

8th International Conference
Protection of Children in Cars
Munich, December 2nd and 3rd 2010

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***Is it possible to optimise the rear seats for children (6 YO
and above) and adults?***

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1 Abstract

While there are stringent regulations for the use of appropriate Child Restraint Systems (CRS) in Europe the share of non-use and misuse of CRS is approximately 2/3. Especially for older children (above an age of 6 years), the share of children using a CRS declines dramatically. There are several reasons for this decrease. The most important one seems to be that parents do not see the benefit of boosters, which mainly adapt the belt geometry to the child's needs. Another reason could be caused by the regulation itself. Although children below 150 cm (which are meant to be less than 12 years old) are obliged to use a CRS (EU directive 2003/20/EC) these child restraint systems are homologated only for children with a weight of less than 36 kg. Several children do not pass the limits for CRS use but are heavier than 36 kg. So, especially older children feel that "CRS are only for babies".

Today's car restraint systems are designed to protect adults (size approximately 1.5 to 2 m) in accidents. Therefore special child restraint systems are necessary to protect children. The design of the rear seat restraint systems is mainly influenced by ECE R14 and ECE R16.

The idea of the research described within this paper is to analyse the possibilities for optimisation of the rear seat to enable good accident protection for children with an age above 6 years and adults. It was possible to develop measures to allow good protection of older children without decreasing the safety for adults and without violating ECE R14 and ECE R16. The capabilities of the measures were proven by numerical simulation and physical testing.

2 Introduction

Child safety is a world-wide discussed issue. Taking into account Germany's accident statistic, it is obvious, that almost half of the children killed in road accidents were car occupants. While there are stringent regulations for the use of appropriate Child Restraint Systems (CRS) in Europe the share of non-use and misuse of CRS is approximately 2/3. Especially for older children (above an age of 6 years), the share of children using a CRS declines dramatically. There are several reasons for this decrease. The most important one seems to be that parents do not see the benefit of boosters, which mainly adapt the belt geometry to the child's needs.

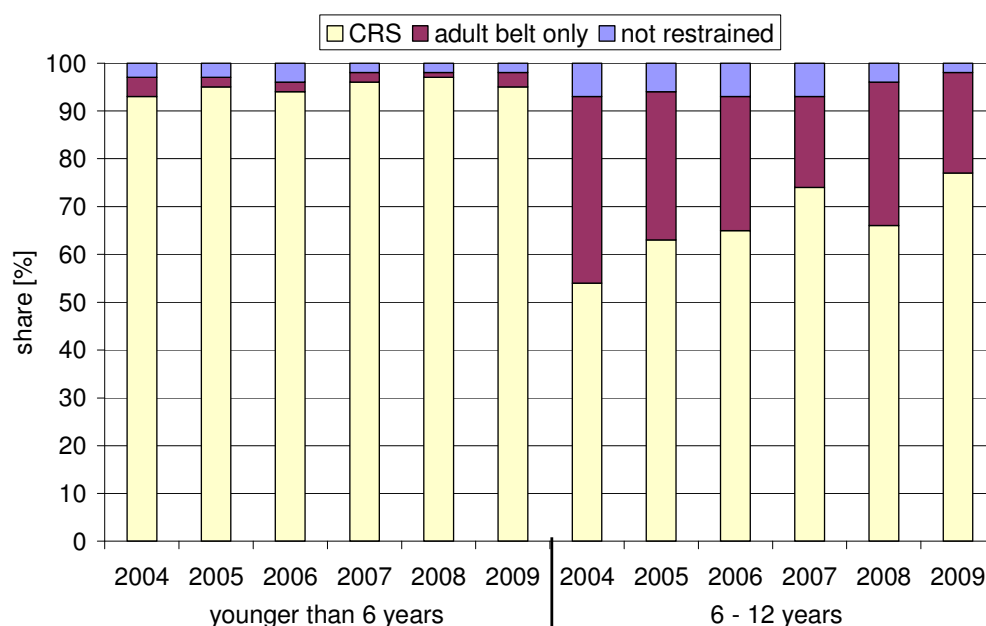


Figure 1: Development of restraining situation of children using the rear seat in urban traffic in Germany depending on age [Statistisches Bundesamt, 2007 / Statistisches Bundesamt, 2010]

Today's car restraint systems are designed to protect adults (size approximately 1.5 to 2 m). Therefore special child restraint systems are necessary to protect children.

Child restraint systems need to be homologated according to ECE R44. Depending on the weight of the child four different groups of CRS are defined. Group 0+ should accommodate children up to a weight of 13 kg. Group I seats are suitable from 9 kg to 18 kg, while group II CRS should be used for children with a weight between 15 and 25 kg and finally group III for children weighing above 22 kg and less than 36 kg. Group III is meant for children with an age of six to twelve years.

Child safety is rated by consumer tests for the CRS and by Euro NCAP for a CRS-car combination. For the time being Euro NCAP assesses the safety level of a P1.5-dummy (representing an 18 months old child) and a P3-dummy (representing a 3 years old child). The Euro NCAP child safety protocol was meant to encourage car manufacturers to improve the car related child safety. From the governmental point of view, efforts by the OEMs to improve the situation are only small. Most of the improvements observed in Euro NCAP assessment resulted from CRS optimisation. Following that Euro NCAP is currently discussing the benefits of including larger dummies in the test protocols such as Q6, Q10 etc. Governments believe that the car manufacturers are getting more responsible for child safety when larger dummies are used.

The question is whether or not it would be possible to accommodate children of 6 YO and older and adults in the same car seat.

3 Safety Needs of Children

Children are not miniature adults. This well known sentence e.g. stated by Tarriere [Tarriere, 1995] describes that children are different from adults and need their dedicated restraint systems. In brief the differences are:

- size
- geometrical proportions
- mass distribution and CoG location
- bone structure
- muscles and ligaments
- vulnerability

According to a study in the former GDR performed in the late seventies and early eighties of the last century 6 YO children have in average a stature of 120 cm [Flügel, 1986], see Figure 2. From that age they are growing to 150 cm in average when they are approx. 12 YO.

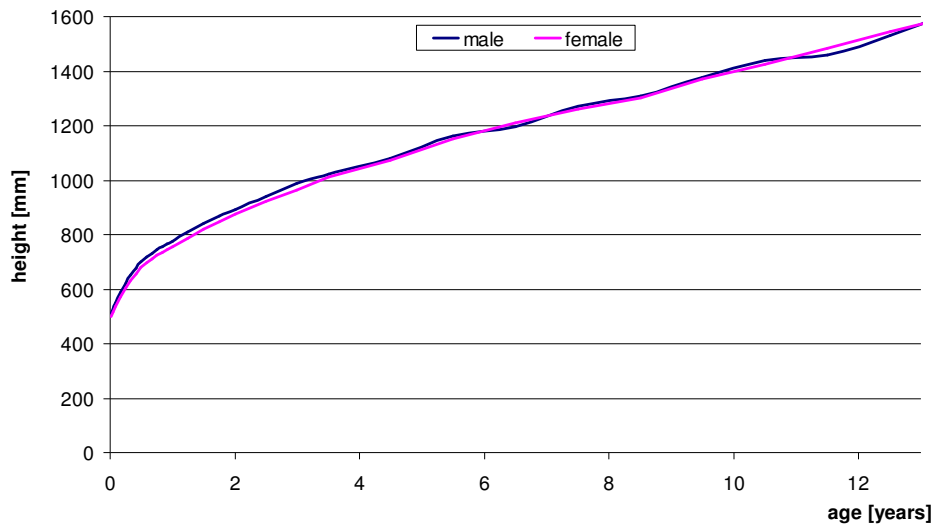


Figure 2: Stature of children depending on age [Flügel, 1986]

The change in sitting height is approx. half of the stature between 6 YO children (sitting height 65 cm) and 12 YO (sitting height 80 cm), see Figure 3. When analysing the Figures from the GDR study it is important to consider the trend that humans still tend to become larger from one generation to the next. That means that the average in Figure 2 and Figure 3 underestimate the size of today's children.

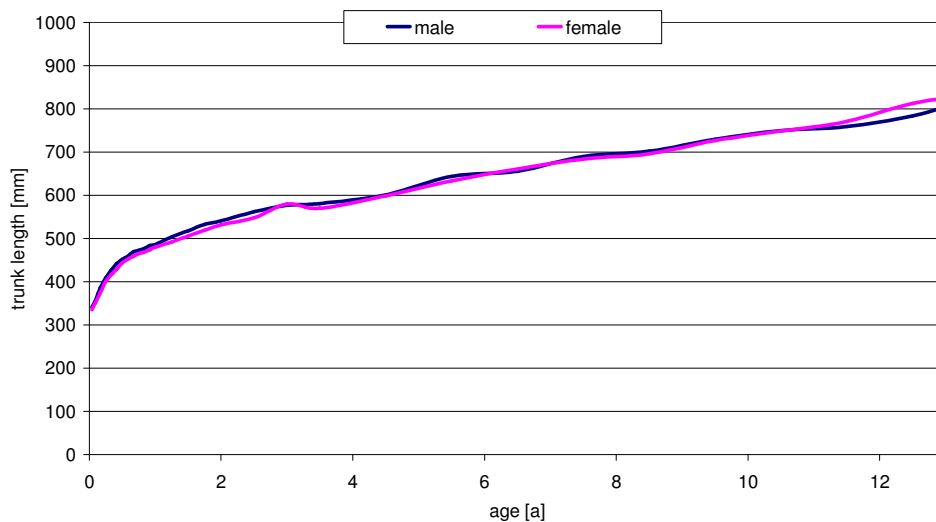


Figure 3: Sitting height of children depending on age [Flügel, 1986]

- In young children the head is predominant with respect to size and weight compared to older children and adults. Following that the centre of gravity (CoG) moves downwards in relation to stature from newborns to 12 YO children, see Figure 4.

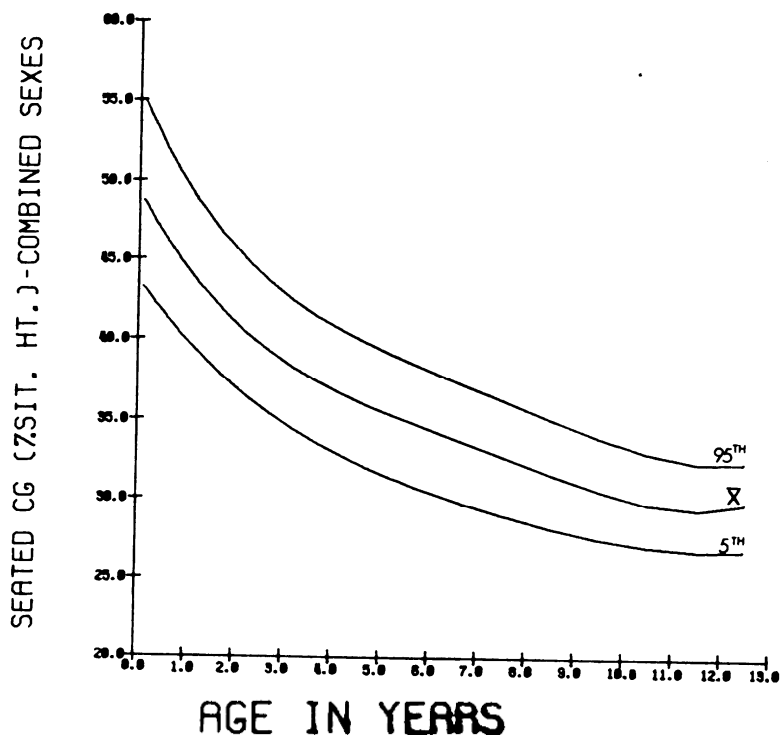


Figure 4: CoG of sitting children depending on the age [Snyder, 1975]

The implications of the size, geometrical proportion and the mass distribution are:

- Sitting height has an influence on the shoulder belt fit in the neck area. While belt-neck contact seems not to be an original safety issue it is a question of comfort which often results in a safety problem. In order to prevent the uncomfortable belt-neck-contact children tend to wear the shoulder belt below the arm or behind the back. Both options are connected with high injury risks.
- Location of the CoG is important in order to judge whether or not an adult belt would be capable to mitigate child ejection from CRS. The higher the CoG the higher the risk is to become ejected in a frontal impact accident. However, the CoG in children above 6 YO is very close to that of adults. It is expected that the risk of being ejected using a three-point belt system is not applicable above an age of 4.
- Finally the leg length defines the leg posture and following that the body posture. If the leg length is longer but the upper leg length is shorter than the length of the seat cushion, children tend to sit in the car in a slouched posture, see Figure 5.

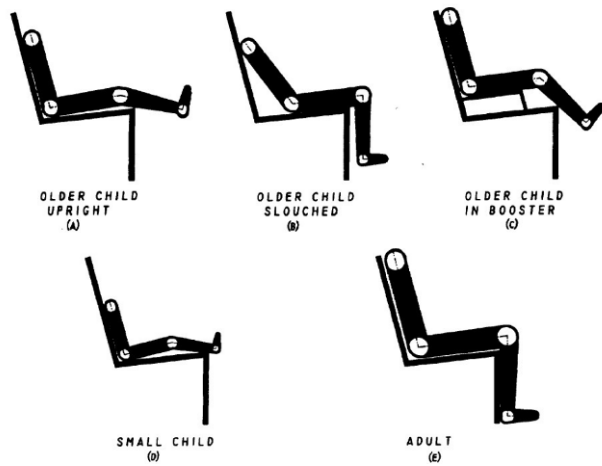


Figure 5: Sitting positions [DeSantis Klinich, 1994]

For the assessment of the sitting position knowledge about the seat design is important. Based on measurements of 64 recent cars (mainly family vehicles) the seat cushion length varies from 380 to 525 mm with an average length of 450 mm, see Figure 6.

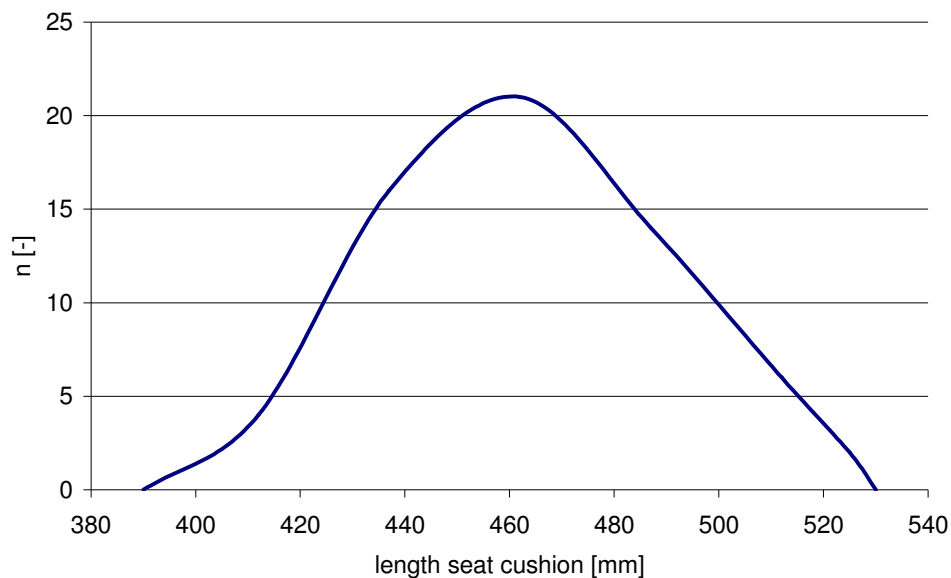


Figure 6: Length of rear seat cushion in 64 cars

The leg length from buttock to feet in average with an age of approx. 4 years already exceeds the cushion length. Following that it is impossible for children above 6 YO to sit comfortably on a normal car seat with stretched legs. The end of the seat cushion would cause discomfort for the calves.

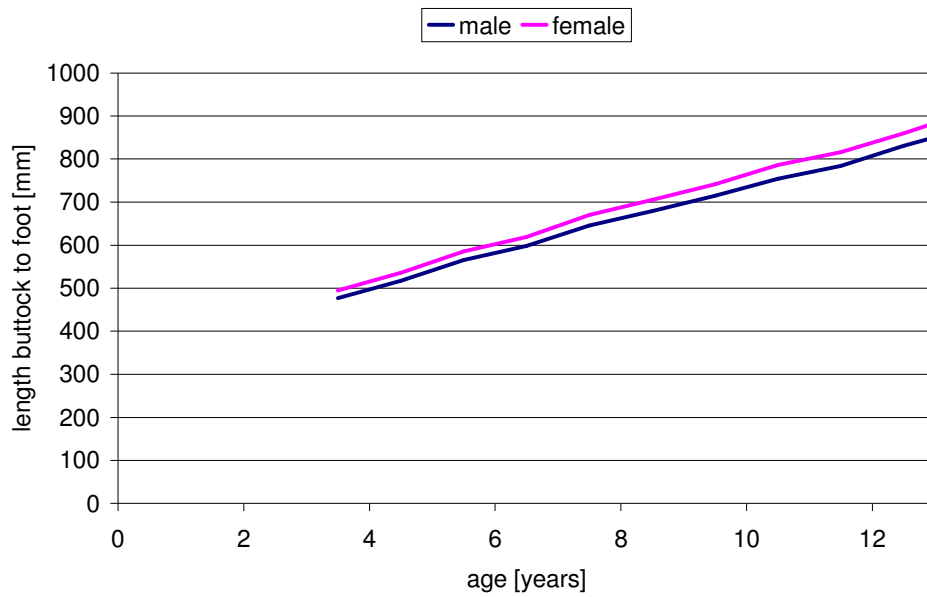


Figure 7: Leg length from buttock to feet [Flügel, 1986]

On the other hand the upper leg is in average not long enough to exceed the seat cushion in order to sit in a normal posture before an age of 12, see Figure 8.

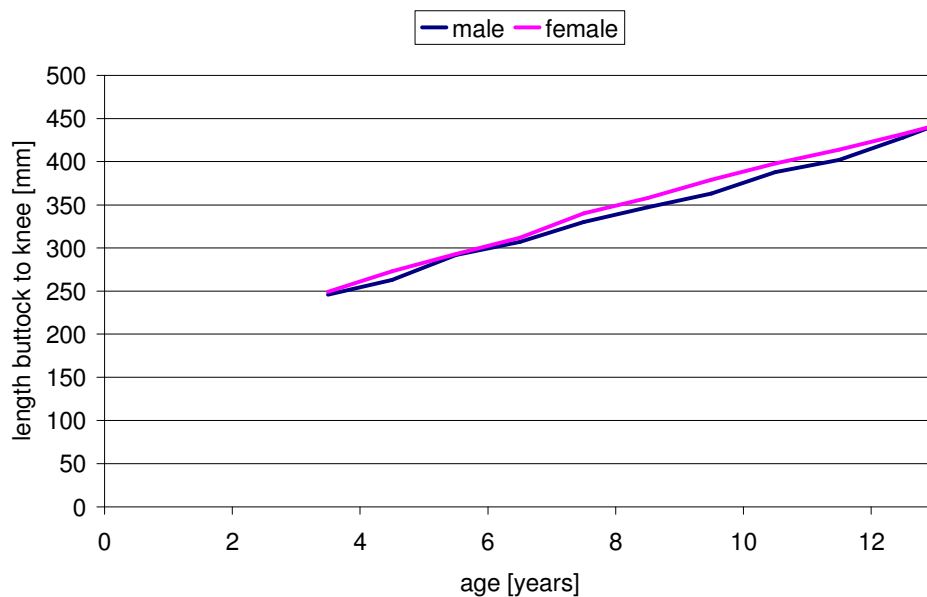


Figure 8: Leg length from buttock to knees [Flügel, 1986]

With respect to the bone structure it is important to mention that bones in children are generally more flexible than in adults. In addition ossification of cartilage takes place until puberty. These issues have the following implications on child safety in cars:

- In combination with the relatively heavy head the neck of young children is not strong enough to withstand frontal impact loads in forward facing CRS

- The pelvic bone design in children does not guide the lap belt in the same way as the adult pelvis is doing, see Figure 9.

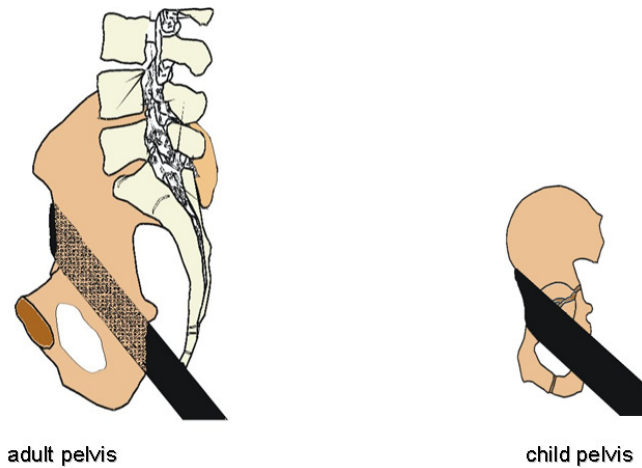


Figure 9: Comparison of pelvic bone design [Tarriere, 1995]

The ossification of the pelvic bone results in the so called iliac crest. The iliac crest guarantees good lap belt fit even if the pelvis is slightly rotated. In children there is a considerable risk for abdominal injuries caused by the lap belt which could slip upwards from the pelvic bone.

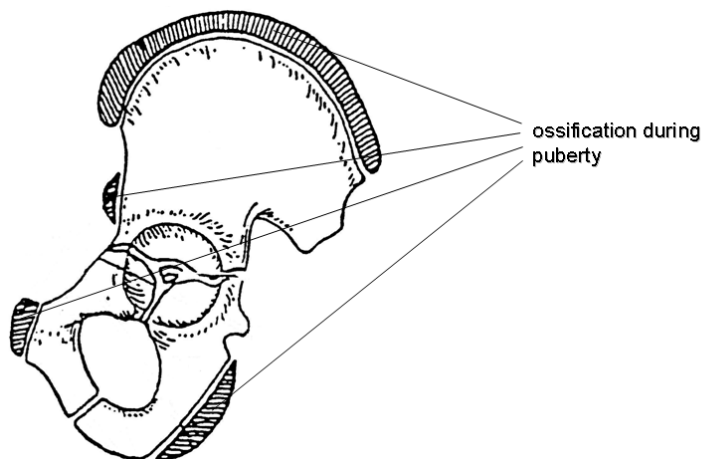


Figure 10: Ossification process in pelvic bone [Tarriere, 1995]

The implications resulting from the neck are not applicable for the age group of interest for this study. The issue can be solved in rearfacing CRS which are recommended to be used at least for the first twelve months. Several publications strongly recommend higher ages for safe forward facing transport of children.

In order to avoid submarining mainly resulting from the pelvis shape in children it is necessary to route the belt more over the thighs than along the pelvis. This can be assured with booster seats. They are improving the belt routing by increasing the height of the pelvis and thighs with respect to the belt anchorage points. If booster seats shall be avoided, other measures are necessary.

4 Concept for an Optimised Rear Seat

Rear seats homologated as ECE R44 group III seats already exist in small sportive cars which do not offer full space rear seats, e.g., Audi TT. For ensuring safety for the corresponding age group retractor pretensioners are normally used. If not only niche cars shall be equipped it is important to analyse the boundary conditions in detail.

To investigate the factors that influence the risk of submarining, dummy tests and numerical MADYMO simulations were conducted focussing on adult occupants [Håland, 1991]. The main factors that support submarining were belt slack, upper belt anchorage far behind the shoulder, higher lap belt angle. A better-restrained torso increases the risk of submarining. That means that the introduction of a seat belt pretensioner for the optimised car seat is reasonable in order to avoid belt slack. However, it seems to be necessary to mainly restrain the pelvis better than the torso. Following that lap belt pretensioners would do a better job for this application than retractor pretensioners (due to the friction at the buckle slip ring the retractor pretensioner mainly reduces belt slack in the diagonal belt while the buckle pretensioner reduces belt slack in lap and diagonal belt with the same efficiency, pretensioning at the lower belt bracket leads to main pretensioning at the lap belt). The main disadvantage of pretensioners at buckle or lower belt bracket is the package. The rear seat benches often do not offer enough space for the integration of pretensioners in the area of the seat cushion. The efficiency of buckle pretensioners was also confirmed by the Håland study [Håland, 1991]. The advantage of retractor pretensioners was found to be less compared to buckle pretensioning.

In addition to the pretensioning of the belt the position of the belt anchorages is important. In general the positions of the belt anchorage points in cars are limited by ECE R14, see Figure 11.

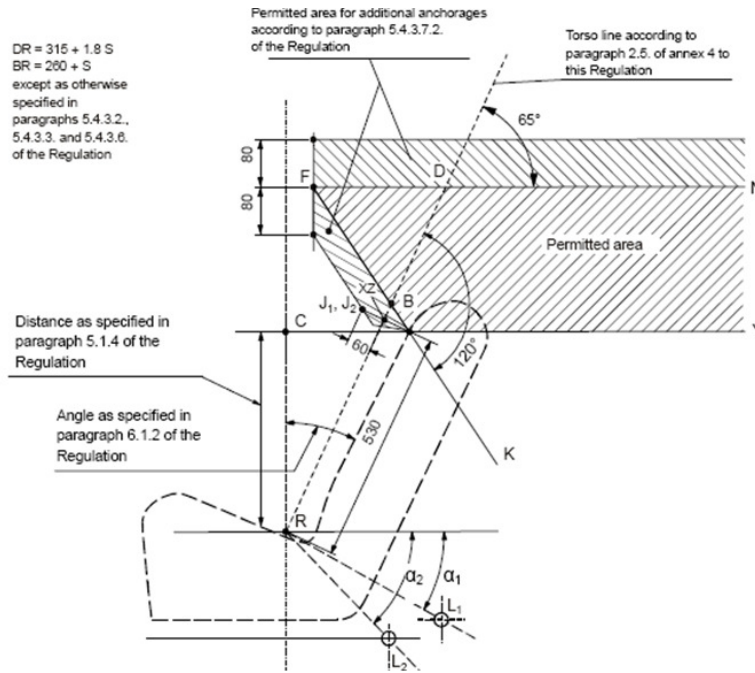


Figure 11: Location of allowed belt anchorage points according to ECE R14

The R point is defined by the seat design and represents for car seats without the possibility for adjustments the pelvic centre of gravity of a 50%ile male. For rear seats the angle α shall be between 30 and 80°. Figure 12 shows the area where the lower anchorage points in the rear seat are allowed to be positioned.

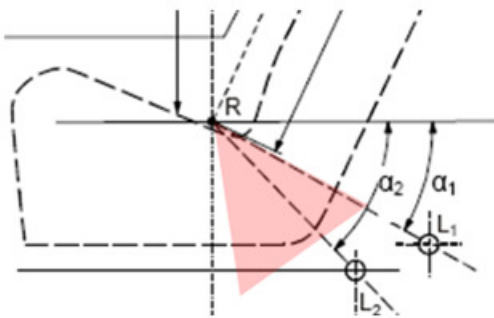


Figure 12: Allowed lower belt anchorage points in rear seats according to ECE R14

Regarding the positioning of the lower belt anchorage points there is a trade-off between the two aims to route the belt more over thighs than along the pelvis (which would require a position in the front) and the other one to have a good pelvis restraint (which would require a lap belt position more in the rear). In general it can be expected, that the trade-off described above can be solved by the introduction of a pretensioner mainly tensioning the lap belt. Following that the lower anchorage points will be positioned as far as possible in the front. During the evaluation (described in chapter 5) the influence of effective anchorage points (e.g., the buckle is outside the

allowed area but rotates around a point inside the allowed area) was analysed. It was found that this measure did not bring any advantage with respect to the scope of this study.

Although it is well known, that seat ramps help to avoid submarining there are still cars on the market not offering these devices in the rear. Following that the concept will utilise a seat ramp also in the rear.

Finally for the analysis of a more comfortable upright seating position for children a shortened seat cushion and a modification of the upper belt anchorage point location is made in order to allow a comfortable shoulder belt routing.

5 Evaluation

The evaluation of the concepts took place in two independent steps. On the one hand MBS simulation using a Q6 model took place. In addition a body-in-white of a small family car of the late 1990s and early 2000 was used for sled tests using a Q6 dummy. For both approaches the influence of the modification for adults was checked using a HIII 50% model or HIII 50% dummy, respectively. All tests and simulations were run with an ECE R44 frontal impact pulse.

5.1 Simulation

The main issue is the belt routing. In order to improve it the distance between the lower belt anchorages was reduced and the height of the upper belt anchorage was reduced within the limits defined by ECE R14. The modification already improved the belt routing but there is still a belt-to-neck contact, see Figure 13.

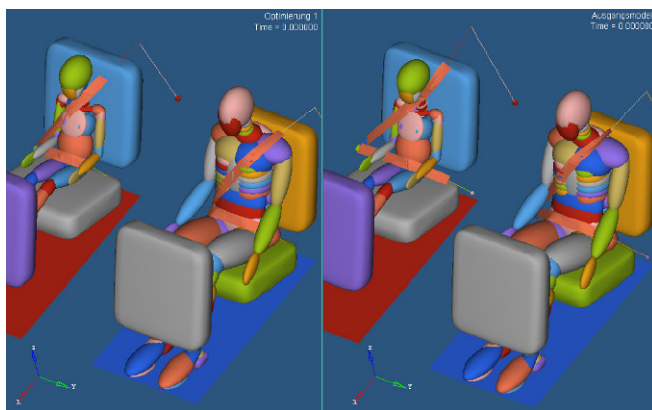


Figure 13: Comparison of modified anchorage points (left) and standard anchorage points (right) for Q6 and HIII model

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Further optimisation would require moving the upper belt anchorage more to the front, the outside or below the ECE R14 area.

The next step involved the forward movement of the lower belt anchorages to the limit as defined by ECE R14 on the one hand and in front of that limit on the other hand. The movement of the lower belt anchorages to front already reduced the submarining risk of Q6 while it almost did not change the HIII performance, Figure 14.

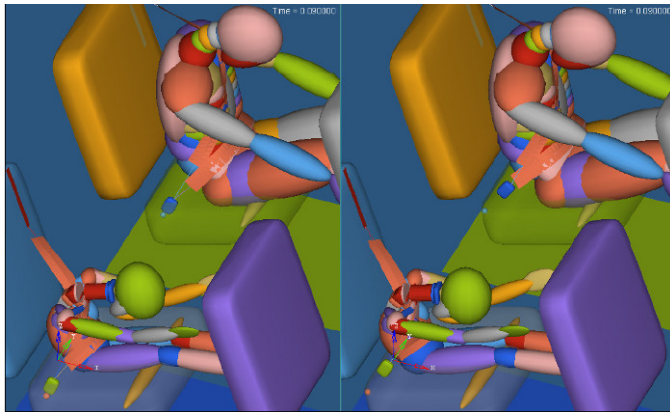


Figure 14: Comparison of lower belt anchorage moved to the front (left) and standard anchorage points (right) for Q6 and HIII model

However, the lap belt still moves towards the abdomen. Therefore another option with lower belt anchorages in front of the ECE R14 zone was tested. In this step the lap belt remained partially at the thighs and did not exceed the pelvis towards the abdomen, see Figure 15.

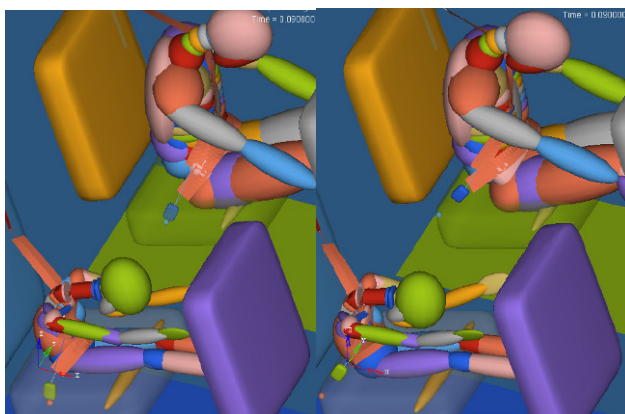


Figure 15: Comparison of lower belt anchorage in front of ECE R14 zone (left) and standard anchorage points (right) for Q6 and HIII model

The introduction of buckle pretensioner and anti-submarining device further improved the situation.

One of the problems of children not using a booster seat is the uncomfortable leg position. In order to solve this issue a shortened seat cushion was evaluated, see Figure 16.

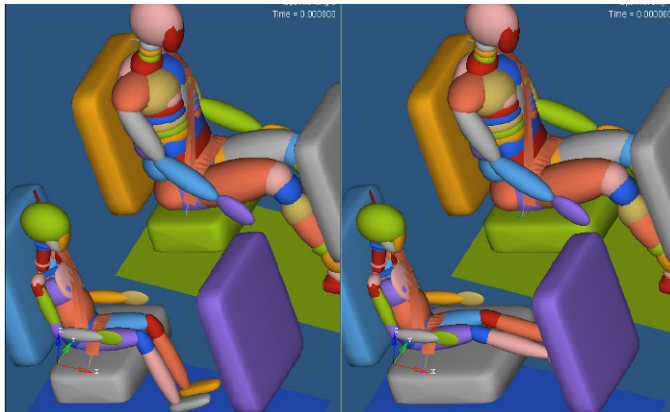


Figure 16: Shortened seat cushion (left) and standard seat cushion (right) for Q6 and HIII model

However, the shortened seat cushion shows considerable disadvantages in crash conditions. The adult dummy's pelvis approaches the end of the seat cushion what is not acceptable. In addition the child dummy tends to submarine, see Figure 17. The changed dummy kinematics is a result of the modified seating position. While in the standard cushion the feet have contact to the front seat and are increasing the pelvis restraint it is not the case for a "standard" seating position on the shortened cushion. However, no pretensioner was applied in this configuration.

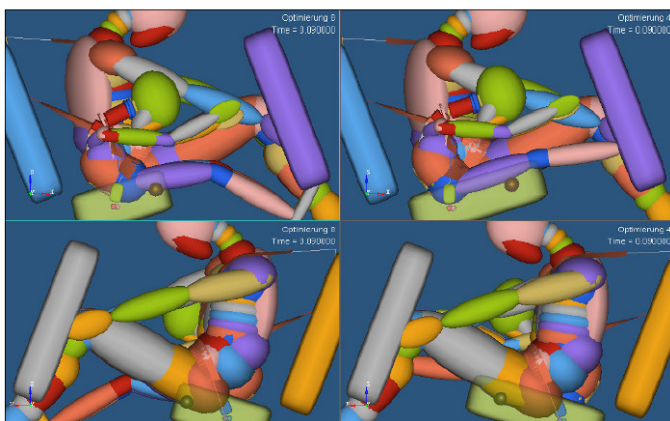


Figure 17: Shortened seat cushion (left) and standard seat cushion (right) for Q6 and HIII model in crash conditions

It is not expected that a pretensioner will solve the safety problem for the adult dummy.

5.2 Testing

The evaluation of the measures by testing took place in a body-in-white of a small family car. Following the results of the simulation the front seats were removed as it was felt to represent the worst case with respect to submarining. Belt pretensioning was simulated by manual tension of the lap belt before the test. Again Q6 and HIII 50% dummy were utilised. In addition to the reference test without CRS tests with backless booster were conducted. Abdominal injury risks were judged by video analysis and abdominal sensors.

The booster seat generally leads to better dummy readings compared to the standard belt without booster cushion. The belt routing is good, submarining was not seen and the abdominal sensors showed low injury risks.

Without CRS but with standard belt the lap belt clearly intrudes into the abdomen, which was confirmed by high abdominal sensor readings. Except the abdominal injury risk all dummy readings were lower with standard belt only compared to the test with CRS. However, except the readings of the abdominal sensor all dummy readings were below known limits (e.g., from ECE R44, CHILD results etc.). For the abdominal sensor the readings without booster cushion was more than double the load limit described by [Johannsen, 2006] and more than four times higher than the readings from the test with booster cushion.

The optimised rear bench resulted in abdominal sensor readings which exceeded the limit with a small margin and were approx. half of the result of the reference test without CRS. Head excursion, head acceleration and chest acceleration were almost the same for the reference test with CRS and the test with the modified belt geometry, see Figure 18.

Is it possible to optimise the rear seats for children (6 YO and above) and adults?

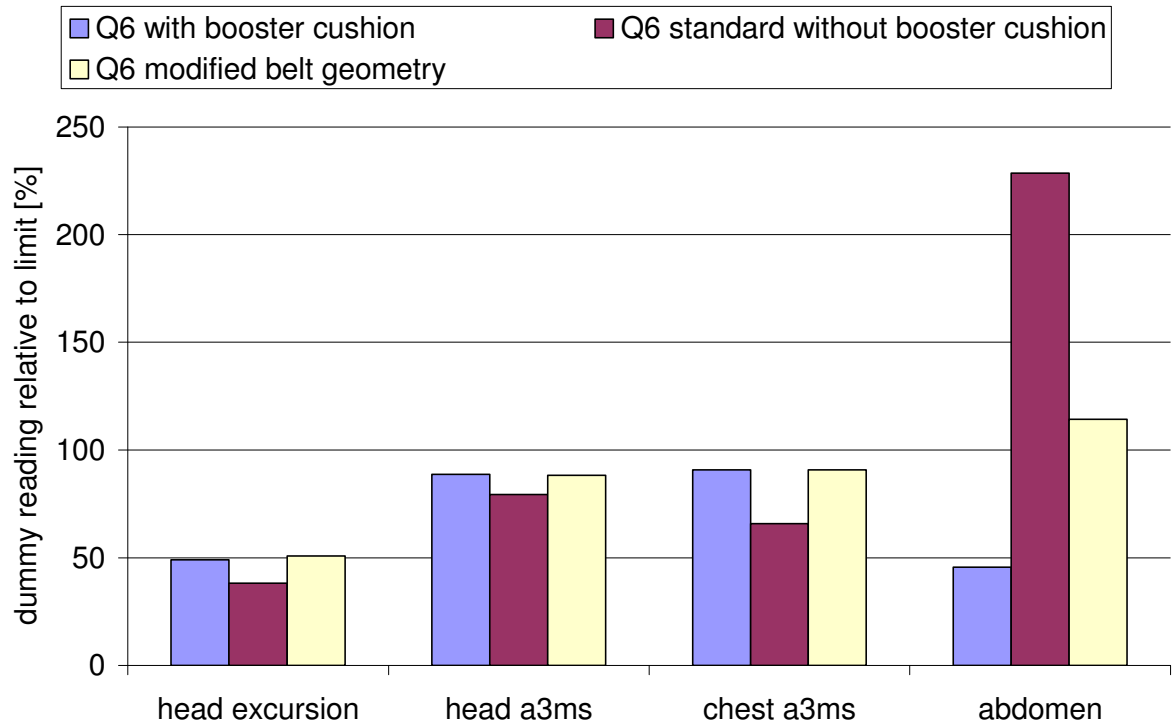


Figure 18: Q6 dummy readings relative to the performance limit (head excursion 550 mm, head a_{3ms} 80 g, chest a_{3ms} 55 g, abdominal surface pressure 0,175 N/mm²)

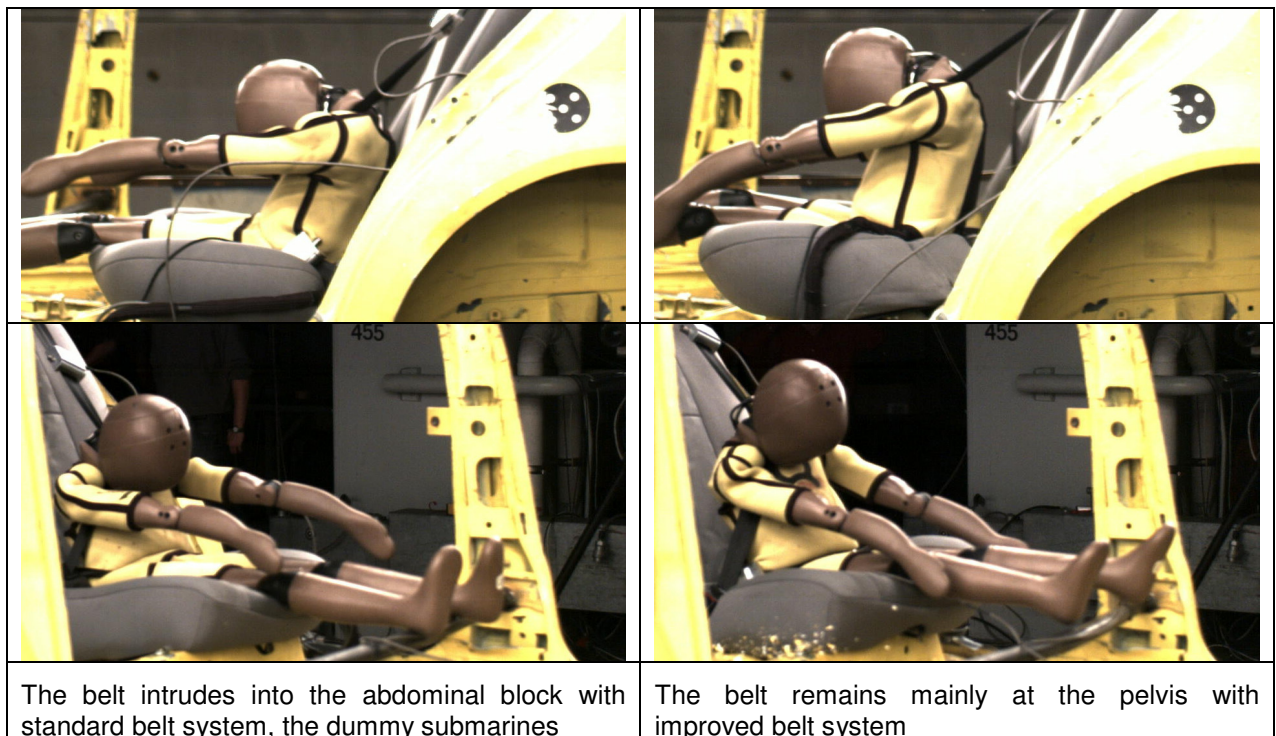


Figure 19: Dummy kinematics with standard and improved belt system

Comparison of the Q6 dummy kinematics (see Figure 19) shows clearly submarining with the standard belt system while the behaviour is considerably better in the improved system. However, belt penetration is still visible.

For the Hybrid III adult the dummy readings were improved with the modified belt system (head, chest compression and neck moments) or were almost the same (chest acceleration, pelvis acceleration), see Figure 20. It is likely that the low chest compression in the modified seat bench is caused by a different belt routing. The chest compression measurement device reacts very sensitive to small changes in the belt positioning at sternum level.

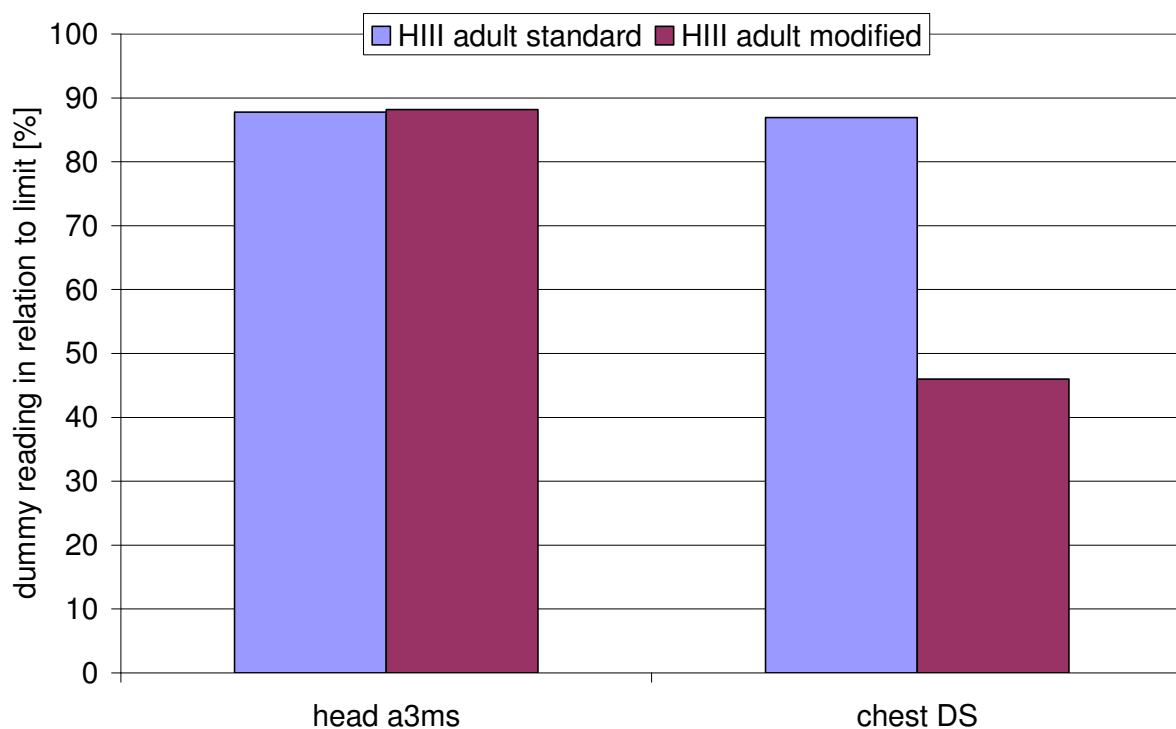


Figure 20: HIII adult dummy readings relative to the performance limit (head a_{3ms} 80 g, chest DS 50 mm)

6 Conclusions

The introduction of pretensioners and seat ramps in combination with modified belt anchorage points in the rear seats are appropriate measures to allow larger children to travel without a CRS. However, the problem of a seat cushion too long for the length of the child's legs needs to be further addressed. In addition it is necessary to confirm the findings with more realistic belt systems that already integrate a pretensioner etc.

7 Literature

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