## CHILD SAFETY IN SMALL AND MICRO CARS

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## ABSTRACT

The recent past shows enormous efforts of some CRS-manufacturers to improve the protective properties of Child Restraint Systems (CRS). Several tests performed by different associations forced these manufacturers to improve the safety qualities of their products. In addition, activities, like the ISOFIX working group, help to increase the child safety in the future.

Examining the car manufacturer activities in passive safety, the development is only partially considering the child safety. At least two trends of upcoming small and micro cars may cause negative effects:

- Lack of space in the rear compartment
- Higher deceleration pulse due to increasing car stiffness

These trends seem to be contradictory to the general requirements given in Figure 1.

Regarding the actual ECE-regulation, it is obvious that commonly certified and used CRS are not designed for those changed requirements. This paper contains the analysis of these both effects on the child and the investigation of three different, actually discussed, CRS attachments.

## INTRODUCTION

Modern small and future micro cars are characterized by short front end designs with increasingly dense arrangements of engine units, nevertheless high quality passive safety standards are demanded. They lead to a stiffer design of the front structure resulting in increasing acceleration of the compartment.

The latest development of the automotive industry and other institutes working on micro cars are proofing this trend. Maximum dynamic car deformation of around 300mm lead to a peak deceleration of 60g and more. Only the design and use of sophisticated restraint systems can guarantee the high level standard of passive safety in these small cars.

At the same time it can be observed that actual small cars rear compartments seem to be more and more optimized. European cars are on average used by 1.2 persons. Due to this real-world observation the car industry tends to reduce the space in the rear compartment in order to improve the comfort for the front passengers.

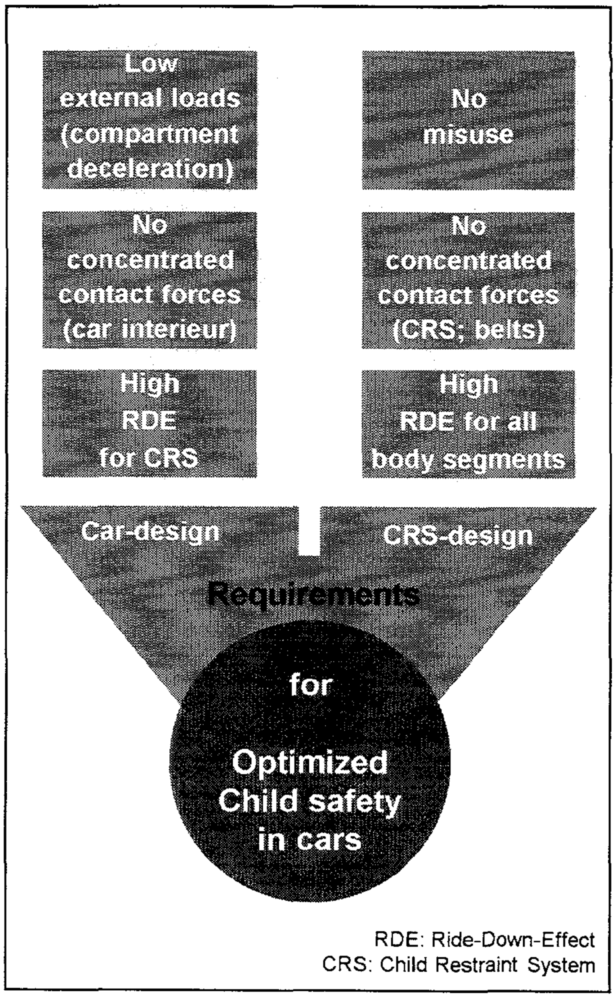


**Figure 1. General theoretical requirements for child safety in cars.**

Seventeen small cars, commonly used in Europe, were investigated on this matter, measuring the horizontal distance between the seat bight of the rear bench and the front seat. The front seats were adjusted 40mm ahead the rear position according to the seated position of a 50-percentile male. Figure 2 makes clear that most small cars provide less headroom for the child than demanded in the actual ECE regulation. The measured values are astonishing low, although they do not represent the worst case of taller front seat passengers.

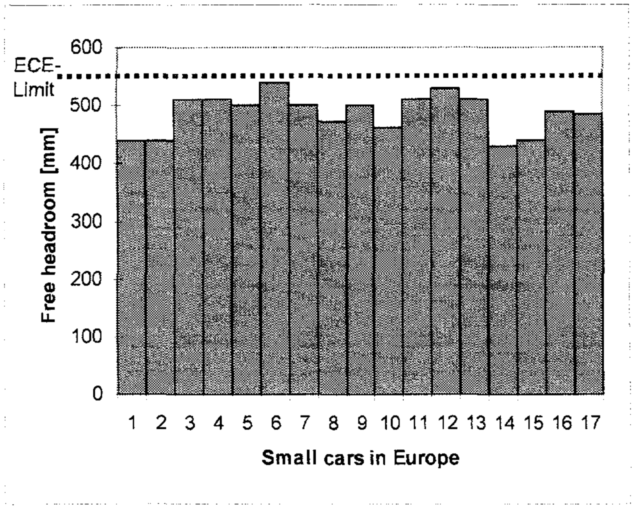


**Figure 2. Horizontal distance in the rear compartment between seat bight of bench and front seats.**

## ACTIONS

Based on those trends following tests were carried out:

**Table 1.**
**All performed tests**

| | | ECE-pulse | 30g-pulse | 40g-pulse |
|---|---|---|---|---|
| Exp. Simulation | Standard 3pt Retr. | • | | |
| | 2pt-ISOFIX | • | | |
| | ISOFIX+ Top Tether | • | | |
| Num. Simulation | Standard 3pt Retr. | • | • | • |
| | 2pt-ISOFIX | • | • | • |
| | ISOFIX+ Top Tether | • | • | • |

A standard forward facing seat (Figure 3.) with 5pt harness was tested with three different types of anchor fittings:

- 3pt-retractor belt:
  This type of CRS fixation represents the actual situation in Germany.
- 2pt-ISOFIX:
  2pt-ISOFIX is proposed for regulation in Europe. The ISOFIX-prototype contains the possibility of pretensioning the CRS versus the seat/bench geometry. Functions like that are prescribed for 2pt-ISOFIX systems.
- 2pt-ISOFIX + Top Tether:
  The Top Tether use is specified in the Australian and Canadian regulations and strongly discussed in Europe.

The experimental tests were used to:

- analyze three different anchorage principles,
- validate the numerical MADYMO-models.

The head- and CRS-displacement curves were transferred to the numerical model. This technique allows a validation process with high quality results which correspond to the experimental tests. The validated numerical models were then used to examine the behavior of those three anchorage types in case of higher external loads.

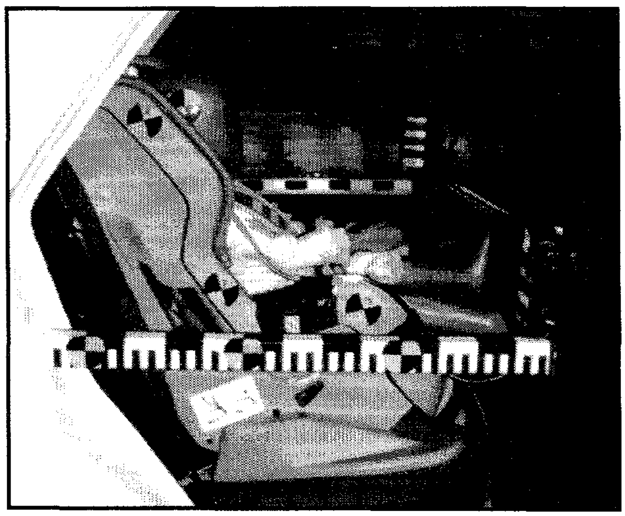

**Figure 3. ISOFIX-prototype on Body-in-White device**

## TEST CONDITIONS

The experimental tests were performed on a body-in-white sled with a TNO P-18month dummy. A conventional, but in comparison to others, stiff rear bench was mounted.

The sled deceleration was set according to the ECE-R44-03 corridor ($v_{coll}$ = 50km/h; $s_{def}$ = 680mm) (Figure 4.).

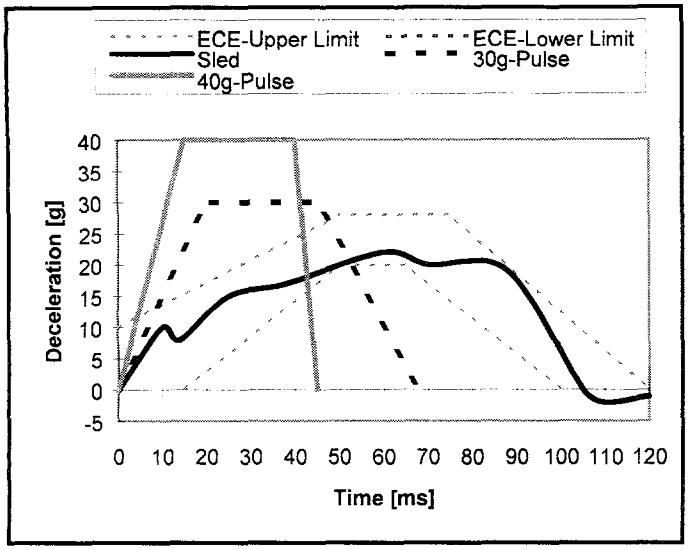


**Figure 4. Variation of sled pulses (v=50km/h)**

The numerical MADYMO models were build up using:

- the validated P-18month database
- the standard belt model of MADYMO.

Due to the unavailability of real car test deceleration pulses, theoretical deceleration pulses were taken (Figure 4.):

- 30g-pulse (v=50km/h, s=500mm)
- 40g-pulse (v=50km/h, s=300mm).

Equal gradation of the maximum deceleration (20g-30g-40g) and the maximum deformation (680mm-500mm-300mm) are considered. Thus, these three pulse types represent a wide range of potential small and micro car decelerations.

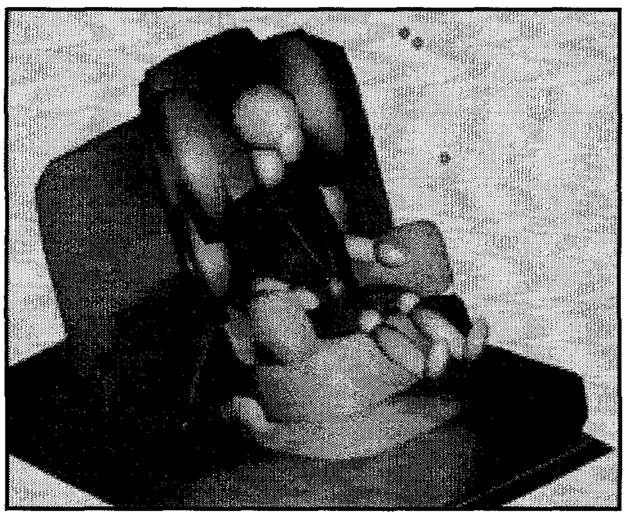

**Figure 5. MADYMO model of the dummy, belted by a 5pt-harness in a forward facing CRS.**

Following measurements were taken:

- Head linear acceleration (Figure 6.)
- Upper neck force & moment (Figure 7.)
- Head & CRS displacement (Figure 10.)
- Chest linear acceleration (Figure 8.)
- Pelvis linear acceleration (Figure 9.)
- Harness force

## TEST RESULTS

The head acceleration is increasing for all kind of CRS attachments, but the highest values were received by 2pt-ISOFIX system. An additional Top Tether reduces the head loads by around 40% (Figure 6.).

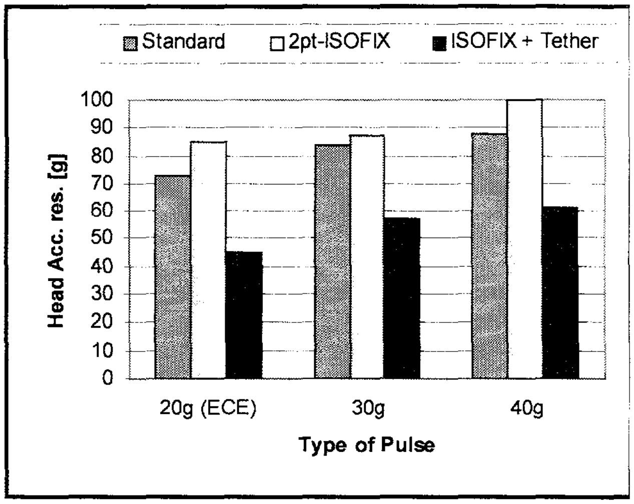


**Figure 6. Head acceleration**

The neck moments are showing the same effect. Only the improvements due to the Tether are less striking (Figure 7.).

The disadvantages of the 2pt compared to the standard 3pt-retractor fixation is observed only for the head/neck region. All other body segments received lower loads than the standard system (Figure 8., Figure 9.).

The head displacements in x-direction (Figure 10.) are almost identical for the standard and the 2pt-ISOFIX CRS.

Only the Top Tether again reduces the values by 30%. Considering the ECE-Limit of the head excursion, only the Top Tether system achieves conformity to this limit. Generally, it is remarkable that increasing deceleration pulses have almost no effect on both ISOFIX systems.

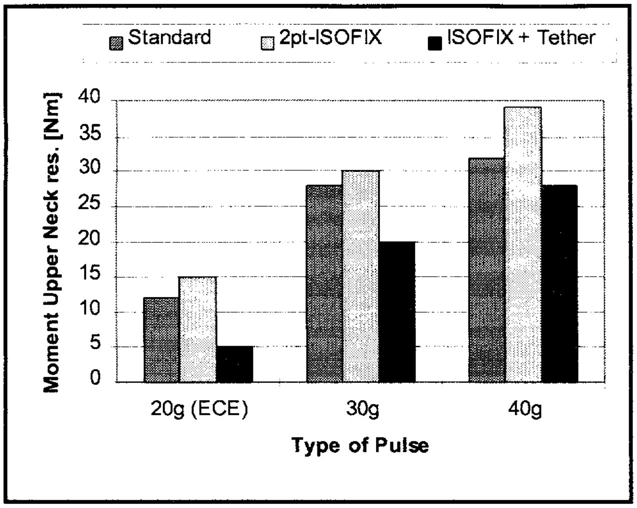


**Figure 7. Upper neck moments**

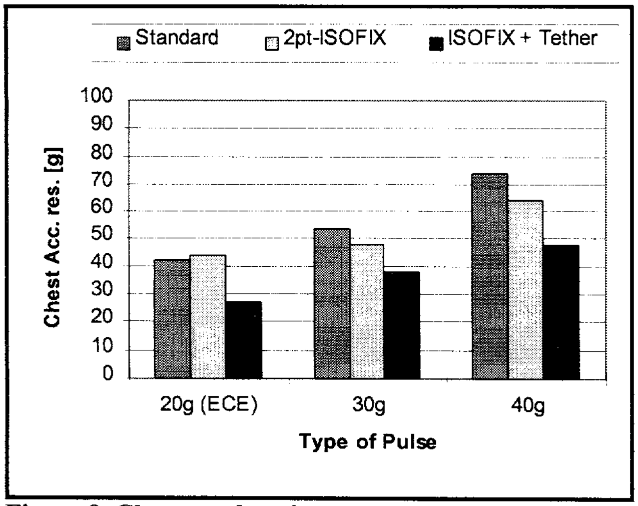


**Figure 8. Chest acceleration**

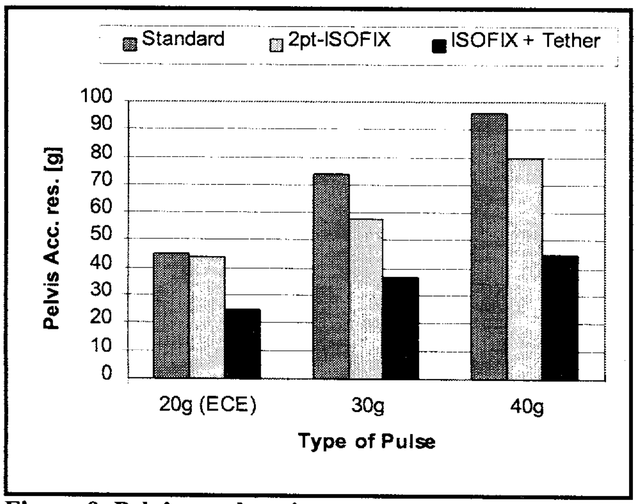


**Figure 9. Pelvis acceleration**

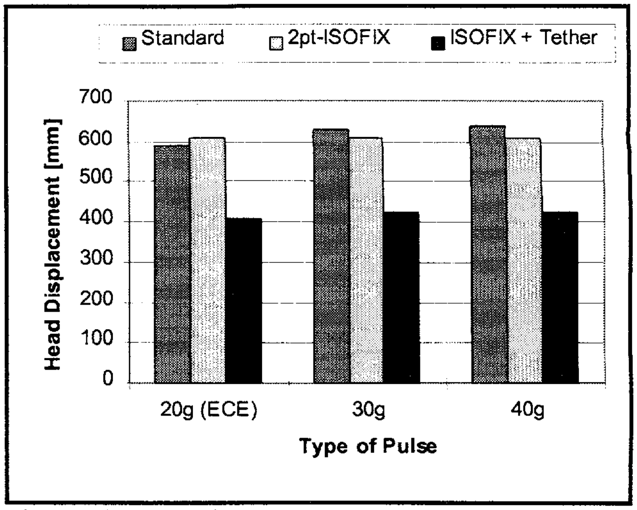


**Figure 10. Head displacement**

## DISCUSSION

Four main effects occured:

- The increasing deceleration pulses lead to increasing loads on the dummy.
- The 2pt-ISOFIX system shows disadvantages concerning the head/neck region, but advantages on the chest & pelvis.
- The use of the Top Tether leads to enormous reductions of all loads on the dummy.
- The Top Tether allows low loads even at high deceleration pulses.

The reasons are known:

2pt-ISOFIX systems need the seat/bench stiffness to reduce the y-axis rotation. Although the CRS was installed with pretension on the bench, large rotation of the CRS and the child's upper body segments were observed. Analyzing the measurements and the high speed films, the stiffness of the rear bench equals a slack in the system. The rigid structure of the seat or bench seems to be more relevant for the CRS behavior than the stiffness of the upholstery.

Structural rigid designs used for the front seats preventing submarining can be adapted to the rear bench to reduce the rotation of 2pt-ISOFIX systems. Regarding the design of car rear benches, you find a remarkable wide range of different designs today (stiffness, thickness of the upholstery, structural support). That is why 2pt-ISOFIX CRS should not be assessed independently.

Latest tests in Germany with a forward facing shield seat proof our investigation. This seat was tested with 3pt-belt and 2pt-ISOFIX attachment. The head acceleration was only slightly higher, but the head excursion increased by 20% for the 2pt-ISOFIX system.

## CONCLUSIONS

- 2-point-ISOFIX systems are neither able to reduce the loads on the child head/neck region nor to reduce the maximum head displacement. In case of higher loads and small headroom in small cars, the 2-point system may not protect the child sufficiently.
- The direct dependency of 2pt-ISOFIX systems to the seat/bench properties needs to be examined in further studies.
- The use of an additional Top Tether reduces all loads and the head displacement extremely. Even in cars with small headroom this protection device will prevent a direct head contact and high loads on the child. The renunciation of the Top Tether use seems to be unacceptable.
- The real-world trends on small car designs show increasing acceleration for the compartments and small headroom for the rear passengers. The ECE-R44 regulation in Europe does not consider this development. A revision of the ECE regulation for frontal testing should be discussed. Future CRS should be certified considering these essential changes in car design.

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