Safety of rear-seat passengers in cars

Compact accident research

Unfallforschung der Versicherer
GDV

Contents

Introduction

Various German and international publications show that the safety of rear-seat passengers in modern cars has not reached the high level of those in the front seats [1, 2, 3]. The aim of the present study [4] was to ascertain the current level of safety of rear-seat passengers in cars and obtain and assess the need for safety by means of suitable measures. To this end, real accident data was examined, surveys and extensive numerical simulations were carried out, and sled tests were analyzed.

The accident database of GIDAS (GIDAS = German In-Depth Accident Study) and that of the UDV (German Insurers Accident Research) were used as the basis for the analysis of the accident data.

To investigate typical behavior on the rear seats, 800 people aged between 18 and 65 were surveyed online. To deepen the knowledge obtained, interviews were also conducted with focus groups in five German cities. In the surveys it was found, for example, that rear-seat passengers often adopt a different sitting position from the normal one (i.e. the one used with crash-test dummies). The findings from the accident analysis and survey were used to create and validate multiple FEM models, which allow different influencing factors to be evaluated on the basis of biomechanical load values.

Accidents

The GIDAS and UDV accident databases were used as the basis for the accident analyses. The GIDAS data used in this study covered the period from 1999 to 2012. The data consisted of 22,000 accidents, involving around 28,000 people who were injured and 26,000 who remained uninjured.

Single-impact collisions dominated in the GIDAS accident data material, accounting for 81% of accidents. The main direction of impact was frontal in 59% of these cases. All further analyses in this paper relate to this subset of the accident data material. Multiple-impact collisions and rolling-over accidents are thus not included.

Table 1 shows that 62% (n=83) of all seriously injured rear-seat passengers (MAIS 2+) in the data material were injured in frontal collisions. At higher levels of injury (MAIS 3+), the percentage of frontal collisions was slightly lower at 59%, there were significantly fewer rear-end collisions, while side-impact collisions were somewhat more common. The average number of occupants in a car was 1.4. 10% of all the car occupants in the case material described above were rear-seat passengers. 94% of them were wearing their seat belts. The three-point automatic seat belt is now standard equipment in the rear seats. 53% of the rear-seat passengers were female. Half of the victims were aged 17 or older. The 17-24 age group featured most often in the GIDAS accident material, for the rear seats as well as the front seats.

The uninjured (MAIS 0) and slightly injured (MAIS 1) featured much more often in the GIDAS accident material than car occupants with higher levels of injury severity (see Figure 1).

If the seat belt status is considered in addition to the level of injury severity, the following picture emerges for rear-seat passengers (see Figure 2): While 97% of the uninjured rear-seat passengers were wearing seat belts, over a quarter of those who were seriously injured (MAIS 2+) were not wearing their seat belts. This demonstrates how important seat belts are in reducing the level of injury severity.

Table 1: Comparison of different levels of accident severity for rear-seat passengers in the data material (without multiple-impact collisions and rolling-over accidents) [source: GIDAS]

	Uninjured N = 1,761		**MAIS 2+ N = 134**		**MAIS 3+ N = 32**	
Frontal impact	1,004	57 %	83	62 %	19	59 %
Right-hand side impact	167	9 %	10	7 %	5	16 %
Rear-end impact	381	22 %	20	15 %	2	6 %
Left-hand side impact	209	12 %	21	16 %	6	19 %

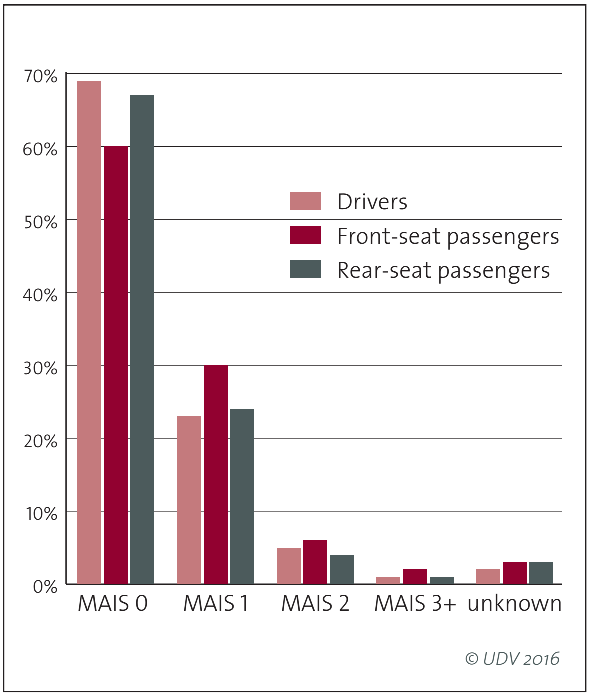

Figure 1: Distribution of uninjured and injured by MAIS score (frontal collisions, without multiple-impact collisions or rolling-over accidents) [source: GIDAS]

Accidents

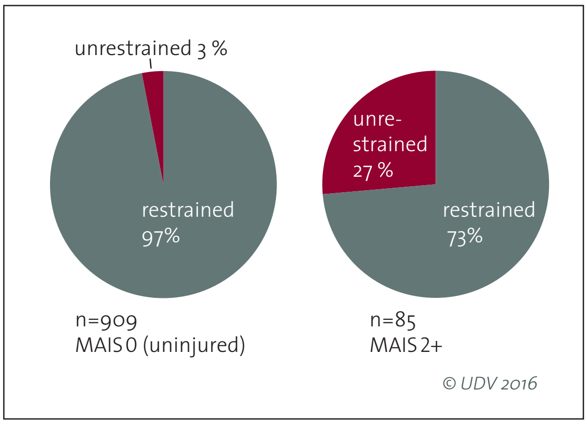

Figure 2: Seat belt status and level of injury severity for rear-seat passengers (frontal collisions, without multiple-impact collisions or rolling-over accidents) [source: GIDAS]

Since the establishment of Euro NCAP, the structural rigidity of vehicles has increased significantly in order to keep car occupants safe [5]. In order to analyze the expected change in the risk of injury to rear-seat passengers, two car registration periods are examined below – before and after the introduction of the Euro NCAP tests.

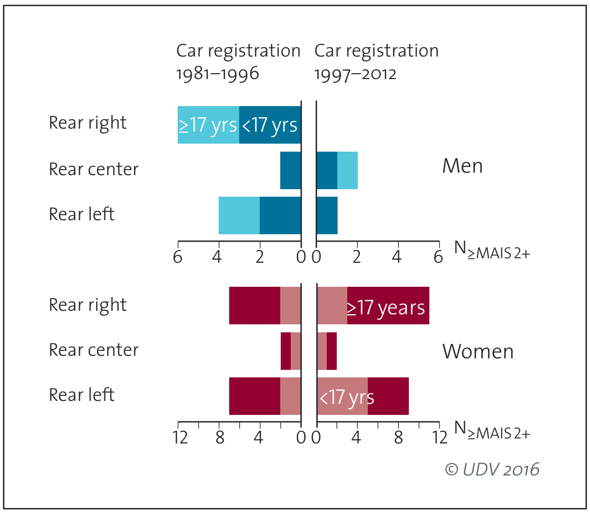

Figure 3: Gender distribution of injured rear-seat passengers for two car registration periods (frontal collisions, without multiple-impact collisions or rolling-over accidents, wearing seat belt) [source: GIDAS]

If you look at the gender distribution of injured rear-seat passengers (see Figure 3), you see that the number of seriously injured victims (MAIS 2+) decreased for the two male age groups (under and over 17 years of age) in the registration period from 1997 to 2012. The picture is different for injured female passengers. The number of seriously injured female rear-seat passengers increased in both age groups. In the under 17 age group the number seriously injured increased by 80% from 5 to 9, and in the over 17 age group it increased by 30% from 11 to 14. However, it must be said that these are very small numbers.

If you look more closely at the distribution of the rear-seat passengers by injury severity, you get the following picture (see Figure 4). In the entire registration period from 1981 to 2012, a total of 55 rear-seat passengers sustained MAIS 2+ injuries (1981-1996: 29 with MAIS 2+ injuries; 1997-2012: 26 with MAIS 2+ injuries). Those with MAIS 2+ injuries as a percentage of those who were uninjured fell from 8.1% to 5.6%.

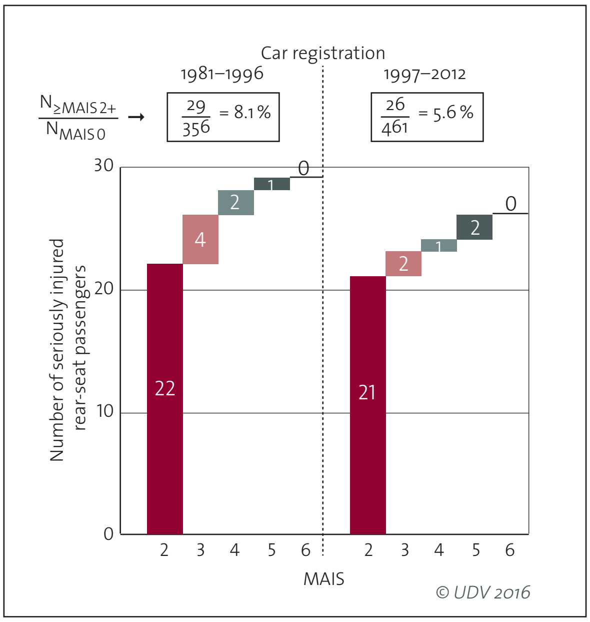

Figure 4: Distribution of those with MAIS 2+ injuries in relation to uninjured rear-seat passengers by car registration period (frontal collisions, without multiple-impact collisions or rolling-over accidents, wearing seat belt) [source: GIDAS]

Overall, the total number of injured rear-seat passengers wearing seat belts who were involved in frontal single-impact collisions fell over the two car registration periods, although the number of individual injuries increased. Figure 5 shows that rear-seat passengers have benefited significantly less from new safety technologies over the years than drivers. The percentage of drivers with serious injuries fell as a percentage of all uninjured drivers by 52%, while the percentage for rear-seat passengers only fell by 37%.

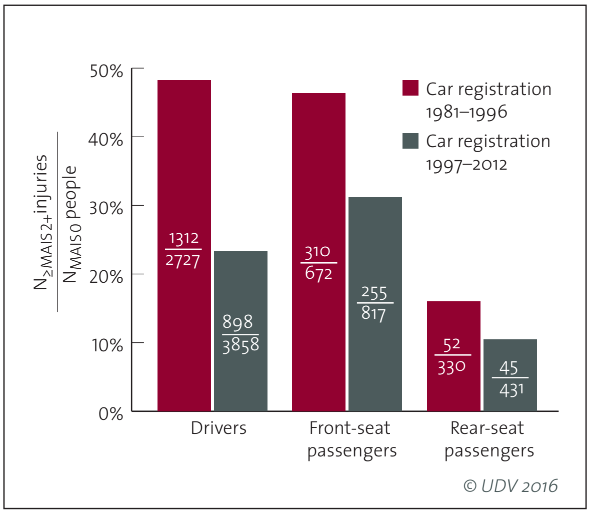

Figure 5: Percentage of serious injuries in relation to uninjured adults by car registration period (frontal collisions, without multiple-impact collisions or rolling-over accidents, wearing seat belt) [source: GIDAS]

If you look at the causes of the injuries, it becomes clear that the forces transmitted by the seat belt webbing strap often cause chest and stomach injuries. Contact with parts of the car's interior is often the cause of AIS 2 head and facial injuries.If you look at the occupants of one and the same vehicle involved in an accident who have similar attributes (age, height and weight) in order to compare the severity of the injuries sustained in the front and rear seats, you find 59 cases in the GIDAS accident material involving injured and uninjured car occupants. Identical levels of accident severity in the front and rear seats are found in 71.9% of the cases (see Figure 6). In the remaining cases, where different levels of injury severity are found in the front and rear seats, the rear-seat passengers had less serious injuries in only 3.5% of the cases and more serious injuries in 19.3% of the cases. That means that, given similar accident conditions, rear-seat passengers are more often seriously injured than people in the front seats.

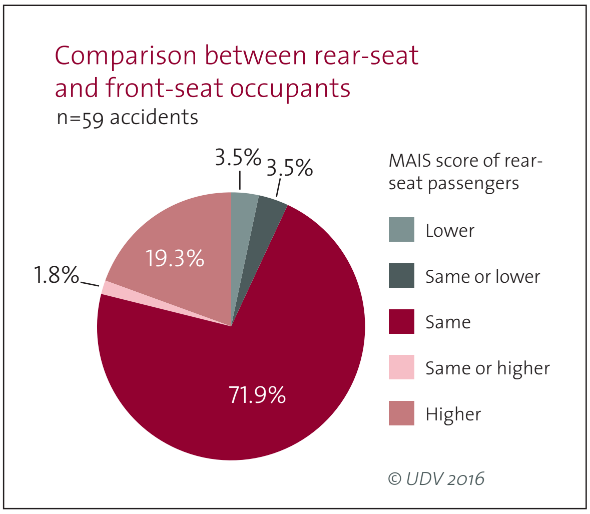

Figure 6: Comparison of the levels of injury severity in car accidents under similar conditions – rear-seat and front-seat occupants (frontal collisions, without multiple-impact collisions or rolling-over accidents, wearing seat belt) [source: GIDAS]

The analyses of the data material of the UDV revealed a similar picture to the GIDAS data. The UDV data is based on serious third-party insurance damage claims involving injuries and damage costs of at least Euro 15,000. In the data material reviewed, there were a total of 709 accidents involving 1,100 cars first registered in 1997 or later where the main point of impact was at the front of the vehicle. In these accidents there were 1,623 car occupants who were wearing seat belts. If you compare the injuries of drivers and rear-seat passengers, you find that life-threatening injuries (AIS 4+) occurred only rarely, but that they were sustained exclusively by rear-seat passengers. The thorax was the area of the body affected. Overall, however, less serious injuries (AIS 1 or 2) predominated among rear-seat passengers. Most of the AIS 2+ injuries sustained by rear-seat or front-seat passengers were to the thorax and the thoracic spine. Rear-seat passengers had more thoracic injuries and significantly more abdominal injuries than front-seat passengers. Front-seat passengers, on the other hand, sustained almost twice as many injuries to their arms.

This picture is confirmed by individual cases in which occupants of the same car, same age and same gender were injured: While the front-seat occupants sustained only slight injuries, the rear-seat passengers sustained very serious and even fatal injuries, above all in the chest area.

Field study

To ascertain the typical behavior of rear-seat passengers, an online survey and interviews with focus groups were conducted. 800 people who had been in the rear seat of a car at least once in the last three months were included in the online survey. It was confirmed that people generally prefer to be in one of the front seats than in the rear seats (70% to 30%). The respondents indicated that they sit in the back when the front seats are already occupied. When they sit in the back, they prefer to take the seat behind the front-seat passenger (see Figure 7).

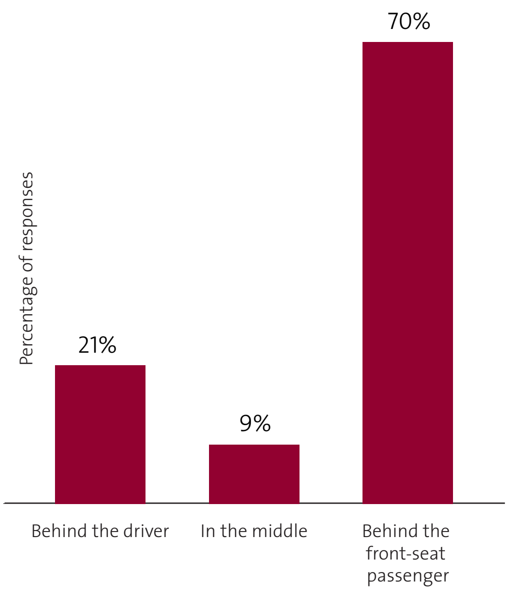

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Figure 7: Preferred seat of the rear-seat passengers (online survey, n = 800).

Figure 8 shows the reasons for seat position preferences when both the front seats are taken. The high priority given to having a good view out of the car is very clear. Although this aspect was mentioned as the reason for their choice of seat particularly often by those people who chose the middle seat, it was also the most common reason mentioned by people who preferred one of the seats at the side. Unsurprisingly, ease of getting in and out was hardly mentioned by those who chose the middle seat, whereas it played a significant role for those who preferred the seats on the left and right. The response category “There is no special reason” also contributes to an understanding of sitting in the back: When people were forced to choose a rear seat, this category was chosen twice as often as when the front seats were also available. Moreover, those who preferred the middle seat chose this category significantly less often; they thus had clear reasons why they wanted this seat.

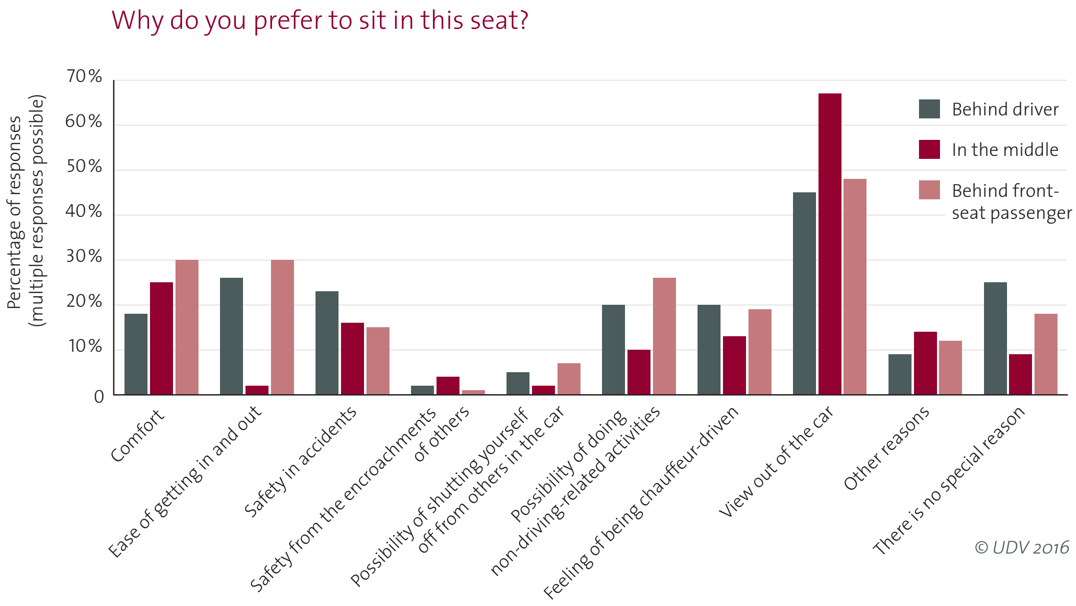


Figure 8: Relative frequency of the reasons for choosing a specific rear seat on the most recent car journey (multiple responses possible, online survey).

The respondents in the online survey were also asked about what they did in the rear seat and how they were sitting. The most frequently mentioned activity was talking to people in the front of the car. Accordingly, sitting forward was mentioned as the second most common sitting position after the normal sitting position. The next most commonly mentioned sitting positions were leaning to the side (e.g. with the support of an armrest) and sitting with their back to the door and their feet on the center console or in the space of the other rear seat (see Figure 9).

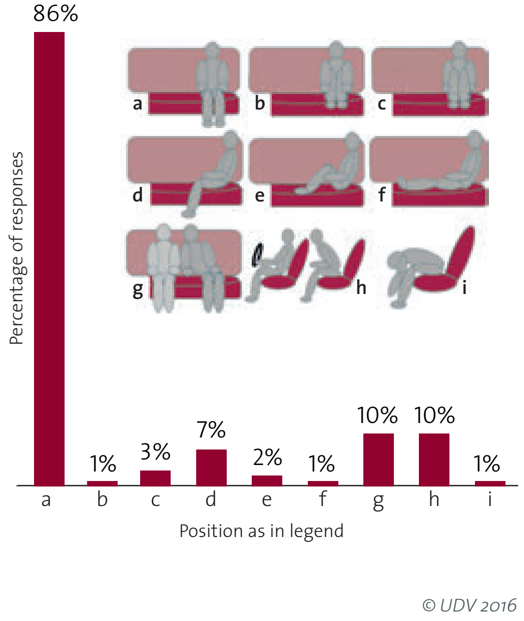


Figure 9: Sitting positions on the rear seats in the online survey (multiple responses possible)

Figure 10: Examples of sitting positions, as reported by the focus groups

The results of the online survey were augmented with results from a total of six interviews with focus groups. These took place with seven to eight participants in each case in five different German cities. The aim was to get a deeper understanding of people's motivations, what they experienced and what they did when sitting in the back of a car. In addition to the direct results from the focus group interviews, they were asked to show the positions they adopted in a real car, which proved to be particularly revealing. It was confirmed that a large number of other positions were adopted besides the "normal" sitting position (see Figure 10).

Figure 11: Examples of the incorrect use of a seat belt, as reported by the focus groups

It was also revealed that, due to problems with the seat belt being uncomfortable, in particular with it rubbing against the neck, people often use the seat belt incorrectly. They deliberately place it over or under their upper arm or use their arm to hold it away from their neck (see Figure 11). This problem with comfort thus ends up as a safety problem.

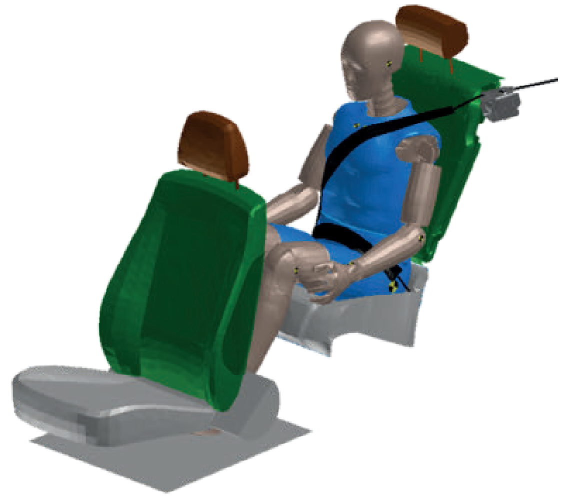
Numerical simulation

The findings from the accident analysis and survey were used to create and validate multiple simulation models, which allow different influencing factors to be evaluated on the basis of biomechanical load values. Different frontal accident scenarios with a high level of accident severity were investigated using different dummy or human models and typical sitting positions and restraint system configurations.

Dummy models

The used simulation model consists of a rear seat with a seat ramp and seat cushion foam. In front of it there is a front seat in the middle position with a foot support. In the standard configuration, the rear-seat passenger is secured by a three-point automatic seat belt without a pretensioner or a belt force limiter. In other configurations there is a pyrotechnic belt pretensioner and a linear belt force limiter. The assessments of the injuries were based on the Euro NCAP lower performance limits. Figure 12 shows the car occupant protection model with the Hybrid III dummy for the fifth percentile female (AF05) and the Hybrid III dummy for the fiftieth percentile male (AM50).

"AF05 dummy"
representing a small woman



"AM50 dummy"
representing an average tall man

Figure 12: Numerical car occupant model AF05 (above) and AM50 (below)

The THOR dummy represents a new dummy generation with improved biofidelity. The neck area has been completely revised and is significantly more flexible than that of the Hybrid III dummy. New biomechanical assessment criteria are being developed for the THOR to assess the risk of injury.

The dummy models essentially represent human kinematics during the crash and enable the risk of injury of specific regions of the body to be assessed. Human models offer greater biofidelity and precision in terms of representing injuries. With their help, more realistic, more flexible movement can be shown, and regions with high load peaks can be identified.

Crash constellations

Vehicle motions with six degrees of freedom of different crash constellations obtained from vehicle tests were applied to the different numerical models of a midrange car. An attempt was thus made to represent the diversity of accident reality in order to be able to make a more robust statement about the results.

Test 1 (see Table 2) with a simulated speed on impact of 50 km/h against a rigid barrier across the full width of the vehicle corresponds to a current model of the vehicle category studied and reaches at 45 ms its maximum deceleration of 61 g. The maximum deformation is around 55 cm.

Table 2: Extent of the numerical simulation

Elements of the numerical simulation	**Description**
4 car occupant models	• AF05 dummy • AM50 dummy • AM50 THOR dummy • human model
3 test configurations	• test 1: against rigid barrier, full overlap, 50 km/h • test 2: against deformable barrier, 40% overlap, 64 km/h • test 3: oblique moving deformable barrier, 15% overlap, 90 km/h
5 technical measures	• 3-point automatic belt • belt pretensioner/force limiter • belt pretensioner/force limiter with stopper • belt height adjuster • rear-seat airbag
3 misuse positions	• leaning forward in conversation • tilted upper body • shoulder belt on upper arm

A further test constellation with 64 km/h against a deformable barrier with a 40% overlap (see Test 2 in Table 2) represents the Euro NCAP offset deformable barrier frontal impact. This vehicle movement has a lower maximum deceleration with a peak load of 46 g in the x-direction at 74 ms. The maximum overall deformation is 134 cm.

In addition, a new crash configuration with an impact against a moving, deformable barrier at 90 km/h, an angle of impact of 15° and a 35% overlap with a stationary vehicle (see Test 3 in Table 2) was also studied. The maximum deceleration in the x-direction is 72 g at 42 ms and is thus significantly above the level of the previous one.

Simulation matrix

Based on the validated models, system parameters and boundary conditions were changed. The aim of this approach was to explain injury characteristics and mechanisms obtained from the accident data analysis and the field study. Table 2 gives a general overview of the calculations carried out. With the four car occupant models, starting from the normal sitting position with a three-point automatic seat belt fastened, the current standard situation was represented. In further steps, different measures were studied that can minimize the injury risk for rear-seat passengers: the use of a seat belt pretensioner and belt force limiter, the seat belt force limiter with stopper functionality, the influence of height adjustment and the effect of a generic rear-seat airbag. The influence of crash severity was taken into account by means of two additional configurations: Test 2 and Test 3 in Table 2. In addition to the normal sitting position, the aim was to clarify what influence a changed initial position of the rear-seat passenger has on the risk of injury in a car accident. To this end, three further misuse positions observed in the field were examined.

Identification and assessment of measures

The current protection system for rear-seat passengers with a three-point automatic seat belt is not adequate for small and medium-sized passengers in serious crashes (see Figure 13). The numerical simulations show that high loads occur, above all, when a seat belt is used without a belt force limiter. The head loads for all rear-seat passengers studied exceed the limit values used. The thoracic loads (deceleration and chest compression) are very high. The extreme shoulder belt forces can result in fractured ribs and a fractured collar bone.

Through the use of a belt pretensioner, which reduces the slack in the belt, the car occupant is linked to the deceleration of the vehicle at an early stage. Combined with a belt force limiter, the shoulder belt forces are limited to a biomechanically tolerable level, and better use is made of the forward displacement path. All car occupant load values are significantly under 100% (see Figure 13).

The use of a belt force limiter with a stopper function limits the extent to which the belt extends and thus also the person's forward displacement in a serious crash. This makes sense in order to minimize the risk of the person's head hitting the backrest of the front seat, particularly in the case of large and heavy people. However, reduced forward displacement of the thorax leads to increased head deceleration. For the AM50 dummy, the forward displacement is reduced with this stopper function (maximum belt extension of 240 mm), but the shoulder belt force and head deceleration are increased. However, the possibility of the person's head coming into contact with the backrest of the front seat could not be eliminated. To achieve this, a shorter belt extension of less than 240 mm would be necessary for the AM50, which would have a negative impact on the load of the AF05. This conflict cannot be resolved with the belt alone, because the kinematics of the head cannot be controlled effectively.

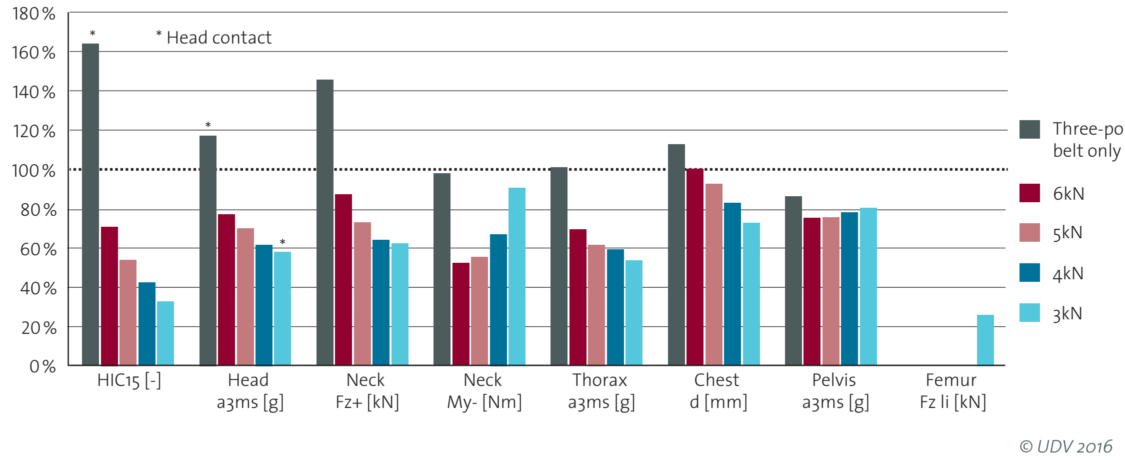


Figure 13: Comparison of car occupant load values for AF05, Test 1 – three-point belt only as well as belt pretensioner/force limiter (3-6 kN)

It is useful to be able to adjust the height of the belt path to suit the car occupant. Pushing the height adjuster up reduces the horizontal retention force, which can contribute to greater forward displacement of the car occupant with the current three-point automatic seat belt and reduce the high loads for rear-seat passengers (see Figure 14).

The limits of a possible height adjustment combined with a lower level of belt force limitation lie in greater forward displacement, resulting in the head coming into contact with the front seat.

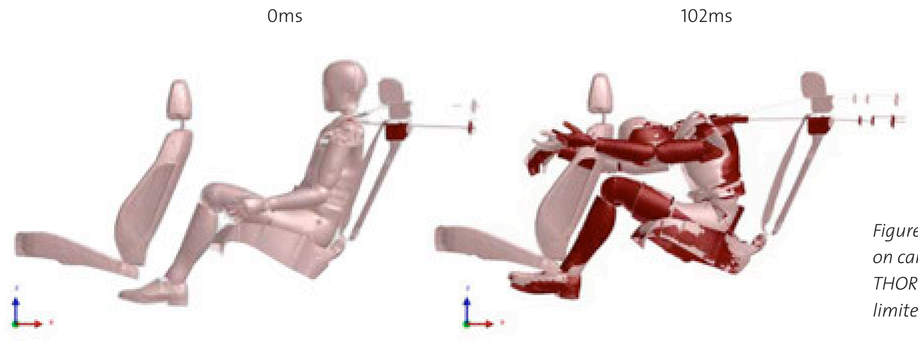


Figure 14: Influence of height adjustment on car occupant kinematics for AM50 THOR with belt pretensioner/force limiter (6 kN)

Another way to improve the protection of rear-seat passengers is to use a suitable airbag. Only with head protection such as this can the movement of the head be effectively controlled and the level of shoulder force be reduced in order to obtain positive effects for the chest area. The head is prevented from coming into contact with the backrest of the front seat.

Figure 15 shows a generic rear-seat airbag (RSAB). The RSAB shown consists of chambers with vertical strips that give it additional rigidity and thus limit the forward displacement of the head and thorax. It has a volume of around 40 liters at an excess pressure of around 0.7 to 0.8 bar.

A comparison of different belt force limitation levels combined with an RSAB shows that the head load is harmonized.

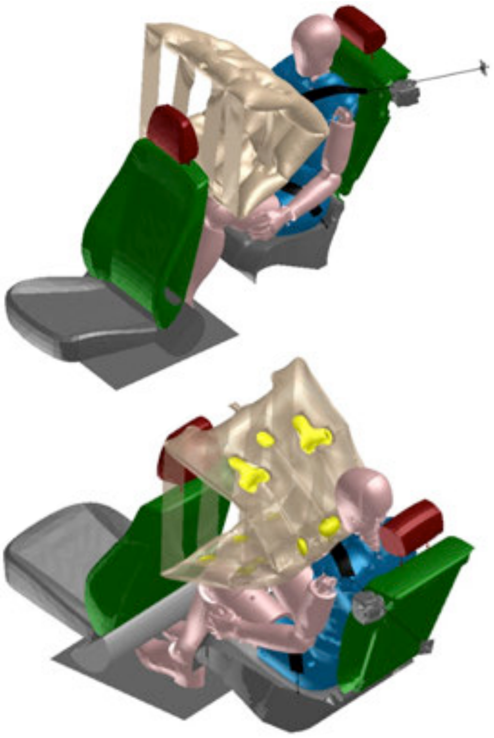


Figure 15: Generic rear-seat airbag with AM50 THOR

Misuse positions

Three positions deviating from the normal sitting position (misuse positions) were studied, too. These can be seen in Figure 16. The position in which the person was leaning forward in conversation with the driver resulted in the head coming into contact with the backrest of the front seat. Chest compression was reduced because the belt exerted more pressure on the shoulder. The extension momentum was increased in comparison to the normal sitting position.

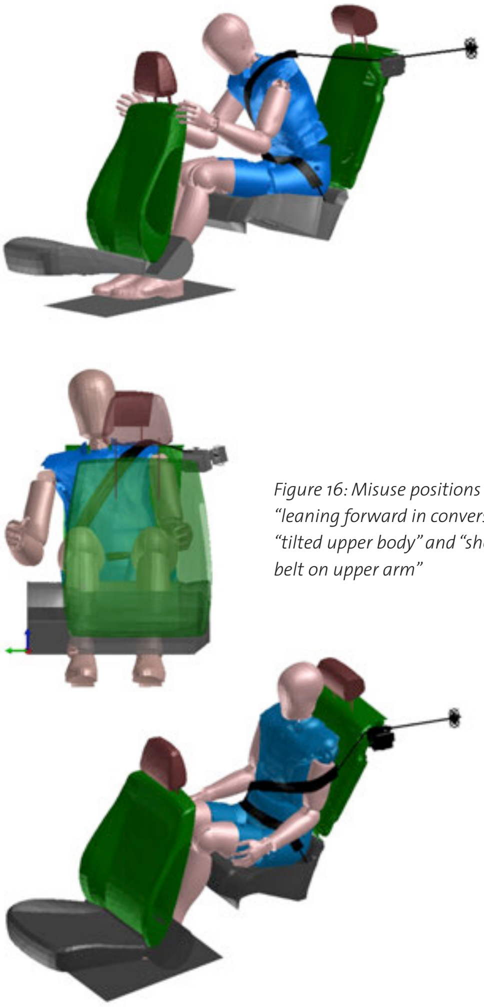


Figure 16: Misuse positions – “leaning forward in conversation”, “tilted upper body” and “shoulder belt on upper arm”

In the position in which the person's upper body was tilted, the shoulder was held back more. There was greater thorax rotation with an increase in chest compression on the belt side. The misuse position in which the person had the belt on the upper arm rather than the shoulder reduced the retention force for the upper body. Here, too, the head came into contact with the backrest of the front seat. Overall, it is clear that the misuse positions studied can become a safety problem for rear-seat passengers.

Summary and recommendations

The accident analyses showed that this issue is relevant. Although this is not a dramatic safety problem compared to other unresolved issues in the passive safety landscape, it is nevertheless unacceptable and incomprehensible to rear-seat passengers. Why are rear-seat passengers not protected to the same extent as people in the front seats? It was shown that rear-seat passengers over recent years have benefited only to a limited extent from the improvements in passive safety.

The results of the online survey and focus group interviews confirm that positions other than the "normal" sitting position are often adopted on the rear seats. It was also revealed that, due to problems with the seat belt being uncomfortable, rubbing against the neck, for example, people often use the seat belt incorrectly. They deliberately place it over or under their upper arm or use their arm to hold it away from their neck. It was shown that this comfort-related problem ends up as a safety problem.

The complex numerical simulations confirm the picture obtained in the accident analysis: Current protection systems for rear-seat passengers are inadequate for small and medium-sized people in serious crashes. The head loads resulting from high deceleration and rotation speeds and contact with parts of the car's interior represent a permanent risk of injury for all rear-seat passengers studied. The thoracic loads ascertained are also critical. The extreme shoulder belt forces can result in fractured ribs and a fractured collar bone. The simulations also show clearly that sitting positions other than the recommended one and incorrect use of the seat belt considerably worsen the injury situation on the rear seats.

The use of a belt pretensioner combined with a belt force limiter can limit the shoulder belt forces to a biomechanically tolerable level. The use of a belt force limiter with a stopper function can be a good compromise in order to reduce the load on the chest and the forward displacement of the head. Adjusting the height of the belt path to suit the person sitting in the rear seat is recommended because it reduces the loads to which the person is subjected.

With a rear-seat airbag combined with a belt pretensioner and belt force limiter, the head can be prevented from coming into contact with the backrest of the front seat and the belt force can be significantly reduced. A comparison of different belt force limitation levels shows that the head load is harmonized (deceleration, HIC, BRIC). However, the critical prerequisite for all these measures designed to protect rear-seat passengers is the use of a seat belt. In addition to awareness-raising campaigns, simple technical measures such as a seat-belt reminder can help here.

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Published: 01/2018

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