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How Did Child Safety Develop During the Last Ten Years?

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1 Introduction

Requirements for the development of cars and CRS changed considerably during the last years. Consumer tests for the rating of side impact performance and the usability of CRS as well as Euro NCAP are mentioned as example.

Within this paper the changes of the performance of CRS has been analysed. Indications for this analysis are changes in the consumer rating programmes, accident data as well as data of full-scale car tests and sled tests.

2 Basics

When discussing child safety one needs to think of influencing factors for this issue. The real world child safety, besides external factors (as rescue quality, accident severity, etc.), depends on:

- protection level of the car
- use / non-use of CRS
- protection level of CRS
- combined performance of car and CRS
- correct or wrong use of CRS

While it is simple to state that these factors are influencing real world safety it seems to be impossible to rate their relative importance.

Looking at the protection level of the car the first issue to be considered is the integrity of the passenger compartment. As long as a minimum of survival space is not given, severe and fatal injuries are very likely independent of the CRS and its use. Other issues influencing real world safety are amongst others the equipment of cars with advanced 3-point-belt systems, air bags (there is a risk of serious injuries caused by frontal passenger airbags), the belt geometry.

When looking at older children (6 years and older) there more than 50% of them observed in Germany in 2004 not appropriately restrained. They were using either the adults' belt or no restraint at all, see Figure 1.

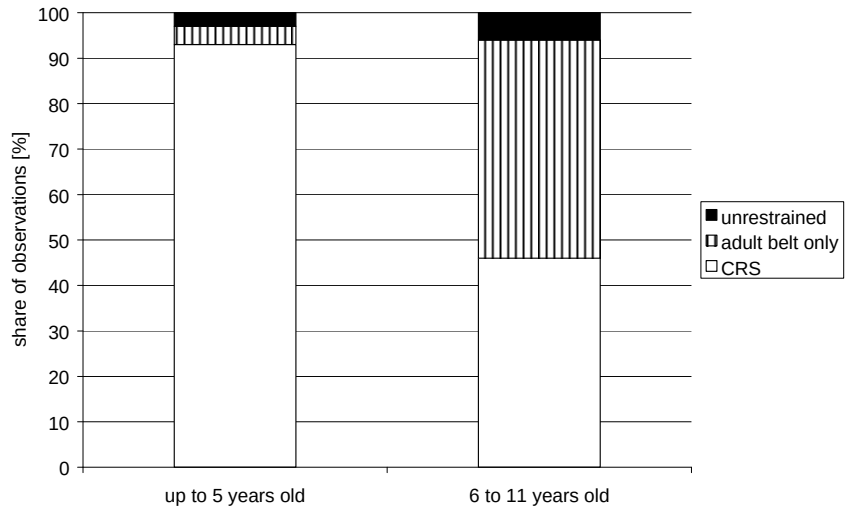

Figure 1: CRS use dependent on age groups [BASt, 2005]

Several studies show that two thirds of the children travelling in cars in Germany are not properly restrained. This includes all kinds of misuse and non-use starting from less severe slight belt slack in the harness system to very severe non-use of any restraint system. In-between everything one can imagine happens (e.g. restraining children in unrestrained CRS, placing children in CRS without closing the buckle, etc.).

Most of the recognised misuse forms lead to increased dummy readings when compared in sled tests [Langwieder, 1997; Lesire, 2007]. However, the correlation between increased dummy readings and increased injury risk has not been finally proven amongst experts.

Weber [Weber, 2008] analysed accidents where children were killed as car occupants. The analysed accidents happened in Germany within the first six months of 2006. In total 12 fatalities were included which represent approx. a quarter of the child fatalities per year. The results are quite clear. In five of the 12 cases there is clear evidence, that the accident had been survivable by using an appropriate CRS (4 cases) or using the CRS properly (one case). In three cases the accident severity was that high that the injury outcome was independent from quality of restraining. In four cases it was not possible to analyse whether the accident severity or the quality of restraining was responsible for the fatality.

The protection level of a CRS also plays an important role. While a minimum safety level is necessary to pass the legal requirements there are better solutions covering also other conditions than those tested in the homologation process (lateral impact is mentioned as one example). Other issues are the potential of misusing the CRS and the capabilities of protection of humans instead of dummies.

Finally the CRS and the car need to work together. On the one hand there is a risk that a specific CRS cannot be installed in a specific car, e.g. because of belt length problems. These cases are probably less dangerous as the user is able to recognise this kind of incompatibility. More problematic seem to be those cases where it is practically possible to install the CRS but because of differences in the design philosophy of car and CRS the combined performance is different from the protection level one would expect when testing car and CRS independently.

3 Requirements for Cars

The requirements for cars influencing child safety are mainly defined in the ECE regulations 14 (belt anchorages), 16 (vehicle belts), 94 (frontal impact protection) and 95 (lateral impact protection). In addition to that the protection level is rated in consumer information programs; within Europe the Euro NCAP test programme is the most important one.

While the original ECE R94 test was a full overlap rigid barrier test its current successor is an off-set deformable barrier test. The most important difference between these two test types with respect to child safety is that the first one is mainly a test of the restraint system and the latter one, which started in the late nineties, emphasises the structure of the vehicle's front forced by the unsymmetrical loading of the car.

Also in the late nineties Euro NCAP was founded. The Euro NCAP frontal impact test utilises the off-set test procedure as defined in ECE R94. However, instead of using an impact velocity of 56 km/h, in the Euro NCAP test the car is running at 64 km/h.

Regarding lateral impact the ECE R95 since its introduction in the mid nineties defines the impact of a 950 kg deformable barrier in a 90° angle to the sample car. Euro NCAP uses the

same procedure. However, since a couple of years the new European Side Impact Dummy ES2 is used in Euro NCAP, while it is not yet in ECE R95. If a head protection system is available an additional pole tests can be performed.

Since Euro NCAP's Phase 9 a dedicated child protection protocol is used; since Phase 13 (2003) the results are published. The rating is based on the assessment of dynamic test results of frontal and lateral impact tests, labelling of CRS and car, the evaluation of the ability of the car to accommodate specific types of CRS (e.g., large rearfacing CRS or at least three places with three-point ISOFIX) and other issues. For the dynamic tests a P1.5 and a P3 sitting in the rear seat are used in the frontal and lateral impact tests as described above. They are using restraint systems as specified by the manufacturer. The P1.5 is sitting at the driver's side (struck side for the lateral impact) tests.

4 Requirements for CRS

Taking into account the homologation of CRS the ECE regulation R44 is mandatory. ECE R44 was initially introduced in the beginning of the 1980s. The regulation among others defines the behaviour in frontal impact tests, the sizes of CRS, material properties and roll-over protection. Since its first introduction it has been amended several times taking into account requirements for easier use and handling (e.g. colour coding), ISOFIX, more stringent Conformity of Production requirements etc. Looking at the regulation there are almost no requirements with respect to side impact performance.

While the regulation defines minimal requirements consumer information organisations are ranking different products and publishing the results. Currently the most important programme is a joint effort of the European Automobile Clubs and ICRT. This so-called ADAC test procedure comprises dynamic tests in frontal and lateral direction and a handling test. ADAC started its publications with respect to child safety with general information and the assessment of different systems (harness, shield, booster, etc.). The assessment of different models started in 2000. Since 2003 they are using comparable test protocols. While from 2003 to 2006 a Golf IV body in white was utilised in 2007 they changed to an Astra H body. The frontal impact pulse was based on the corresponding Euro NCAP pulse. For lateral impact ADAC is using a fixed door concept. The car body is mounted in an angle of 80° at the sled. This configuration places emphasis on the containment of the dummy; especially in forward facing CRS. The score of the product in the ADAC rating results from the worst score of safety and handling. Since 2007 the same procedure is applicable for assessing the safety rating based on the results for frontal and lateral impact. Before 2007 the lateral impact's influence on the rating was limited. In addition to the change of the car body, the dummy family was changed from P-dummies to Q-dummies for the 2007 test. The usability test rates the experience for installing the CRS and securing voluntary children and dummies.

In addition to the ADAC test other test procedures presented by different organisations are published, e.g. the magazine auto motor und sport assessing mainly safety and Auto Bild assessing mainly the usability of CRS. Most of them are less important than the ADAC test procedure e.g. as they normally do cover only a small number of CRS.

Finally a consortium of different EU member states, research organisations and test houses defined a unified test programme for CRS called NPACS. This programme includes frontal and lateral impact tests as well as a usability assessment. The programme is not yet in widely spread.

5 Use and Misuse of Child Restraint Systems

Incorrect use and non-use was the focus of several studies. When analysing the details of misuse it becomes evident that belt slack either in the vehicle's belt or in the harness is observed most often (approx. 40 to 60%) [Fastenmeier, 2006]. Other misuse forms are inappropriate CRS used, wrong belt path, wrong orientation etc.

The issue of misuse is currently addressed by several parent awareness campaigns and is one of the major goals for the development of CRS. The introduction of ISOFIX was mainly meant to reduce both the rate and severity of misuse.

However, comparing three German studies conducted in the area of Munich following the same method in different years it becomes evident that the share of misuse did not change, see Figure 2.

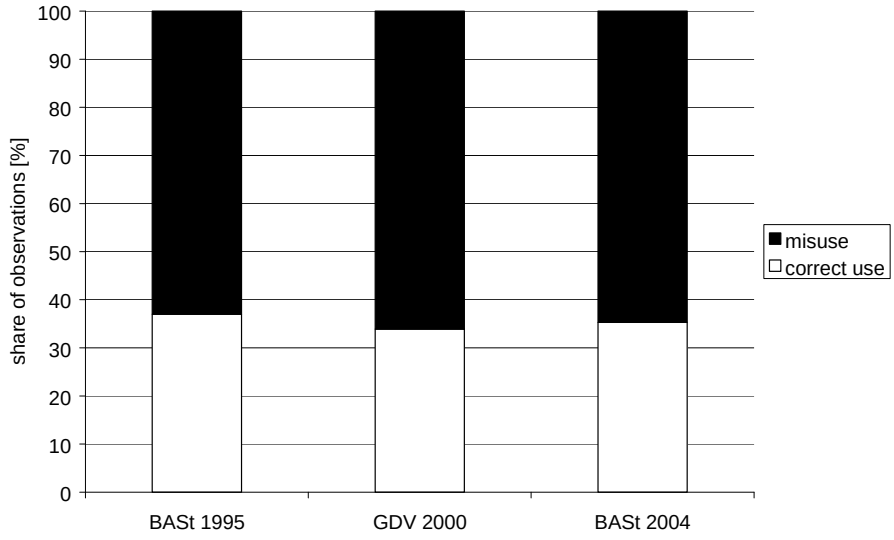

Figure 2: Overall misuse rate in different studies [Fastenmeier, 2006]

Looking at the severity level of the observed misuse one can see significant improvements, see Figure 3.

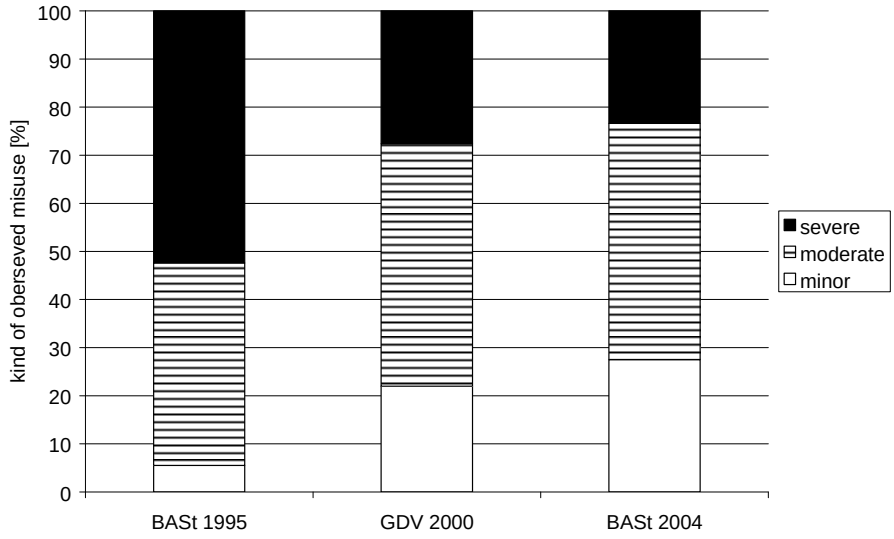

Figure 3: Severity of observed misuse in different studies [Fastenmeier, 2006]

6 Development of the Rating Results in Consumer Tests

Analysing results of consumer information publications for different years gives an indication of the development of products. The ADAC test protocol stayed unchanged between 2003 and 2006 and the changes in 2007 do not change the complete picture as the general design is the same. Although the average of the scoring depends not only on the developments in the CRS market (CRS selection for publication also plays a major role), it indicates the direction of the market. Figure 4 shows that the rating of CRS improved during the years (low rates correspond to good results). Especially the handling rating shows a continuous improvement over the years. The safety and the overall rating are varying over the years but also tend to improve from 2003 to 2008.

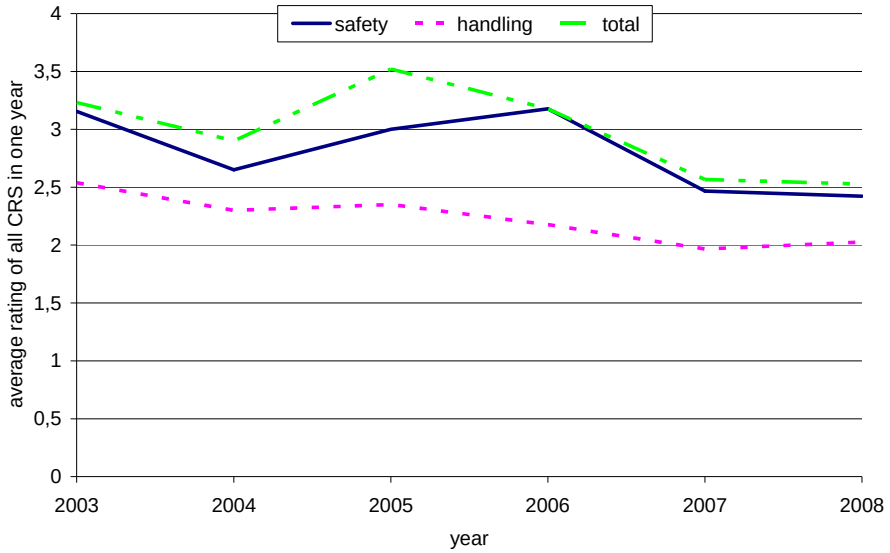

Figure 4: Averaged results in the ADAC tests [ADAC, 2008]

Doing the same analysis for Euro NCAP tests (good results correspond to high rates) it seems that apart from the period between phase 13 and 14 almost nothing changed for the CRS assessment, the car assessment and the dynamic testing. Another interesting information is that the child seat manufacturers of the CRS tested in Euro NCAP did their homework and on average achieve almost the maximum achievable points. The car related ranking is nearly half of the achievable points and the assessment of the dynamic tests gives on average a little bit more than half of the achievable points.

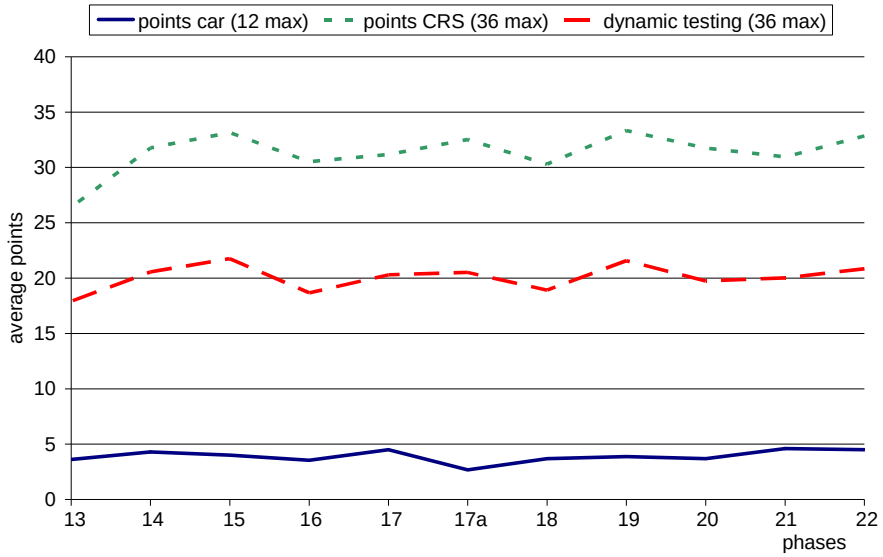

Figure 5: Averaged results in the Euro NCAP test phases

7 Results from Full-Scale and Sled Tests

For achieving another indication for the development of child safety during the last years full-scale tests using a modern car built in 2007 achieving 4 stars in the Euro NCAP child safety protocol and its predecessor developed ten years before were conducted. In both cars a 2007 branded group I forward facing CRS and its predecessor developed ten years before were tested using Q3 dummies. Finally both CRS types were analysed in sled tests according to ECE R44 and NPACS test procedures. The cars were tested according to the old ECE R94 frontal impact test procedure against a rigid wall. As mentioned earlier, this test is mainly a test of the restraint systems.

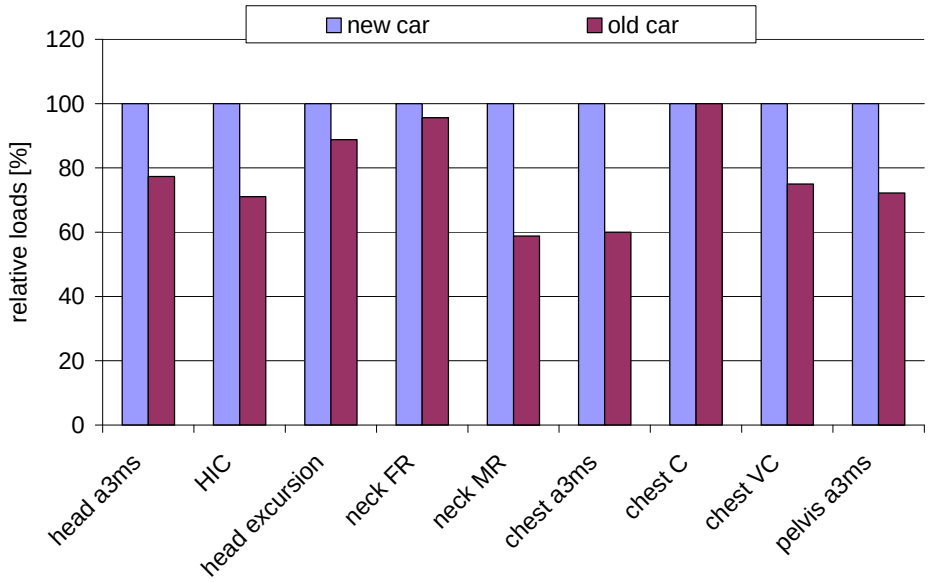

Figure 6: Comparison of new and old car with new forward facing CRS

According to the expectations the safety performance for children in the rear seat is better in the old car compared to the new car, see Figure 6. This is mainly due to the increased force level of the front structure of the newer car to cope with the Euro NCAP requirements, e.g.,

passenger compartment integrity. This increased force level is compensated for adult passengers in the front seats by improved belt systems and airbags.

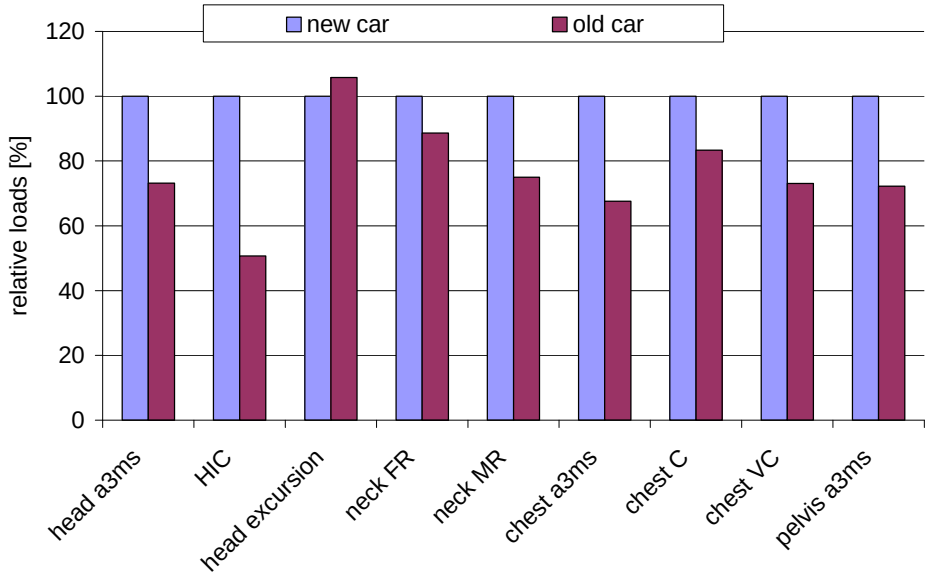

Figure 7: Comparison of new and old car with old forward facing CRS

Surprisingly the comparison of old and new CRS in one car indicates better performance of the old CRS compared to the new one, see Figure 8. Note that the new CRS is equipped with a device for reducing slack in the vehicle's belt. Therefore especially improvements in chest acceleration and head excursion were expected. The head excursion improvement may be jeopardised by a thicker back rest and CRS rear structure resulting in a more forward initial head position in the new CRS compared to the old one.

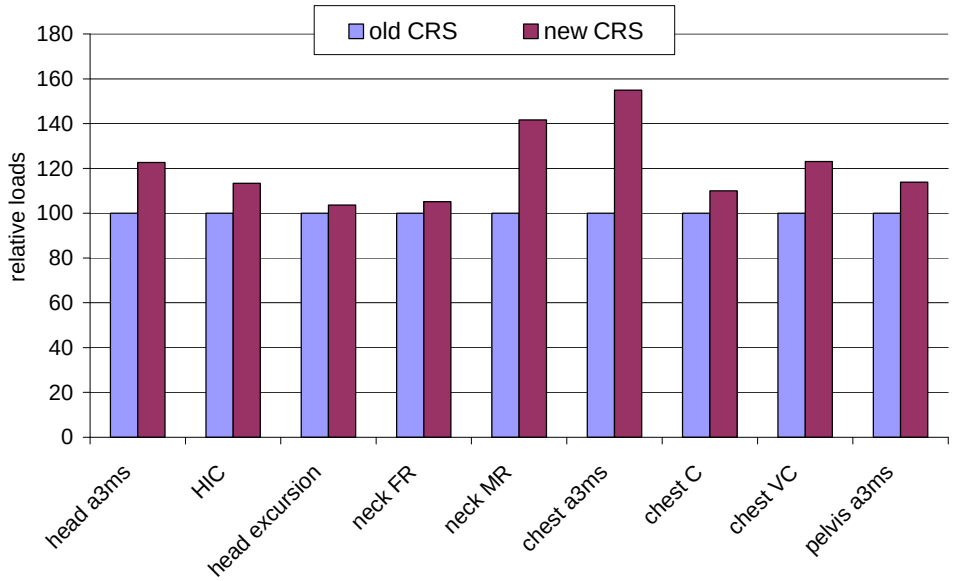

Figure 8: Comparison of new and old CRS in new car

While in the new car all dummy measurements show better results in the old CRS for the old car at least the head excursion is better in the new CRS compared to the old one, see Figure 9.

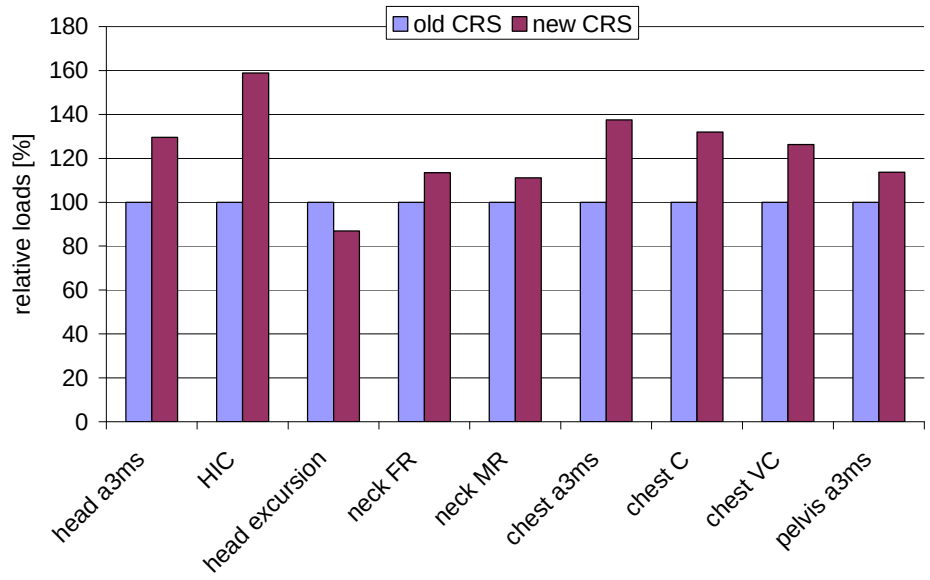

Figure 9: Comparison of new and old CRS in old car

To further analyse the behaviour of the CRS sled tests according to ECE R44 and NPACS frontal and lateral protocol were conducted.

Looking at the frontal impact test results mainly minor differences are visible. The head excursion is better in the new CRS for both test procedures – in the NPACS test the difference is larger, see Figure 10. Important differences are visible for neck forces and chest VC where the new CRS is considerably worse in both test procedures than the old CRS. Another interesting issue is the mismatch between chest acceleration in Z-direction and the neck forces. While in the ECE R44 test procedure the chest acceleration in Z-direction is considerably lower in the new CRS the neck forces are much higher compared to the old CRS.

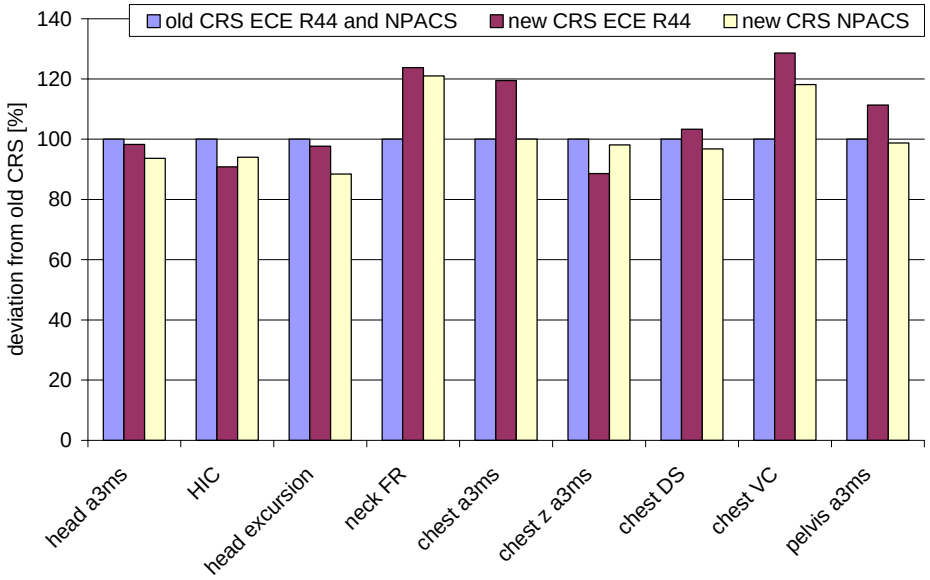

Figure 10: Comparison of new and old CRS in ECE R44 and NPACS frontal impact tests

To assess the overall development of the CRS it is necessary to use a rating system that combines the different criteria to one result. In principle three different rating schemes are possible. First of all the NPACS rating procedure which has been designed for the NPACS

test procedure; in addition the ADAC procedure and the Euro NCAP system. Both the ADAC and the NPACS frontal impact test procedures are based on Euro NCAP tests. Therefore all the three rating systems are meant for the same kind of test severity. The rating according to the Euro NCAP protocol results in 0 points for all tests. The rating according to NPACS and ADAC is shown in Figure 11. According to the ADAC rating no difference exist. Looking at the NPACS rating scheme the new CRS is considerably worse in the ECE R44 test compared to the old one while there is no difference in the NPACS test.

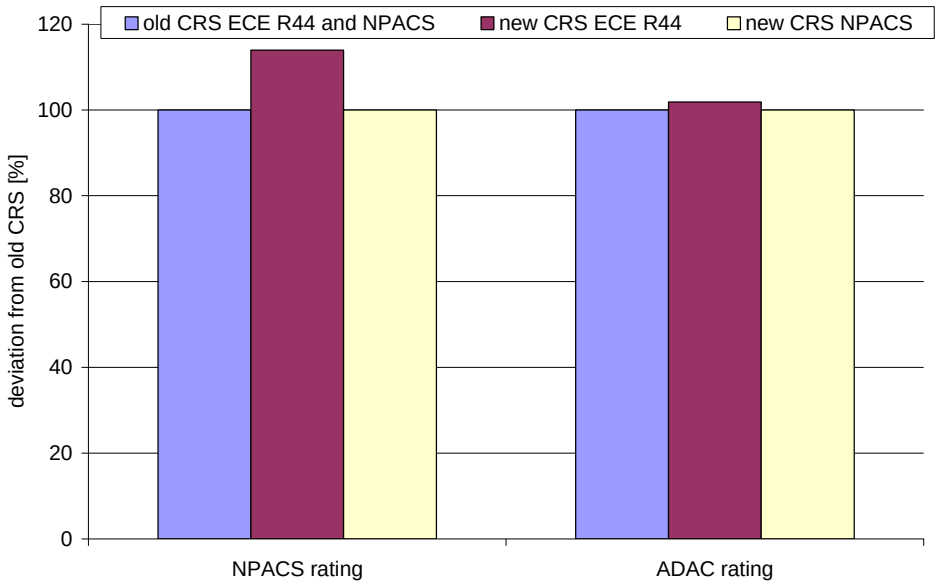

Figure 11: Comparison of rating of new and old CRS in ECE R44 and NPACS frontal impact tests

For lateral impact improvements are visible. First of all the head containment capabilities - the side wings for supporting the head became larger in CRS X- and Z-direction in the new CRS. However, according to the NPACS rating protocol the head containment of the old CRS was already good. The head acceleration is slightly higher in the new CRS but HIC is considerably lower in the new one, see Figure 12. Other improvements are visible for chest compression and VC as well as pelvic acceleration.

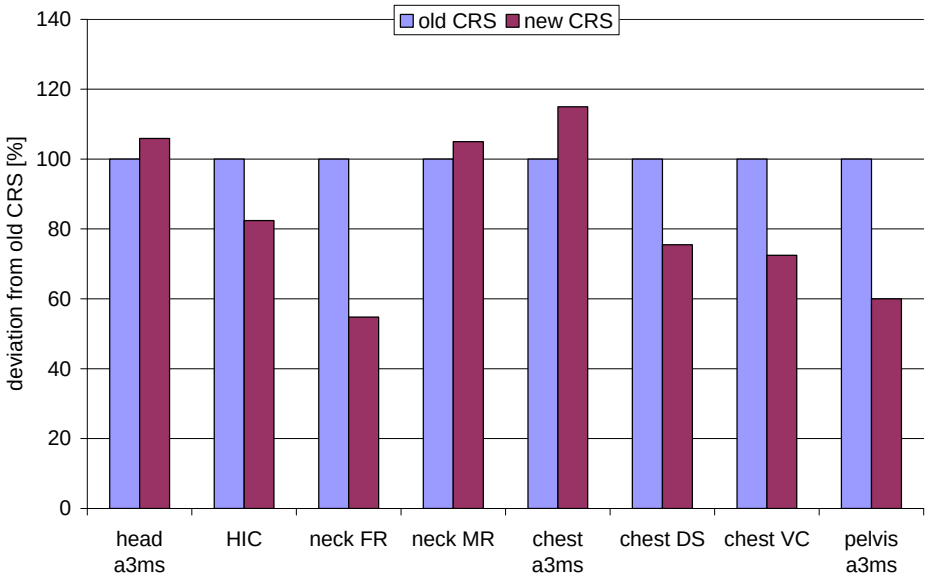

Figure 12: Comparison of new and old CRS in NPACS lateral impact test

To assess the overall development of the CRS it is necessary to use a rating system that combines the different criteria to one result. Again the rating schemes according to ADAC, Euro NCAP and NPACS are used for this comparison. According to ADAC and NPACS rating protocol a 10% improvement is given for the new CRS. Looking at the Euro NCAP rating nothing changed as in the old CRS too small side wings lead to a rating of 0 points and in the new CRS the high head acceleration results in 0 points. Note that the rating schemes of ADAC and Euro NCAP are not designed for the assessment of NPACS tests. One example for a mismatch is the head containment. Due to different test procedures it is very likely that the head kinematics is different in all three test procedures.

When comparing the results of the different dynamic tests one may forgot the influence of handling and misuse. The evaluated CRS is much easier to handle and seems to be less sensitive to misuse compared to the old one. Therefore better results can be expected in the field.

8 Development of Real World Safety

The real world safety for children as car occupants depends on

- safety performance of the car (including active and passive safety)
- safety performance of the CRS
- correct use of the CRS
- environmental issues like traffic organisation and rescue.

Based on the German overall accident data considerable improvements in the safety performance of cars and the environmental issues as described above can be observed. Within the time frame from 1997 to 2007 the number of killed car occupants dropped by approximately 60%. This development is a benchmark for the development of child safety within the same period.

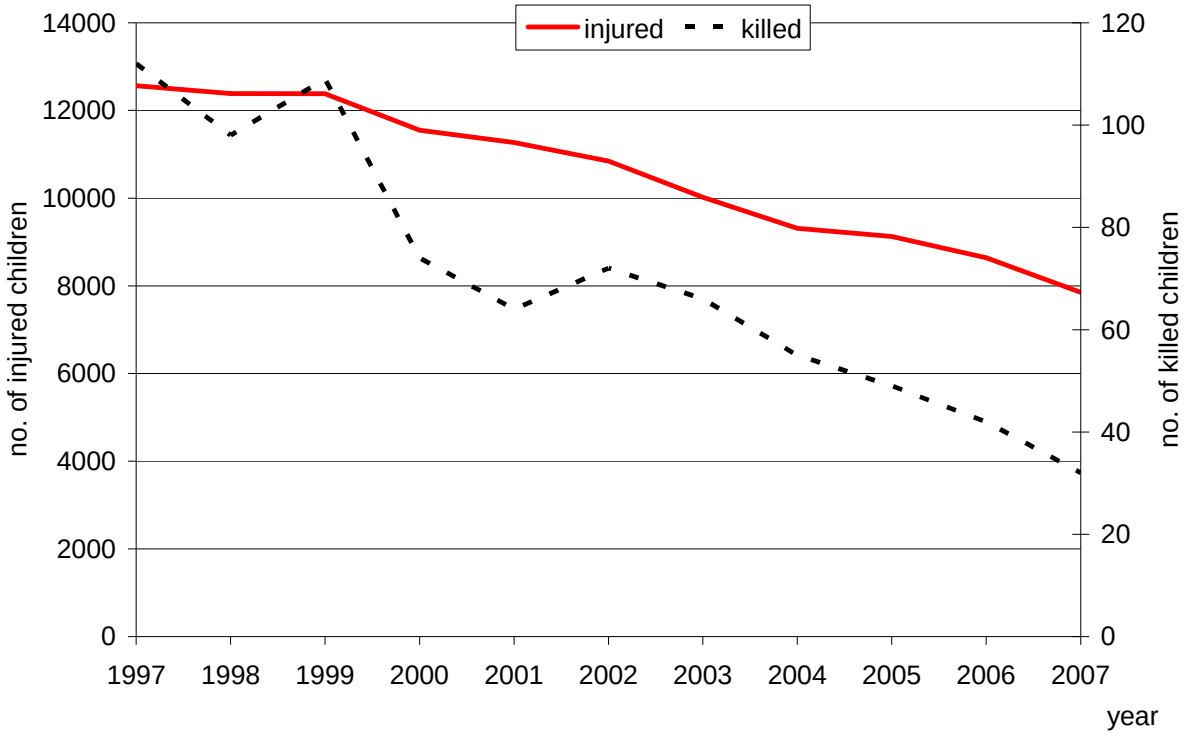

Figure 13: Accident data time history for children (younger than 12 years) as car occupants in Germany [STATIS, 2008]

Another issue is that the general population increased by approx. 5% while the child population decreased by approx. 15% between 1997 and 2007. Following that, a reduction in the numbers of children killed as car occupants of approx. 68% can be expected. The actual development of children injured or killed as car occupants is shown in Figure 13. Comparison of the number of children killed as car occupants in 1997 and 2007 shows a reduction of approx. 71%. That means that almost nothing specific happened in child safety in this period of time. The development of number of children killed just followed the general trend in car safety.

9 Conclusion

The requirements for cars and CRS did change considerably during the last decade, e.g., usability of CRS moved in the focus of consumer rating programmes and therefore the CRS development. In addition the dynamic response in the well known consumer information test procedures improved globally. However, when comparing one specific group I product with its ten years old predecessor in different test procedures no dynamic improvement in frontal impact tests can be observed. The same is true for a comparison of rear seat safety in the same group I seat as mentioned above in a specific car and its ten years old predecessor. For lateral impact minor improvements are visible. In addition the German accident time history shows for children exactly the same trend as for adults. That means that the CRS modifications did not change the accident outcome in general. Following that it is questionable if the requirements for the development of cars and CRS are well adjusted.

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