injury.

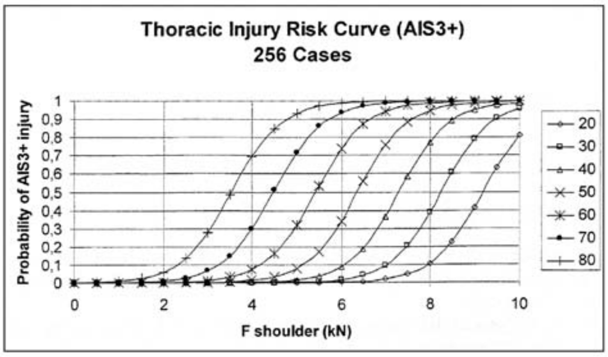

Figure 4. Probability of severe thoracic injuries (AIS3 or more severe) depending on the shoulder belt force and the occupant´s age /7/

FIGURE 26 THORACIC RISK CURVES DEPENDING ON SHOULDER FORCE AND AGE [3]

CONCLUSIONS

The study of German accident data and accident statistics are showing a positive trend in reducing traffic accidents and also in the reduction of killed people in traffic accidents.

This numbers could also be seen in the European accident data.

So in general the injury severity of belted front seat occupants is on a very low level right now. The implication of consumer tests such as Euro NCAP is showing a positive effect in the development of passive safety over the last decade.

So the share of injured occupants decreased from 50% in vehicle models registered before 1990 down to 40% in models registered after the year 2000.

But a deeper look in the accident data and the injured body regions are showing problems in the thorax area. In those cases the injuries of the occupants in the real life accidents were not comparable with the tests conducted for consumer test programs, even when the vehicle and the kind of impact were comparable.

Especially for elderly occupants, which are in general more frequently injured, independent from the vehicle age, seems to exist a slightly increased risk.

The risk for female occupants to suffer thoracic injuries however this is only observable on minor injury levels AIS 1-2 [1], while the ADAC data is showing a risk of 1.4 times higher for life threatening injuries.

For smaller persons <165cm there is also in increasing risk of thorax injuries at the level of AIS 1-2.

Future developments in consumer test programs should take this development into account. The actual test condition and the actual dummy is not able to reflect the injuries in the Thorax area. Investigation should be put in the development of new test tools to address this issue. A short term solution would be the use of results of the Thorax project and an update of the actual dummy and injury criteria.

Consumer Test/Accident Research

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Acknowledgement: Ford kindly provided the GIDAS data to ADAC

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[1] GIDAS German In-Depth Accident Study,
[2] ADAC Accident Research
[3] Zellmer et al.; Optimized pretensioning of the belt system, 2004